**χMCF (xMCF)**

**Extended Master Connection File**

**A Standard for Describing   
Connections and Joints  
in the Automotive Industry**

****

**FAT-AK25 Fügetechnik**

**Version 3.0 *revision 1***

Documentation of Contents and File Format

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Foreword to χMCF 3.0

Joining technologies play an important role in modern automotive structures whose designs are mainly determined by weight and cost. This leads to the application of a variety of materials with a wide spectrum of mechanical and physical properties and, hence, requires joining technologies specifically tailored to the joining partners. These joining technologies have to be cost-optimized and to deliver desired mechanical properties like high fatigue and crash strengths.

In order to characterize a specific joint completely, numerous attributes like geometry, process parameters, strengths etc. are necessary. Different divisions like CAD, CAE Manufacturing or different OEMs use often only a subset of these attributes. Therefore, each engineering function has been using their own way to describe joints leading to incompatibilities or gaps in data transfers. In order to allow a seamless data flow from CAD data creation through the various virtual and physical optimization & verification steps (CAE, Testing, Feasibility) and finally to manufacturing control processes a comprehensive standard for the characterization of joints is required.

More than 10 years ago, the AK25 (Working Group 25) "Joint Technologies" of the Research Association of German Automotive Industry (FAT/VDA) began to develop the standard χMCF (Extended Master Connection File) for joints, in co-operation with several leading vendors for pre- and post-processors in CAE and fatigue software. While the focus was around a seamless process especially for fatigue prediction of welds in the beginning, meanwhile, the project has significantly grown into a cross-functional standard that can also support the definition and automated virtual builds of full vehicle assemblies.

χMCF is aimed at describing the major attributes of a joint in a neutral way. Information contained in χMCF can be shared by all participants in the development process (e.g. geometrical data for CAD, CAE and CAM, process parameters for CAM etc.). Once fully deployed, all application software uses the same χMCF. No interface or data conversion software is required and there is no risk of information loss.

The documents χMCF 2.1 and 3.0 are results of a project funded by FAT. χMCF 2.1 comprises the definition of all joint types (welds, adhesives, bolts and screws etc.) which were already supported either by the Pre-processor Ansa (Beta CAE Systems) or Medina (T-Systems). χMCF 3.0 is a further extension of χMCF 2.1 with more detailed attributes & parameters and introduces also a new element <custom\_attributes/> by which users can enrich a specific joint with useful information which is not (yet) defined by the standard. All relevant joint types for practical application are included in χMCF 3.0:

1. 0d-joints: spot welds, robscans, rivets, bolts and screws, gum drops, clinches, heat stakes/thermal stakes, clips/snap joints, nails.
2. 1d-joints: seam welds, adhesive lines, hemming flanges, sequence connections.
3. 2d-joints: adhesive faces.

The CAE engineers will benefit from the implementation of χMCF 3.0 in the pre-processors for a fully automated assembly of FE-models using batch-meshing and auto-assembly techniques, or the implementation in fatigue solvers for accelerated fatigue evaluations of complex structures. It is hopeful that it will find a broad application in the complete process chain CAD-CAE-CAM.

Genbao Zhang, Wolfsburg, Germany

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Adding following connection types:

* + - Adhesive points, lines and faces,
    - Bolts and screws,
    - General rivets and self-piercing rivets,
    - Hemming flanges,
    - Robscans,
    - Sequence connections

Clarifying following connection types:

* Spotwelds

Applying changes suggested during meeting of 6th November, 2014 in Leinfelden.

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* Blind and solid rivets
* Flow drilled screws
* Clinches
* Heat stakes
* Clips / snap joints
* Nails

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* 6.5 Distinction between <custom\_attributes\_list/> and <appdata/>

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# Introduction

## Motivation

An automobile is a complex system like many other technical systems. It consists typically of thousands of individual parts which are assembled by joints. Depending on the involved materials and the manufacturing process, different joint types are often necessary in order to obtain an economical and reliable complete structure.

A wide range of joints are used in the automotive industry: From welded joints to screws, adhesives and mechanical joints like clinching etc. They differ from each other not only in their physical and mechanical properties but also in their geometrical shapes and manufacturing processes.

The development of a new car typically passes through the stages of design, simulation and testing until it reaches SOP (start of production) at the end. The information concerning the joints arises peu à peu during the progress of the development. The types of the required information may vary. For designers and CAE-engineers, geometrical information may be of primary interest whereas additional information like fillers etc. is important for prototyping and production, and so on.

An effective development process relies on the efficient management of connection information, which is extensive for a system like an automobile. This is only possible, if the involved information is standardized and mapped into a database or file. The advantage of a standard is evident: Typically, different systems like CAD, CAE and CAM are employed in the developing process. Based on a standard, there is no necessity to convert the same information from one system to the others which are often interested in only a part of the joint information. This prevents possible errors and reduces the development effort of the involved systems.

## MCF at Ford

Up to the present day, there is still no standard which is capable to describe all the joint information needed in the development process. The companies use internal file formats to hold the joint information, which is typically in-house and incomplete. The **M**aster **C**onnection **F**ile (**MCF**) by Ford is one of these formats. The MCF format is based on the XML-standard and covers only few joint types (cf. [1]).

## From MCF to χMCF - The Scope of the Document

Facing the difficulty that joints are represented or realized quite differently in different CAE tools, FAT-AK 25[[1]](#footnote-2) made the proposal to develop a standard for connections and joints in cooperation with the vendors of CAE-software.

The evaluation of existing formats revealed that the MCF format by Ford was the most suitable basis for further developments and extensions. In order to distinguish it from the original Ford-MCF, the FAT-format was named the Extended Master Connection File, abbreviated asχMCF (read: chi-M-C-F) or xMCF (read: x-M-C-F).

In 2005, the consortium decided to begin with the extension of MCF to seam welds. There were several reasons for this decision. First of all, the demand for the fatigue evaluation of seam welds was increasing rapidly. Furthermore, there are a wide variety of weld types with partly complex geometrical shapes. The proper description of these welds meant a big challenge. The successful treatment of seam welds would lay the foundation for the integration of any other joint type.

The current document provides a complete documentation of the spot weld and welded seams after some basic properties and features of χMCF are explained.

The current version of χMCF does not cover all information relevant for the joints treated here. Thanks to the simple extensibility of χMCF, additional information can be integrated on demand.

# Design Principles and Basic Features of χMCF

The Extended Master Connection File (χMCF) is a container for connection information of a complex structure (here the focus is put on automobiles).

Typically, a complex structure consists of a lot of individual parts which are joined together. Unconnected parts are amorphous. Connections establish a topology between the parts. It is thus evident that any efficient database or container designed to gather connection information should be equipped with structures which are able to map this kind of topology between the parts.

Real development processes are complicated. The amount of connection information is huge. It is intended to promote χMCF to become an industry standard in the long term. This demands certain rigorousness of χMCF. On the other hand, some flexibility is desired in order to enable an easy integration of χMCF into different processes. This makes clear that χMCF needs a sophisticated design.

This chapter explains the design principles and some basic features of χMCF, which are important for a proper understanding and straight-forward future extensions.

## Design Principles

The design of χMCF is guided by the following principles:

1. χMCF should be able to *completely* and *unambiguously* describe all relevant connections/joints used in the automotive industry. These include spot welds, seam welds, rivets and adhesives, and so on.
2. It should be able to address all kind of processes, let it be in CAD, CAE and CAM, on the long run.
3. χMCF contains *only* information relevant to connections. Hierarchical product structure, assembly sequence, part variants etc. are *not* subject of χMCF. Such kind of information needs different vessels for propagation. However, χMCF may *refer* to such "external" information, e. g. part codes.

This principle grants χMCF’s flexibility for application to any kind of process variants, established at different automotive OEMs.

1. The format has to be flexible and easy to extend to any future joint types and applications.
2. χMCF is built upon the industry standard XML.
3. Connection data are unique.
4. The content of χMCF may be incomplete to a certain extend. This addresses the fact that new data is created and needs to be stored throughout the course of CAx processes, without changing its vessel.
5. χMCF follows the max-min principle: It contains information as much as necessary, at the same time, as little as possible.
6. At any certain stage of any involved process, connectors can be reconstructed from χMCF without loss of data or ambiguities.
7. The format description is kept compact. Elements are reused, whenever possible.
8. Application specific data can be stored in χMCF even without standardization: χMCF offers corresponding "empty" containers which can be assigned to any certain connector or to the complete collection / file.
9. Due to its simplicity and extensibility, χMCF forms a good candidate for long-term archiving connector information.

Using XML deserves some comments. XML is by itself an industry standard and human readable. XML allows for contents getting certain structure which is the precondition to easily map the topology of connectivity of complex structures like automobiles.

## Idealization of Joints

Different joints possess different characteristics. They may differ from each other by their geometrical shapes, mechanical properties like strengths for different loadings, manufacturing processes etc.

To allow an efficient description of joints, some simplifications and idealizations are necessary. The way chosen by χMCF is to classify joints by their most basic and mandatory attribute, namely its geometrical dimensions. Thus, there are 0-, 1- and 2-dimensional joints in χMCF.



Figure 1: Seam weld as 1‑dimensional joint

A spot weld is treated as a 0-dimensional joint in χMCF. In this way, a (an idealized) spot weld is geometrically described by its coordinate vector ***x*** and its diameter *d* as an additional attribute. Besides spot welds, there are more joints which can be treated as 0-dimensional.

A seam weld is a representative of 1-dimensional joints, see Figure above. It is characterized by a curve describing its spatial course and additional parameters (attributes) determining its sectional shape perpendicular to the curve. Details are referred to later chapters.

Similarly, adhesive joints are idealized as 2-dimensional surfaces. Details are subjects of future extensions.

## Reconstruction of Joints from χMCF

An important topic worthwhile to mention is the *reconstruction* of the joints. It is crucial that it is possible to reconstruct the corresponding joint in its idealized form uniquely by means of the introduced parameters and attributes. In case of spot weld, a unique reconstruction is possible by the coordinate vector **x** and the diameter d, plus the sheet thicknesses which by themselves are not a constituent of χMCF (recall χMCF contains only information relevant to joints), but of the corresponding CAD or CAE model.

## Description of Topology

As mentioned before, a complex structure arises by connection of parts and sub-structures (assemblies). The connections introduce a topology between the individuals. There are many ways to describe the topological relations. The following example demonstrates the way that χMCF adopted to describe the topology:

* Part (or Assembly) A is joined to Part B by the seam weld 1 along the curve l1 and the spot welds at positions xi, and
* Part (or Assembly) A is connected to Part C by the adhesive ADx in the area Ax, etc..



Figure 2: Topological Relations between Parts and Assemblies

The description is mapped into XML by using an element tagged ***<connection\_group/>***. A ***<connection\_group/>*** comprises all joints which connect the same parts (or assemblies). Details are referred to later chapters. Here one of the merits of employing XML becomes apparent.

It is to mention that frequently more than two parts are joined together. A spot weld can e.g. join three sheets, a screw even more. Such situations have to be taken into account, too.

According to design principle 3), overall product structure cannot be reproduced from χMCF. For example, any of the following product structures would equally fit to Figure 2:



Figure 3: Product Structures Fitting to Previous Figure.

And this list is far from being complete.

## χMCF in the Development Processes

The typical development process is a long chain involving many (maybe overlapping) single steps like design, construction, prototyping, simulation, testing, production planning, etc., see Figure 4. Depending on the individual manufacturer considered, information of connections and joints arises at different stages of the process and comes from different parties (Figure 5). An efficient handling and management of this information can only be guaranteed by a (common) database/container which contains the information *uniquely*. This shall be guaranteed by a standard like χMCF.



Figure 4: The Development Process



Figure 5: χMCF as a Platform for Connection Information  
in the Complete Development Process

A careful examination of Figure 5 enables one to get more feeling and understanding about how the work with χMCF in a real process could look like: χMCF is a structured set which can be divided into several overlapping subsets. Each subset contains a part of connection information which is of interest for a certain party, e.g., simulation or planning. The intersection of all subsets contains information which is of interest for all other parties involved, e. g. coordinates and flange partners.

As mentioned before, the information contained in χMCF is not necessarily complete, at least not at an early stage of the development process. Rather its content grows while the process is advancing. Defining the individual joint and filling up the container thus build up a continuous process. As shown in Figure 5, connection information could be created by any of the involved parties (design, construction, engineering, planning, etc.). The common situation is that each party contributes part of information (geometrical, technological etc.) defining a specific joint. Merging of the partial information leads to the complete characterization of the joint. Therefore, χMCF is an ideal tool to enable this dynamic process since filling up χMCF means merging information.

Figure 5 makes also clear that connection information (full or partial) is available to everyone once it is defined and stored in χMCF. Thus, unnecessary duplication of effort is avoided automatically. Typically different parties work in different environments using different software tools. Provided all systems support χMCF, transfer of data from one format to another will be not necessary any more. This will save development cost and avoid loss of data caused by the transfer.

Information contained in χMCF can be used to automate many tasks in the development and thus to enhance efficiency:

* **Automatic CAE assembly**

Meanwhile most FE-preprocessors are able to mesh parts automatically in the batch-meshing mode. An automated assembly can be realized by the connection information contained in χMCF.

* **Automatic Programming of Welding Robot**

Based on χMCF, welding robots can be programmed automatically.

An essential feature of χMCF is that it contains only information relevant to the joints. No data are included which are dependent on the process. Hence it is relatively easy to implement χMCF into any real process. Depending on the application, it is possible to use χMCF as a stand-alone database or integrate χMCF into an even more comprehensive database.

# Keywords of XML specification

## Keywords

The carrier of information in a χMCF file is an element which can be equipped with some attributes and child elements. Elements and attributes are defined by their names (identifiers) and values (information).

By the XML standard, values assumed by elements can be distinguished by their types like boolean, float, double, string, date, etc. The same applies to attributes. The user can determine how elements and attributes are used (optional, required or prohibited). If necessary, the frequency of occurrence of elements with the given name (i.e., number of siblings of identical names) can be restricted (in XML schema, this is specified by the attributes *minOccurs* and *maxOccurs*).

In accordance with the XML standard (version 1.0[[2]](#footnote-3)), the following key-words are used in the current document to characterize the elements and attributes:

* Type
* Value Space
* Default
* Use
* Multiplicity (corresponds to the attributes *minOccurs* and *maxOccurs* of the element ***<xs:element>*** of XML schema)
* Restrictions (corresponds to the element *restriction* of XML schema)

The type of the value of an element or attribute is specified by the key-word *Type*. The numerical ID of a property (attribute "pid") of a ***<part>***opening tag for instance is an integer, which is a built-in type of XML standard.

The most common types are:

* xs:*string*
* xs:*decimal*
* xs:*integer*
* xs:*float*
* xs:*boolean*
* xs:*date*
* xs:*time*

**Note:** The maximum number of decimal digits you can specify is 18.

However, only positive integers are usually used in this context. That means, the possible value of ID of the type integer is restricted. To specify the values which are assumable by an element or an attribute, the key-word *Value Space* (a set) is used. The Value Space can be given as an enumeration (a finite set) or a set defined explicitly. E.g. positive integer is symbolized by > 0 whereas a float between 0.0 and 1.0 is given by [0.0, 1.0], similar to mathematics.

Some elements and attributes obtain default values if they are not given explicitly in the χMCF file. The default values adopted are specified by the keyword *Default*.

In this document, the special type "alphanumeric" is frequently used for labels of parts and assemblies, which deserve a careful discussion. In the CAD world, a label is synonymous with the name of a part, a geometric object etc. Not only letters "[A-Za-z]", but also numbers "[0-9]" and other special characters like "[-\_.$#±]" and more are used for labels. Sometimes, first character is restricted to "[A-Za-z]". Thus, it is difficult to give an exact definition for the type "alphanumeric" which would fit to the individual need. Fortunately, using XML’s "encoding" attribute, even non-ASCII characters can be handled easily, e. g. Arabic, Chinese, Cyrillic, Greek, Hebrew, etc.   
Nevertheless, as sort of general recommendation, labels should not start or end with white space.

The key-word *Use* specifies, whether an element or an attribute is optional, required or prohibited. The frequency of the occurrence of an element or attribute is defined by *Multiplicity* e.g. in the form: *minOccurs* ≤ *Multiplicity* ≤ *maxOccurs.* By convention, when *Use* is optional, *minOccurs* is 0. Any additional restrictions imposed on an element or an attribute are specified by the key-word *Restrictions.*

As explained above, the individual use of some elements or attributes may be optional. But some of them are coherent (thus in certain sense redundant). An important example is the label and pid of a part or an assembly. They represent the same part (except for e. g. tailored blanks). One can use the one or the other or both to identify a part.

# Parts, Properties and Assemblies

χMCF describes, how parts, properties and assemblies are connected by joints in a pre-defined way. Hence, we need a clear understanding about what a part, property or assembly actually is in our context.

## Parts

Parts are logical groupings of 3D objects, on first hand. Their objective is to provide a general nomenclature of the pieces which form a certain product. This nomenclature allows communications between all stake holders of all involved processes.

Typically, it is assumed that parts do not disintegrate into several physical compounds.

Parts can be instantiated at different locations of a product, e. g. wheels in a car etc.

Parts can be mirrored at a symmetry plane of the model, e. g. front doors of a car.

Parts can contain other parts (sub-parts): A car, for instance is made of body in white, power train, doors and claps etc. A door is made of an outer sheet, an inner sheet, a window with its mechanics, some crash enforcements etc. The mechanics of a window are made of some guiding rails, an electric motor and so on.

Hence, in sense of graph theory, parts form a tree (if their instances are considered) or a directed, cycle free graph. Parts without sub-parts are called the "leaves" of this tree or graph.

If a part is mentioned in a list, not only its own content (e. g. finite elements) is addressed, but also all contents of its sub-parts and their children, down to the lowest level (leaves) of the part graph.

### Part Labels

A part is uniquely identified by its *label*, up to ditto-parts. Connectors within a connection group that refers to ditto parts must be able to "detect" the "correct" part instance according to their respective geometrical location.

We assume that mirror parts have other part labels than their "base" parts.

**Note:** In most CAx processes, parts actually have two string attributes: One label describing the name and/or usage of a part in a human readable form, and another one used for indexing this item in the OEM’s "part store". The latter one typically consists of only few characters (some 8 to 12, e. g.), resembles more to a number than to a name, and hence is not human readable. In our context, we refer to the latter one, if we say "part label".

## Properties

In CAE, properties are a concept for assigning physical behavior to a number of finite elements. Hence, any finite element can have at most one property. However, there frequently are elements without such properties (RBEs, masses, etc.). In most solvers, properties are uniquely identified by positive integers, so called property IDs or short: PIDs.

Even, if finite elements of different parts have same physical behavior (let’s say, left and right wing of a car), they usually have assigned different PIDs. This can be considered as reminiscence to ancient times, when parts just have not been invented. PIDs were also used for administrative purposes, then.

However, for χMCF, PIDs are just alternative, non-recursive means for addressing collections of elements.

One specific part frequently consists of one specific property (PID), only. However, there are important exceptions:

* A tailored blank is a metal sheet which consists of several pieces of simple sheets joined together. Both, the thicknesses and the materials of the individual sheets, may differ. Nevertheless, a tailored blank is one single part from the χMCF point of view. Since one PID would not provide a name for the *complete* part, the part label has to be used, or else an assembly of several PIDs.
* Sometimes, a cast part can be treated with shell formulation in its thin areas, whereas solid elements (with different PIDs) are used in other areas.
* Due to e. g. stamping processes, physical behavior and thickness may vary even within one originally homogeneous sheet metal, requiring several PIDs for correct simulation.
* Occasionally, CAD parts containing several subparts with their PIDs are aggregated to one single CAE part, consequently still containing several PIDs.

## Assemblies

In many CAx systems, parts containing sub-parts are called assemblies. The notion distinguishes them from leaves of the part tree or graph.

However, in χMCF, an assembly is just a set of parts and/or properties, denoted by their part labels and PIDs. They do not need to possess any special relation respective to the part graph. The opposite is true: χMCF-assemblies address situations, where specifying a single PID would address not enough, a high level part would address way too many elements and medium-size parts would not make the job.

On the other hand, this does not happen too often: If a weld line e. g. crosses property boundaries, these properties usually belong to the same tailored blank, hence the same part. If there would be a physical gap between the properties, welding would be applied to a single sheet across this gap, which causes new questions to the welding process:



Figure 6: Weld line crossing tailored blank vs. weld line crossing physical gap

And even then: Due to geometrical proximity and usual assembly processes, it is very likely that properties A and C belong to the same part just one level above in part graph.

# File Structure of χMCF

As mentioned before, χMCF is built upon XML. This eases χMCF to possess a clear logical structure.

The root/document element of χMCF is mandatorily named ***<xmcf/>***[[3]](#footnote-4). The root element may contain the following types of child elements

1. Comments following the usual XML standard; hence not further discussed here.
2. Elements containing general information.
3. Variant declaration.
4. Groups of connection specific elements ***<connection\_group/>*** of arbitrary number.
5. Element ***<appdata>*** containing data specific for individual applications
6. Element ***<femdata/>*** containing finite element specific data.

## Elements containing general information

χMCF is equipped with the following elements for general information:

* ***<date/>*** optional
* ***<version/>*** mandatory
* ***<units/>*** optional

The root element ***<xmcf/>*** contains the following nested elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| date | 1 | Optional | - |
| version | 1 | Required | - |
| units | 1 | Optional | - |
| appdata | 1-\* | Optional | See section 5.2.1 |
| femdata | 1-\* | Optional | See section 5.2.1.1 |
| connection\_group | 1-\* | Optional | See section 5.3 |

Table 1: Nested elements of element **<xmcf/>**

### Date

The element ***<date/>*** of the format "yyyy-mm-dd" specifies the date on which of the file is created. It follows norm ISO 8601, cf. <http://en.wikipedia.org/wiki/ISO_8601>.

**Example:**

<?xml version="1.0" encoding="UTF-8" ?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xsi:noNamespaceSchemaLocation="**xmcf\_3\_0\_1.xsd**">

**<date> 2015-08-27 </date>**

<version> 3.0.1 </version>

<units length="mm" angle="rad" mass="kg" force="N" time="s"/>

...

</xmcf>

### Version

The version code of the χMCF standard upon which the current file is built must be specified by the element ***<version>.***

The version code of χMCF files following this document is 3.0.1.

**Example:**

<?xml version="1.0" encoding="UTF-8" ?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xsi:noNamespaceSchemaLocation="**xmcf\_3\_0\_1.xsd**">

<date> 2015-08-27 </date>

**<version>** 3.0.1 **</version>**

<units length="mm" angle="rad" mass="kg" force="N" time="s"/>

...

</xmcf>

### Unit System

The unit system used by χMCF is based upon the International System of Units (SI[[4]](#footnote-5)) and specified by the element ***<units>***. Both the base and the derived units are supported, including decimal prefixes.

Following non-SI units are allowed, additionally: Length [in] and [ft]; Mass [lb].

There is no need to declare units for dimensionless physical quantities, e. g. friction coefficients.

XML-specification of ***<units>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attribute*** | ***Use*** | ***Value Space*** | ***Default*** |
| length | Optional | "mm", "m", "in", "ft" | "mm" |
| angle | Optional | "deg", "rad" | "deg" |
| mass | Optional | "g", "kg", "t", "lb" | "kg" |
| force | Optional | "kN", "N" | "N" |
| time | Optional | "s", "min", "h" | "s" |
| torque | Optional | "Nm" | "Nm" |

Table 2: XML-specification of *<units/>*

**Example:**

<?xml version="1.0" encoding="UTF-8" ?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xsi:noNamespaceSchemaLocation="**xmcf\_3\_0\_1.xsd**">

<date> 2015-08-27 </date>

<version> 3.0.1 </version>

**<units length="mm" angle="rad" mass="kg" force="N" time="s"/>**

...

</xmcf>

## Application, User and Process Specific Data

The user/application software can store additional information into a χMCF file. In this way, flexibility is introduced which enables an easy integration of χMCF into an existing development process.

The current χMCF definition allows two such data elements:

* ***<appdata>***Contents has to be documented by the corresponding application or user. It is *no* official part of the χMCF standard.
* ***<femdata/>***Contents is documented in FATXML [[7](#CiteFATXML)] and hence does not need to be described, here.

### User Specific Data <appdata>

***<appdata/>*** is suitable for any user/application specific information and can be placed on root level (directly within ***<xMCF/>*** tag) and within any single connector (tags ***<connection\_0d/>***, ***<connection\_1d/>***, and ***<connection\_2d/>***). Additionally, it is also allowed to define directly under element ***<connection\_group/>***.

***<appdata/>*** must contain at least one nested element named after the application or user that is intended to interpret the data.

Content of ***<appdata/>*** is regarded to be "private property" of the corresponding application. However, in the sense of "best practices", it is recommended, but not required,

* to place application specific tags into a separate namespace,
* to provide an XML schema for its content,
* to import, store and export ***<appdata>*** of 3rd party applications on block – to prevent loss of data in applications allowing export,
* for a FE pre-/post processor to offer means for editing 3rd party data "formally", i.e. according to the corresponding XML schema, but regardless of the physical meaning of that data.

The user must be aware that different systems are likely to introduce the same physical parameter at the same time (inducted e. g. by a certain new emerging connecting method), but describe them in their own XML schemata with different element/attribute names.

A preprocessor does not have any chance to detect these equivalent parameters, then. Hence, it cannot prevent contradictions between different <appdata> blocks of the same χMCF file.

As of November 2015, the following applications (in alphabetical order) have been registered:

* ANSA
* FEMFAT
* HyperMesh
* LMS Virtual.Lab
* MEDINA
* nCode
* SyncroFIT

The above given list does *not* imply that other application names are forbidden. Its only purpose is to reserve the registered names against inappropriate use.

XML-specification of ***<appdata>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| ANSA | 1 | Optional | - |
| FEMFAT | 1 | Optional | - |
| HyperMesh | 1 | Optional | - |
| LMSVirtualLab | 1 | Optional | - |
| MEDINA | 1 | Optional | - |
| NCODE | 1 | Optional | - |
| SyncroFIT | 1 | Optional | - |

Table 3: XML-specification of *<appdata>*

**Example A (*<appdata>*** for MEDINA at root level**):**

<?xml version="1.0" encoding="iso-8859-1" standalone="no"?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xmlns:MEDINA="http://servicenet.t-systems.com/medina/xMCF"

xsi:schemaLocation="http://servicenet.t-systems.com/medina/xMCF mcf\_MEDINA.xsd"

xsi:noNamespaceSchemaLocation="xmcf\_3\_0\_1.xsd">

<date> 2014-08-07 </date>

<version> 3.0.1 </version>

<units length="mm" angle="rad" mass="kg" force="N" time="s"/>

**<appdata>**

**<MEDINA[[5]](#footnote-6) xmlns="http://servicenet.t-systems.com/medina/xMCF">**

**<data\_at\_root>**

**<version MEDINA="MEDINA 8.4.2 Maintenance Release (64 Bit)"/>**

**...**

**</data\_at\_root>**

**</MEDINA>**

**</appdata>**

...

</xmcf>

**Example B (*appdata*** for MEDINA at connection level**):**

<?xml version="1.0" encoding="iso-8859-1" standalone="no"?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

**xmlns:MEDINA="http://servicenet.t-systems.com/medina/xMCF"**

**xsi:schemaLocation="http://servicenet.t-systems.com/medina/xMCF mcf\_MEDINA.xsd"**

xsi:noNamespaceSchemaLocation="xmcf\_3\_0\_1.xsd">

<date> 2014-08-07 </date>

<version> 3.0.1 </version>

<units length="mm" angle="rad" mass="kg" force="N" time="s"/>

...

<connection\_group id="1">

<connected\_to>

...

</connected\_to>

<connection\_list>

<connection\_1d>

<loc\_list>

...

</loc\_list>

<seamweld>

...

</seamweld>

**<appdata>**

**<MEDINA xmlns="http://servicenet.t-systems.com/medina/xMCF**"**>**

**<data\_at\_connector>**

**....**

**</data\_at\_connector>**

**</MEDINA>**

**</appdata>**

</connection\_1d>

</connection\_list>

</connection\_group>

</xmcf>

#### Finite Element Specific Data <femdata/>

For the numerical simulation by finite element method, a joint can be discretized (realized) in different kinds and ways depending on the focus of the simulation (crash, fatigue etc.). It is thus frequently necessary to switch from one realization to another one. For this purpose, details of a specific realization may be of interest.

The optional ***<femdata/>*** can be placed within any single connector[[6]](#footnote-7) (relevant tags are ***<connection\_0d/>, <connection\_1d/>*** and ***<connection\_2d/>***).

***<femdata/>*** references FEM-entities that are related to the connector in which it is placed. Its content, i.e. nested elements are specific to a single solver.

This solver naming should be taken from FATXML version 1.2 R2 (as current version) which are the following:[[7]](#footnote-8)

* PAM-CRASH
* LS-DYNA
* RADIOSS
* OPTISTRUCT
* NASTRAN[[8]](#footnote-9)
* PERMAS
* ABAQUS

And these should be extended by other also required solver names to enable wide usage of the standard:

* FEMFAT

XML-specification of ***<femdata/>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| PAMCRASH | 1 | Optional | - |
| LSDYNA | 1 | Optional | - |
| PERMAS | 1 | Optional | - |
| ABAQUS | 1 | Optional | - |
| RADIOSS | 1 | Optional | - |
| OPTISTRUCT | 1 | Optional | - |
| NASTRAN | 1 | Optional | - |
| FEMFAT | 1 | Optional | - |

Table 4: XML-specification of element *<femdata/>*

Only ***<entity/>*** is allowed as a nested element of the child element of ***<femdata/>***. Its definition and documentation follows ***<ENTITY/>,*** the corresponding element in FATXML [[7](#CiteFATXML)].

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| entity | 1-\* | Required | Corresponds to element ***<ENTITY/>***, defined in [[7](#CiteFATXML)]. |

Table 5: Nested elements of the child element of *<femdata/>*

For further definition of *ENTITY* see the document source website for FATXML [[7](#CiteFATXML)].

**Example A (**example of ***<femdata>*** within a ***<connection\_0d/>*** element**):**

<connection\_0d>

...

**<femdata>**

**<NASTRAN>**

**<entity>**

**<TYPE>**

**CQUAD**

**</TYPE>**

**<ID>**

**12345-12356**

**</ID>**

**</entity>**

**</NASTRAN>**

**</femdata>**

...

</connection\_0d>

Similar to FATXML, χMCF data can be embedded into solver decks by this means: Any receiving system can easily detect and remove discretization objects, created by a sending system, in order to substitute them by its own new discretization objects.

## Connection Data <connection\_group/>

***<connection\_group/>*** comprises the topological information about the involved parts and assemblies (Chapter 4), respectively. As explained in Section 2.4, joints are grouped together by the parts or assemblies which they commonly connect.

The topological relation (relation of neighbors) is defined by the child element ***<connected\_to>*** whereas all involved joints are listed in the child element ***<connection\_list>*** according to their types (see Section 2.2).

Each ***<connection\_group/>*** is uniquely identified by a numeric identifier (id).

Note: From this, it follows that χMCF files *cannot* be simply "pasted together" by use of a standard text editor.

XML-specification of ***<connection\_group/>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | Use | ***Constraint*** |
| id | Integer | Required | unique within a χMCF file |

Table 6: Attributes of element *<connection\_group/>*

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| connected\_to | 1 | Required | - |
| connection\_list | 1 | Required | - |
| contact\_list | 1 | Optional | - |

Table 7: Nested elements of element *<connection\_group/>*

***Remarks:***

* In addition to parts and properties, *no* other means (e.g. sets) for grouping objects are allowed.

### Connected Objects

The basic objects which can be jointed together are parts and assemblies (see Chapter 4) which appear as nested elements ***<part/>*** and ***<assy/>*** of ***<connected\_to>***.

XML-specification of ***<connected\_to>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| part | 1 - \* | Optional | - |
| assy | 1 - \* | Optional | - |

Table 8: Nested elements of **<connected\_to>**

#### Element <part/>

In χMCF, a part may refer to one CAx part or one CAE property, as well.

It is described by the element ***<part/>*** and a numeric *index*, a *label* (part code) or a *pid* (property id) or *pname* (property name)[[9]](#footnote-10), all provided as attributes. However, if both attributes "label" *and* "pid" or "label" *and* "pname" are present, the label governs.

The *index* needs to be unique only within the parent element ***<connected\_to>.*** For specific connections, it is used as the matching index for the base sheet.

The attribute *index* of ***<part/>*** element is required only if the *part* element is being used as nested element under element <connected\_to>. In case if the ***<part/>*** element is used within the element ***<assy/>*** then NO *index* is allowed to be present as attribute of the ***<part/>*** element.

XML-specification of ***<part/>***:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| index | Integer | > 0 | Required | Unique and required only within the parent element ***connected\_to*** |
| label | Alphanumeric | Alphanumeric | Optional | At least *label*, *pid*, or *pname* must exist.  *pid* and *pname* may not exist at the same time. |
| pid | Integer | > 0 | Optional |
| pname | Alphanumeric | Alphanumeric | Optional |

Table 9: Attributes of element **<part/>**

**Example A (**only required attributes**):**

<connected\_to>

**<part index="1" label="PART\_7000400"/>**

</connected\_to>

**Example B (**within optional attributes**):**

<connected\_to>

**<part index="1" label="PART\_7000400" pid="3202132"/>**

</connected\_to>

**Example C (**using pname to identify a property**):**

<connected\_to>

**<part index="1" pname="P400 Thin Shell Property"/>**

</connected\_to>

#### Element <assy/>

An assembly represents a sub-structure consisting of at least two ***<part/>*** elements. It is described by the element ***<assy/>*** with only the mandatory attribute *index*.

XML specification of element ***<assy/>***:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| index | Integer | Required | Unique within the parent element |

Table 10: Attributes of element *<assy/>*

**Example A (**only ***<assy/>*** element within ***<connected\_to>*** - full definition**):**

<connected\_to>

**<assy index="42">**

**<part label="PART\_7000400" pid="110013"/>**

**<part label="PART\_7000800" pid="110099"/>**

**</assy>**

</connected\_to>

**Example B (**<part/> and ***<assy/>*** elements within ***<connected\_to>*** - full definition**)**:

<connected\_to>

**<part index="1" label="PART\_9004400" pid="3202132"/>**

**<assy index="42">**

**<part label="PART\_7000400" pid="110013"/>**

**<part label="PART\_7000800" pid="110099"/>**

**</assy>**

</connected\_to>

**Example C (**<part/> and ***<assy/>*** elements within ***<connected\_to>*** - minimum definition**)**:

<connected\_to>

**<part index="1" label="PART\_9004400"/>**

**<assy index="42">**

**<part label="PART\_7000400"/>**

**<part label="PART\_7000800"/>**

**</assy>**

</connected\_to>

OR

<connected\_to>

**<part index="1" pid="3202132"/>**

**<assy index="42">**

**<part pid="110013"/>**

**<part pid="110099"/>**

**</assy>**

</connected\_to>

The body of an ***<assy/>*** tag equals that of a ***<connected\_to>*** tag. But the meaning is different: All parts within one ***<assy/>*** tags are meant to constitute *the same* side/layer/partner of a flange, whereas all members of a ***<connected\_to>*** tag are *different* sides/layers/partners of a flange.

Recursion, i.e. an ***<assy/>*** tag nested within another ***<assy/>*** tag, is not allowed.

#### Special Topological situations

The aim of the ***<connection\_group/>*** element is to group up all the joints that connect the same parts.

Figure 7: special topologies

Therefore, ***<connected\_to/>*** contains each part connected in the joint only once. However, it may be important to explicitly define in which order some parts of the group are connected.

This includes the following scenarios:

* the stacking order of the connected parts may be important
* some parts may be involved more than once in the samejoint (self-connected joint).
  + each part involved in a self-connected joint more than once is known individually, or
  + just the *number* of parts involved in a self-connected joint is known,
  + or some combination of the two sub-scenarios above.

In Figure 7, all joints, A, B, C, exist within the same ***<connection\_group>***, but each joint is connected in a different way.

<connection\_group>

<connected\_to>

<part index="1" label="PART\_7000800"/> <!-- green -->

<part index="2" label="PART\_7000400"/> <!-- red -->

</connected\_to>

</connection\_group>

For joints A and C the number of flanges connected is more than the number of parts in <connected\_to>. Between joints A and C, the flanges feature the same parts, but in a different order.

To store this information for each case, the ***<stacking/>*** element comes to use.

##### Element <stacking/>

***<stacking>*** may dictate list of flanges/sheets involved in a joint, as well as their order. Alternatively, ***<stacking>*** may indicate the number of flanges/sheets of a joint, without defining which are the parts that are connected more than once.

***<stacking/>*** has the nested element:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| level | 1 - \* | Optional | - |

Table 11: Nested elements of **<stacking>**

and the following attribute:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| nr\_levels | Integer | > 0 | Optional | if ***nr\_levels*** exists, no ***<level/>*** elements are allowed in ***<stacking/>***.  ***nr\_levels*** must be greater than the number of nested elements of ***<connected\_to/>*** |

Table 12: Attributes of <stacking>

* ***nr\_levels***: dictates the number of flanges/sheets connected by the joint.

Where ***<level>*** within ***<stacking/>*** is specified as:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| order | Integer | > 0 | Required | Unique only within the parent element ***stacking*** |
| part\_index | Integer |  | Required |  |

Table 13: Attributes of <level>

* ***part\_index***: The flange partner with this index (see section 5.3.1.1). The part of the flange is referenced by the attribute index inside the element <part> or <assy> of the <connected\_to> element.
* ***order***: indicates the position of a flange relative to other flanges.

**Remarks:**

The order of the levels in the stacking list is identified by the numerical value of their attribute ***order***, in ascending order. Hence, indices must be unique within one stacking list.

Restriction “***nr\_levels*** must be greater than the number of nested elements of ***<connected\_to/>***” implies that element ***<stacking/>*** *must not* be used, if the connection is not self-connected.

**Example A:**

The situations in Figure 7 may be described using ***<level/>*** elements in order to explicitly define the stacking of the part flanges involved.

<connection\_group>

**<connected\_to>**

**<part index="1" label="PART\_7000800"/>** <!-- green -->

**<part index="2" label="PART\_7000400"/>** <!-- red -->

**</connected\_to>**

<connection\_list>

<connection\_0d label="A">

**<stacking>**

**<level order="1" part\_index="1"/>** <!-- green -->

**<level order="2" part\_index="2"/>** <!-- red -->

**<level order="3" part\_index="1"/>** <!-- green -->

**</stacking>**

...

</connection\_0d>

<connection\_0d label="B">

**<stacking>**

**<level order="1" part\_index="2"/>** <!-- red -->

**<level order="2" part\_index="1"/>**  <!-- green -->

**</stacking>**

...

</connection\_0d>

<connection\_0d label="C">

**<stacking>**

**<level order="1" part\_index="1"/>** <!-- green -->

**<level order="2" part\_index="1"/>** <!-- green -->

**<level order="3" part\_index="2"/>** <!-- red -->

**</stacking>**

...

</connection\_0d>

</connection\_list >

</connection\_group>

**Example B:**

Figure 7 may be expressed using the ***nr\_levels*** attribute, which simply states how many flanges of the ***<connected\_to>*** parts are involved in each joint.

<connection\_group>

<connected\_to>

<part index="1" label="PART\_7000800"/> <!-- green -->

<part index="2" label="PART\_7000400"/> <!-- red -->

</connected\_to>

<connection\_list>

<connection\_0d label="A">

**<stacking nr\_levels="3"/>** <!— "red", "green" and one of "red"/"green" -->

...

</connection\_0d>

<connection\_0d label="B">

... <!— "red", "green" in any order -->

</connection\_0d>

<connection\_0d label="C">

**<stacking nr\_levels="3"/>** <!— "red", "green" and one of "red"/"green" -->

...

</connection\_0d>

</connection\_list >

</connection\_group>

### Contacts and Friction

For many joint types like bolts, screws etc., friction between the jointed partners plays an important role for the manufacturing and the mechanical behavior of the joints in service.

In general, friction is a property of pairs of materials in contact. Normally it can be assumed that the friction property, here simply characterized by the static and kinetic friction coefficients, is homogenous. Nevertheless, friction properties must allow for local modification of an individual connection in order to enhance the service behavior.

In χMCF, friction coefficients for any combination of joint partners defined in ***<connected\_to>*** can be specified by the element ***<contact/>*** which is nested in the element ***<contact\_list/>.*** Each part in contact is given by the element ***<partner/>.*** The static and kinetic friction coefficients are defined by the element ***<coefficients/>***.

The friction property between the head of a bolt to jointed parts is specified, where the joint is defined.

#### Element *<contact\_list/>*

Relevant contacts, which are possible between the flange partners of a ***<connection\_group/>***, are collected in a ***<contact\_list/>***.

XML specification of ***<contact\_list/>*** element***:***

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| contact | 1 - \* | Required |  |

Table 14: Nested elements of element *<contact\_list/>*

The element ***<contact\_list/>*** does not allow for any attributes.

#### Element *<contact/>*

The features or coefficients of a physical contact between flange partners are described by an element ***<contact/>***.

XML specification of ***<contact/>*** element***:***

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| partner | 2 | Required | - |
| coefficients | 1 | Required | - |

Table 15: Nested elements of element *<contact/>*

Ordering of ***<contact/>*** elements within a ***<contact\_list/>*** is irrelevant, since it is assumed that features of a physical contact are invariant under permutation of the two involved materials.

The element ***<contact/>*** does not allow for any attributes.

#### Element *<partner/>*

Each joint partner involved in a contact is specified by the element ***<partner/>***. Only the first level parts which are listed in ***<connected\_to/>*** are allowed.

XML specification of ***<partner/>*** element***:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| part\_index | Integer |  | Required |  |

Table 16: Attributes of element *<partner/>*

These attributes have following semantics:

* part\_index: The flange partner with this index (see section 5.3.1.1). The part of the flange is referenced by the attribute index inside the element <part> or <assy> of the <connected\_to> element

The element ***<partner/>*** does not allow for any nested elements.

#### Element *<coefficients/>*

Static and kinetic friction coefficients are defined by the attributes ***static\_friction*** and ***kinetic\_friction*** of an element ***<coefficients/>***, respectively.

**Example**

**<connected\_to>**

**<part index="1" label="PART\_9004400" pid="3202132"/>**

**<assy index="42">**

**<part label="PART\_7000400" pid="110013"/>**

**<part label="PART\_7000800" pid="110099"/>**

**</assy>**

**</connected\_to>**

**<contact\_list>**

**<contact>**

**<partner part\_index="1"/>**

**<partner part\_index="42"/>**

**<coefficients static\_friction="0.3" kinetic\_friction=".25"/>**

**</contact>**

**</contact\_list>**

The element ***<coefficients/>*** does not allow for any nested elements.

#### Local Contact Properties

If necessary, local contact properties can be given within any element ***<connection\_0d/>***, ***<connection\_1d/>*** or ***<connection\_2d/>***, respectively (see section 5.3.3 Joints). In case of conflict, a local ***<contact\_list/>*** overrules the global one.

XML-specification of ***<coefficients/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| static\_friction | Floating point | [0, ∞[ | Optional | - |
| kinetic\_friction | Floating point | [0, ∞[ | Optional | - |

Table 17: Attributes of element *<coefficients/>*

A ***<connection\_list/>*** must not be empty. That means, at least 1 connection has to be defined.

### Joints

All the joints which connect the same set of objects (order does not matter) described in the element ***<connected\_to>*** are listed in the element ***<connection\_list>***. There should be *only one* connection group for any distinct set of objects in a χMCF file.

As discussed in Sect. 2.2, χMCF differs between 0-, 1- and 2-dimensional joints which will be specified in detail in the following chapters. Thus, an element ***<connection\_list>*** can comprise child elements ***<connection\_0d>***, ***<connection\_1d>*** and ***<connection\_2d>*** of arbitrary repetitions.

XML-specification of ***<connection\_list>***:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| connection\_0d | \* | optional | - |
| connection\_1d | \* | optional | - |
| connection\_2d | \* | optional | - |

Table 18: Nested elements of element *<connection\_list>*

A ***<connection\_list>*** must not be empty. That means, at least 1 connection has to be defined.

## A Minimalistic Example of a χMCF file

In the following, an example shows how the xMCF xml file should look like:

<?xml version="1.0" encoding="iso-8859-1" standalone="no"?>

<xmcf xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xmlns:MEDINA="http://servicenet.t-systems.com/medina/xMCF"

xsi:schemaLocation="http://servicenet.t-systems.com/medina/xMCF mcf\_MEDINA.xsd"

xsi:noNamespaceSchemaLocation="xmcf\_3\_0\_1.xsd">

<!-- some comments -->

<date> 2016-01-11 </date>

<version> 3.0.1 </version>

<units length="mm" angle="rad" mass="kg" force="N" time="s"/>

<appdata> <!—appdata at root level -->

<MEDINA xmlns="http://servicenet.t-systems.com/medina/xMCF">

<data\_at\_root>

<version MEDINA="MEDINA 8.4.2 Maintenance Release (64 Bit)"/>

...

</data\_at\_root>

</MEDINA>

</appdata>

...

<connection\_group ...>

<connected\_to>

<part index="1" label="PART\_8000880" pid="20123213"/>

<part index="2" label="PART\_8100340" pid="90123213"/>

</connected\_to>

<appdata> <!—appdata at connection\_group level -->

<MEDINA xmlns="http://servicenet.t-systems.com/medina/xMCF">

<data\_at\_connection\_group>

...

</data\_at\_connection\_group>

</MEDINA>

</appdata>

<connection\_list>

<connection\_0d>

<femdata>

<NASTRAN>

...

</NASTRAN>

</femdata>

...

</connection\_0d>

<connection\_1d>

<loc\_list>

...

</loc\_list>

<seamweld>

...

</seamweld>

<appdata>

<MEDINA xmlns="http://servicenet.t-systems.com/medina/xMCF">

<data\_at\_connector>

....

</data\_at\_connector>

</MEDINA>

</appdata>

...

</connection\_1d>

<connection\_2d>

...

</connection\_2d>

...

</connection\_list >

</connection\_group>

...

</xmcf>

## XML Schema Definition

XML-Schema definition (XSD) will be published at a later time on VDA web server.

# Data Common to any Connection

## Indices and their properties

MCF provides several elements which are essentially ordered sets of the same data type (strings, integers or decimals). More precisely they are like lists or vectors. For example, the <loc\_list/> for the coordinate list of a seam weld or the <string\_list/> in the <custom\_attributes/>. Often the order of the elements in a set is essential. E.g. the coordinates in the <loc\_list/> for a seam weld define the weld in the space uniquely by their values and their explicit order in the list.

The current XML standard allows that several child elements with an identical name can share the common parent. However, it lacks a built-in mechanism to introduce a logical structure (like an order) in an xml-document. MCF resolves this problem by introducing an index (attribute) in such cases. Indices may play a twofold role: to distinguish from each other and to ensure a unique arrangement in the list. Usually an index may be strictly monotone increasing natural numbers. In some cases strictly monotone increasing real numbers may also be rationally. For example, the "loc\_list" for the coordinate list of a seam weld can be indicated both by real numbers like arc length of the line or any increasing integer series.

Depending on the context the name of an index (attribute) may *index*, *v* or something else. They will always explicitly be declared at the appropriate places in the text.

## Attribute label

Any connection should have an attribute called***label***, which identifies it throughout the entire CAE process. It is not necessary that these labels are unique: For instance, if a weld line is split into different parts at a certain step in the process (e.g.: when crossing holes in the structure), its components shall keep the ***label*** attribute. A system "way down" in the process (i.e. detached from any centralized naming authority) may create new connections with all the same label, e.g.: "0" or empty string.

The ***label*** may be composed of digits only, but it should not be confused with e.g.: a finite element’s ID. If desired, finite element IDs would have to be placed within some ***<appdata>*** element.

## Dimensions and Coordinates

Connections may come in three different dimensions: ***<connection\_0d/>***, ***<connection\_1d/>*** and ***<connection\_2d/>***.

Any connection must have *coordinates*. How many they are and how they are described depends on the connection’s dimension. Details are described in the following sections.

## Attribute quality\_control

Some connections are more relevant than others, e. g. with respect to crash safety. Hence, several levels of quality control are well established in manufacturing processes. For this reason, any con­nec­tion can have an optional attribute ***quality\_control***. Since there is no general standard for such quality controls, χMCF cannot define a set of possible values for this attribute. Hence, it must be of type ***Alphanumeric***.

## Custom Attributes list

It was mentioned in Chapter 2.1 that only information relevant to connections should be contained in χMCF. Exceptions ***<appdata>*** and ***<femdata/>*** were introduced in Chapter 5.2. ***<appdata>*** and ***<femdata/>*** aim mainly at specific needs of application software. The internal structure of ***<appdata>*** itself is not standardized, may be very complex and depends on the specific software. The content can usually not be interpreted by other software systems.

There are frequently situations where a user of χMCF wishes to introduce supplementary information (attributes) to enrich the standard attributes defined by χMCF. In principle, the supplementary information could also be placed in an ***<appdata>***-block, but with a substantial drawback, namely, its exchange between different commercial software tools will be difficult in case the tool specific internal structure is not documented.

With ***<custom\_attributes/>*,**χMCF provides an element which is simple in handling and flexible enough to meet many requirements. All descendants of ***<custom\_attributes/>*** are key-value-pairs, following the same pattern *key ↔ value(s)*, with supported *value-type* ∈ [*int*, *real*, *string*]*N*, where *N* is a positive integer:

(*value-type*) *key* = {*value1, value2, … , valueN*}.

The case *N>1* is reminiscent of the *vector* or *list* from the STL of C++ and is called *list* in χMCF.

In detail, the individual elements of ***<custom\_attributes/>*** are of one of the following forms:

*<int key="NameofIntValue"> value </int>*

*<int\_list key="NameofIntListValue">*

*<value index="1"> value1 </value>*

*…*

*<value index="N"> valueN </value>*

*</int\_list>*

*<real key="NameofRealValue"> value </real>*

*<real\_list key="NameofRealListValue">*

*<value index="1"> value1 </value>*

*…*

*<value index="N"> valueN </value>*

*</real\_list>*

*<string key="NameofStringValue"> value </string>*

*<string\_list key="NameofStringListValue">*

*<value index="1"> value1 </value>*

*…*

*<value index="N"> valueN </value>*

*</string\_list>.*

I.e. the name of the elements specifies the *value-type* while the *value(s)* is/are hold in one or several element(s) *<value/>*. A list is signified by the suffix *\_list*. All elements own the attribute *key*.

Often the ***<custom\_attributes/>*** has an *owner* and is needed *for* a special purpose. For example, Mr. Brown needs for one and the same joint element an integer valued attribute named *priority* which should assume different values for two applications *"Fatigue"* (1) and *"Statics"* (22). These could be specified in a ***<custom\_attributes\_list/>*** as follows:

**Example**

<custom\_attributes\_list>

<custom\_attributes owner="Mr Brown" for="Fatigue">

<int key="priority"> 1 </int>

</custom\_attributes>

<custom\_attributes owner="Mr Brown" for="Statics">

<int key="priority"> 22 </int>

</custom\_attributes>

</custom\_attributes\_list>

In the above example, the *owner* is in both cases *"Mr Brown"* while the applications can be distinguished by the attributes *for="Fatigue"* and *for="Statics"*, respectively.

The more general case that several ***<custom\_attributes/>*** with different ownerships and for different purposes is considered by the element ***<custom\_attributes\_list/>*** with all the ***<custom\_attributes/>*’s**as child-elements. No attributes are associated to the element ***<custom\_attributes\_list/>***.

Existence of ***<custom\_attributes\_list/>*** inside a connection is optional. There can be up to one element inside each connection.

The ***<custom\_attributes\_list/>*** contains at least one of the following nested elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| custom\_attributes | 1 - \* | Required | - |

Table 19: Nested elements of element *<custom\_attributes\_list/>*

Existence of ***<custom\_attributes/>*** inside ***<custom\_attributes\_list/>*** is required. There must be at least one element inside ***<custom\_attributes\_list/>***.

XML specification of ***<custom\_attributes/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| owner | Alphanumeric | Alphanumeric | Required | Non-empty string |
| for | Alphanumeric | Alphanumeric | Optional | Non-empty string |

Table 20: Attributes of **<***custom\_attributes/***>** element

The attributes *owner* and *for* together of each ***<custom\_attributes/>*** element must be unique within each ***<custom\_attributes\_list/>.***

The ***<custom\_attributes/>*** element may contain at least one of the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- |
| string | 1 - \* | optional | At least one of these nested elements. |
| real | 1 - \* | optional |
| int | 1 - \* | optional |
| string\_list | 1 - \* | optional |
| real\_list | 1 - \* | optional |
| int\_list | 1 - \* | optional |

Table 21: Nested elements of element *<custom\_attributes/>*

The elements ***<string/>***, ***<real/>*** and ***<integer/>*** are allowed to have the following data type assignments for their value:

* **string element:** alphanumeric that is covered by string data type in xsd, which can contain characters, line feeds, carriage returns, and tab characters.

*Remark:* If required to handle not needed items e.g. line feeds or tab characters another data type should be used in XML Schema Definition that is the so called normalized string data type. The normalized string data type is derived from the String data type. The normalized string data type also contains characters, but the XML processor will remove line feeds, carriage returns, and tab characters.)

* **real element:** floating point that is covered by decimal data type is xsd, which can contain a numeric value. The maximum number of decimal digits you can specify is 18.
* **integer element:** integer that is covered by integer data type in xsd, which can contain a numeric value without a fractional component.

XML specification of ***<string/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 22: Attributes of **<string/>** element

XML specification of ***<real/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 23: Attributes of **<real/>** element

XML specification of ***<integer/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 24: Attributes of **<integer/>** element

XML specification of ***<string\_list/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 25: Attributes of **<string\_list/>** element

***<string\_list/>*** has the nested element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Nested Elements*** | ***Type*** | ***Multiplicity*** | ***Use*** | ***Constraints / Remarks*** |
| value | Alphanumeric | 1 - \* | required | - |

Where ***<value/>*** within ***<string\_list/>*** is specified as:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| index | Integer | >0 | Required | unique within the parent element |

Table 26: Attributes of **<value/>** element inside <*string\_list*/>

XML specification of ***<real\_list/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 27: Attributes of **<real\_list/>** element

***<real\_list/>*** has the nested element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Nested Elements*** | ***Type*** | ***Multiplicity*** | ***Use*** | ***Constraints / Remarks*** |
| value | Floating point | 1 - \* | Required | - |

Where ***<value/>*** within ***<real\_list/>*** is specified as:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| index | integer | >0 | Required | unique within the parent element |

Table 28: Attributes of **<value>** element inside <*real\_list*/>

XML specification of ***<int\_list/>***:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| key | Alphanumeric | Alphanumeric | Required | Non-empty string |

Table 29: Attributes of **<int\_list/>** element

***<int\_list/>*** has the nested element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Nested Elements*** | ***Type*** | ***Multiplicity*** | ***Use*** | ***Constraints / Remarks*** |
| value | Integer | 1 - \* | Required | - |

Where ***<value/>*** within ***<int\_list/>*** is specified as:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| index | integer | >0 | Required | unique within the parent element |

Table 30: Attributes of **<value/>** element inside <*real\_list/*>

**Remarks:**

1. Values of ***key***'s must be unique within their common parent element.
2. The order of the values in the corresponding list is identified by the numerical value of their attribute ***index***, in ascending order. Hence, indices must be unique within one list.
3. In case of strings the whitespaces deserve extra mention: To avoid mistakes, whitespaces are *not* to be used at beginning and end of a string.

**Example:**

<custom\_attributes\_list>

<custom\_attributes owner="DepartmentA" for="Fatigue">

<int key="priority"> 1 </int>

<string key="used S-N curve">Steel\_225\_ISO</string>

<real key="fatigue\_limit"> 223.1 </real>

</custom\_attributes>

<custom\_attributes owner="DepartmentA" for="Statics">

<int key="priority"> 2 </int>

</custom\_attributes>

<custom\_attributes owner="DepartmentB">

<string key="priority">high</string>

<real\_list key="direction vector">

<value index="1">10.3 </value>

<value index="2"> -2.1</value>

<value index="3">-1.5</value>

</real\_list>

<string\_list key="verifiedby" >

<value index="1">john</value>

<value index="2">Smith</value>

</string\_list>

</custom\_attributes>

</custom\_attributes\_list>

## Distinction between <custom\_attributes/> and <appdata/>

At first glance, ***<custom\_attributes/>*** and ***<appdata/>*** seem to address similar purpose or even to be redundant. This is deceptive, as evidenced by the following subsections.

### Needs of different process roles, addressed by *<custom\_attributes/>* and *<appdata/>*

In context of χMCF, at least two different roles can be clearly identified: The programmer of an application and the engineer using this application. The programmer needs to store extra data that are specific to the application. The engineer needs to store extra data that are specific to the process that the connections are involved.

As its name implies, ***<appdata/>*** is used to store application-specific data, whose structure and purpose is known only by the application itself, or applies to this application alone. The software vendor may choose to standardize and publish the format of this data in order to allow other applications to port data to it, and/or may choose to use ***<appdata/>*** as a private storage of internal state.

***<custom\_attributes/>*** represent OEM- or process-specific data, whose purpose is known by the engineers, but may not be known by the application.

Engineers store connection-related information in ***<custom\_attributes/>***. Engineers choose which attributes they need to store, and designate the corresponding data in ***<custom\_attributes/>***.

Applications store auxiliary data in ***<appdata/>***. These data possibly may be data that the engineers do not know of. ***<appdata/>*** may include information about the internal state of the application specific data model.

Engineers know the purpose and representation of ***<custom\_attributes/>***. The software may not know what each custom attribute represents, but must nevertheless be able to transport these data unchanged, or to offer a (generic) GUI for accessing it.

### Needs of different applications, addressed by *<custom\_attributes/>* and *<appdata/>*

***<appdata/>*** may be used as means of intercommunication between different applications. In this case, the format of ***<appdata/>*** needs to be standardized and published by the ***<appdata/>*** owner. Of course, information stored in ***<appdata/>*** does not necessarily need to be handled or maintained by 3rd party software. Therefore, ***<appdata/>*** should be considered as data that can be disregarded or thrown away by a 3rd party software. Hence, applications must not rely on preservation of ***<appdata/>*** in a way that cause e.g. data corruption or crash, if this data gets lost.

Internal structure of ***<custom\_attributes\_list/>*** is completely standardized, whereas internal structure of ***<appdata/>*** is arbitrary and can for instance be described by a software specific XML schema. (But this is optional.) Hence, ***<custom\_attributes\_list/>*** cannot be used as flexible as ***<appdata/>***, but its content is easier to be preserved across system boundaries.

### Different levels of *<custom\_attributes/>* and *<appdata/>* within χMCF data model

***<appdata/>*** may be used on different levels of a χMCF file:

* It may appear on root level (directly within ***<xmcf/>*** tag)
* and within any single connector (tags ***<connection\_0d/>***, ***<connection\_1d/>*** and ***<connection\_2d/>***)

In contrast to this, ***<custom\_attributes\_list/>*** can only be used within any single connector, but not at root level. There are good reasons for this:

Consider the common scenario, where many χMCF files each containing connections of subsystems are to be read in an application. The application will have to deal with conflicts between root level data, connection group level data and conflicts with data at connector level.

* At root level (within *<xmcf/>* element), any application should be able to deal with conflicts of its own *<appdata/>*, because their nature is known by the application. On the other hand, the purpose of a possible *<custom\_attributes/>* element is not known by the application. The application would therefore have to pass the task of resolving *<custom\_attributes/>* conflicts to the engineer. This is undesirable.
* At connection group level (within *<connection\_group/>* element), same considerations apply.
* At the connector level (within *<connection\_xd/>* elements), any application should be able to handle conflicts between connectors. This is because connectors are domain objects: both, the application and the engineer, are aware of the connectors' role and existence. So, both the application and the engineer can resolve connector conflicts if needed. After such a conflict has been resolved, there is no conflict of *<appdata/>* or *<custom\_attributes/>* left to be solved by the engineer or the application, because these data have a limited scope; they live within the confines of the connector. This is very convenient.

# 0D connections

## Generic Definitions

### Identification

Each point connection is optionally identified by its ***label***. This identification can be made at the element called ***<connection\_0d/>***.

The XML definitions of all 0D connections i.e. ***<connection\_0d/>*** elements are containing the following attributes:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint*** |
| label | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 31: Attributes of element *<connection\_0d/>*

##### Attribute "label"

The label defines the human readable identification of connection. It might contain a description of the connection or simply an index as an integer.

**Example A (**minimum definition**):**

<connection\_list>

**<connection\_0d>**

<loc>

...

</loc>

<spotweld>

...

</spotweld>

**</connection\_0d>**

</connection\_list>

**Example B (**within assigned text to ***label*):**

<connection\_list>

**<connection\_0d label="SPOT\_3490">**

<loc>

...

</loc>

<spotweld>

...

</spotweld>

**</connection\_0d>**

</connection\_list>

### Location

The definition of the connection location is described by the element <loc>. This element is nested below the parent element ***<connection\_0d/>***. It contains three values specifying the x, y and z coordinates of the location as text content.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Text*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| x | Floating point | (-∞,+∞) | Required | - |
| y | Floating point | (-∞,+∞) | Required | - |
| z | Floating point | (-∞,+∞) | Required | - |

Table 32: Text values of element **<loc>**

Example (with minimum definition for *<connection\_0d>*):

<connection\_0d>

**<loc> 2581.21 -708.408 31.6532 </loc>**

...

</connection\_0d>

### Direction

The definition of connection directions, where applicable, is described by the elements ***<normal\_direction/>*** and ***<tangential\_direction/>***. They both specify a direction vector. Lengths of both vectors are not relevant, as long as they are > 0.0.

Their XML definition is the same. If some definition requires both vectors, then their names signify their usage:

Element <normal\_direction/> denotes a direction of a local z axis.

Element <***tangential\_direction/>*** denotes the direction of an axis tangential to (base) part surface next to the point given in <***loc>***, giving locale x axis. Its orthogonalization[[10]](#footnote-11) relative to <***normal\_direction>*** must not vanish, i. e. both vectors must not be collinear.

If both elements are given, a right handed coordinate system is uniquely defined:

* Origin is in <***loc>***.
* z-axis is in direction of <***normal\_direction/>***.
* x-axis is the orthogonalization of <***tangential\_direction/>*** relative to <***normal\_direction/>***.
* y-axis is given by cross product[[11]](#footnote-12) z-axis × x-axis.

XML specification of <***normal\_direction/>*** and <***tangential\_direction/>*** elements:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| x | Floating point | (-∞,+∞) | Required | - |
| y | Floating point | (-∞,+∞) | Required | - |
| z | Floating point | (-∞,+∞) | Required | - |

Table 33: Attributes of elements *<normal\_direction/>* & *<tangential\_direction/>*

Both elements do *not* allow for any nested elements.

Unless otherwise stated, direction elements are optional. However, if omitted, importing systems may use a geometric search for determining ***<normal\_direction/>***, using a spherical characteristic, which may not be very reliable. ***<tangential\_direction/>*** can then only be guessed, implying a random orientation of the connection (e. g. a Robscan) in receiving system. Hence, it is recommended for a receiving system to issue a warning, at least.

Examples:

**<normal\_direction x="0.0" y="0.0" z="-1.0" />**

**<tangential\_direction x="70.7" y="70.7" z="0.0" />**

### Type Specification

Each connection is identified by its type. The XML definitions of all 0D connections are containing the following elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| clinch | 1 | Optional | - |
| clip | 1 | Optional | - |
| heat\_stake | 1 | Optional | - |
| nail | 1 | Optional | - |
| gumdrop | 1 | Optional | - |
| rivet | 1 | Optional | - |
| robscan | 1 | Optional | - |
| spotweld | 1 | Optional | - |
| threaded\_connection | 1 | Optional | - |
| contact\_list | 1 | Optional | See section 5.3.2.5. |
| stacking | 1 | Optional | See section 5.3.1.3 |

Table 34: Nested elements of element *<connection\_0d/>*

Note: Exactly *one* of the type elements (***clinchclinch, clip, heat\_stake, gumdrop, nail, rivet, robscan, spotweld, or threaded\_connection***) must exist in <connection\_0d/>. There is *no* default type.

## Spot Welds

A spot weld is denoted by an element ***<spotweld/>***. This element is described completely by its attribute and nested elements.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| spotweld | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 35: Nested elements of **<connection\_0d/> for <spotweld/>**

XML specification of ***<spotweld/>*** with element ***diameter:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| diameter | Floating point | > 0.0 | Optional | - |
| technology | Selection | resistance,  laser,  projection,  friction | Optional | - |

Table 36: Attributes of element*<spotweld/>*

##### Attribute "diameter"

The diameter of a spotweld is specified by the attribute diameter for the child element of ***<connection\_0d/>***.

##### Attribute "technology"

The technology used to weld the connection can be specified for each of the spot welds of a connection separately.

This technology can be one of

* Resistance welding
* Laser welding
* Projection welding
* Friction welding

Example:

<connection\_0d label="SPOT\_Left\_Gh\_2123921">

**<spotweld diameter="5.0"/>**

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Robscans

A Robscan is a pattern of arbitrary shape, drawn onto the flange partners by a laser optic. Such a shape has a length and width significant larger than the diameter of the laser focus. The laser beam defines a local z-axis and is assumed to be perpendicular to the flange partners. However, the pattern can be rotated around this z-axis, and it can be mirrored at its x-axis. This is depicted in following figure:



Figure 8: Robscans with Different Rotation Angles; Two of them Mirrored

The pattern of the bottom left Robscan is oriented with no rotation and no mirroring with respect to its own coordinate system (yellow). The next instance has 30° rotation. The two Robscans, top right in the figure, have a mirrored pattern; the uppermost having again 30° rotation.

There is a continuum of patterns for Robscans. Each one which shall be used at assembly line needs to be verified (by simulation plus test) in advance. This is expensive. Some implications are:

* Companies regard this information to be their own intellectual property.
* A pattern must not simply be stretched etc. It would need a new validation.
* Validated Robscan patterns are usually not part of distributions of FE processors.
* However, subcontractors shall have access to the position and "bounding box" of the Robscan, e. g.
* Hence, χMCF definition shall contain some "abstract" data.
* FE processors may address the danger of inconsistency by taking both levels of information from the same configuration file. So it is at the responsibility of the companies’ admins to have consistent data in that file.

Since the exact shape of the Robscan pattern is 3rd party intellectual property, it cannot be part of χMCF definition. It is referred to by just a string attribute "pattern". Possible values of attribute "pattern" are *not* subject of standard: In general, they are very OEM specific. However, to provide a minimum amount of information, width and length of the pattern are given by attributes "pattern\_width" and "pattern\_length".

A Robscan is denoted by an element ***<robscan/>***. This element is described completely by its attribute and nested elements.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| robscan | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 37: Nested elements of **<connection\_0d/> for <robscan/>**

XML specification of ***<robscan/>*** element:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| base | Integer | > 0 | Optional | - |
| pattern | Alphanumeric | Alphanumeric | Optional | Non-empty, if present. |
| gap | Floating point | >= 0.0 | Optional | - |
| width | Floating point | > 0.0 | Optional | - |
| pattern\_width | Floating point | > 0.0 | Optional | - |
| pattern\_length | Floating point | > 0.0 | Optional | - |
| mirrored | Boolean | "false" (default), "true" | Optional | - |
| orientation\_angle | Floating point | [-180°, 180°] | Optional | According to the unit of angles, defined in element <units/>. |
| filler\_material | Alphanumeric | Alphanumeric | Optional | - |

Table 38: Attributes of element *<robscan/>*

All attributes of element <***robscan***/> are optional for import to CAD or CAE processors. However, specific FE solvers may declare some of them to be mandatory.

General defaults are: false for boolean values, 0 for numeric values, "" for strings. However, these defaults are not always useful for CAE.

* gap: is the gap between both flange partners, probably defined by so-called "spacers".
* width: is the width of the laser beam.
* Width and length of the pattern are given by attributes pattern\_width and pattern\_length.
* mirrored: denotes, whether pattern has to be mirrored along its length-axis x, i. e. local y coordinate has to be inverted.
* orientation\_angle: allows a rotation around z axis, following right-hands-rule. Angle is measured in the unit of angles, defined in element <units/>, within range [-180°, 180°]. -180° and +180° degree are regarded to be identical. (Ranges can be defined in equivalent range in other unit.)

Both parameters, mirrored and orientation\_angle address optimization simulations: They allow to vary their parameters more easily, if it is just an angle and a boolean, compared with calculating completely new orientation vectors.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |
| tangential\_direction | 1 | Optional | - |

Table 39: Nested elements of element *<robscan/>*

* Element ***<normal\_direction/>*** denotes direction of laser beam, giving locale z axis.
* Element ***<tangential\_direction/>*** denotes direction of length-axis, giving locale x axis.

***<normal\_direction>*** and ***<tangential\_direction>*** elements are described in section 7.1.3.

Example:

<connection\_0d label="RSC\_1272360">

<loc> 507 1 0.8 </loc>

<robscan base="1" pattern="KL\_ST" gap="0.15" width="0.4"   
 mirrored="false" pattern\_width="5" pattern\_length="12" orientation\_angle="0">

<normal\_direction x="0" y="0" z="-1"/> <!-- locale z axis -->

<tangential\_direction x="1" y="0" z="0"/> <!-- locale x axis -->

</robscan>

<appdata>

...

</appdata>

</connection\_0d>

## Rivets

There are many types of rivets. If at some state of the model the specific type of rivet (e. g. SPR, Self-Piercing Rivet) is not known, then a generic rivet element should be used to capture just the necessary information, like direction, length and diameter.

A rivet is denoted by an element <***rivet/>***. This element is described completely by its attributes and nested elements.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| rivet | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 40: Nested elements of **<connection\_0d/> for <rivet/>**

XML specification of ***<rivet/>*** element***:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| hardness | Floating point | > 0.0 | Optional | - |
| shaft\_diameter | Floating point | > 0.0 | Optional | - |
| length | Floating point | > 0.0 | Optional | - |
| head\_diameter | Floating point | > 0.0 | Optional | - |
| head\_height | Floating point | ≥ 0.0 | Optional | If at least one of them is specified  *head\_height + sink\_size > 0*  is required. |
| head\_type | Alphanumeric | Alphanumeric | Optional | - |
| sink\_size | Floating point | ≥ 0.0 | Optional | - |
| strength\_property\_class | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | - |

Table 41: Attributes of element *<rivet/>*

  

|  |  |  |
| --- | --- | --- |
| Dome | Large Flange | Countersunk |

*Source of image:* <http://sfsintecusa.com/files/2011/09/Rivet-Brochure-Feb-2011.pdf>

Figure 9: Rivet head types

* hardness: Vickers hardness HV of the rivet material.
* shaft\_diameter: the diameter of the shaft of the (unmounted) rivet.
* length: is the overall length of the (unmounted) rivet itself.
* head\_diameter: the diameter of the head of the (unmounted) rivet.
* head\_height: the height of the head.
* head\_type: description of head type ("dome", "countersunk" or "large\_flange").
* sink\_size: the size of the head that is sunk.
* strength\_property\_class: Strength according to ISO, EN, BSW, DIN, etc.

e.g.: **SAE J492** - *Guide for Rivet Selection and Design Consideration*

* part\_code: the part code of the rivet, as used e. g. in a PDM system. Frequently, it may be convenient to use the rivet norm (according to ISO, EN, BSW, DIN, …) as part code.

If possible, a rivet should know the direction of fixation, i.e. possess a nested element ***<normal\_direction>***. However, this is not mandatory in order to allow for importing incomplete data. Direction sense of ***<normal\_direction/>*** is from rivet head to foot, which element’s definition can be found in section 7.1.3.

A ***<rivet/>*** is always placed into holes drilled before, whereas its subtype ***<self\_piercing/>*** creates its own hole during placement.

Specific subtypes of rivets are defined by adding according nested elements, listed in following table:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |
| blind self\_piercing solid swop | 1 | Optional | Maximum one of the listed elements. |

Table 42: Nested elements of element *<rivet/>*

The subtypes are described in detail in the following sections.

Example:

<connection\_0d label="RVT\_2123921">

...

**<rivet shaft\_diameter="5.0" head\_diameter="8" length="3.5">**

**<normal\_direction x="0" y="0" z="3"/>**

**</rivet>**

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

### Blind Rivets

Blind rivets are one-sided rivets that require a pre-drilled hole. Blind rivets form their shape when the

mandrel is pulled out from the rivet body. This action securely clamps the sheets together.

A blind rivet is denoted by a nested element ***<blind/>*** within ***<rivet/>***. This element is described completely by its attributes and those of ***<rivet/>***.

XML specification of ***<blind/>*** element:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| min\_grip | Floating point | > 0.0 | Optional | - |
| max\_grip | Floating point | > 0.0 | Optional | greater equal to min\_grip |
| clearance | Floating point | > 0.0 | Optional | - |
| material | Alphanumeric | Aplhanumeric | Optional | Material of the rivet body |

Table 43: Attributes of element **<blind/>**





*Source of image*: <http://www.stanleyengineeredfastening.com/brands/pop/rivets/selection-factors>

Figure 10: Cross Section of a blind rivet

The pictures above describe what the attributes of ***<rivet/>*** and ***<blind/>*** correspond to:

* min\_grip, max\_grip: these two attributes collectively describe the effective grip range of the rivet. A blind rivet is engineered so that it can be used for a specific range of material thickness for which it provides proper joining between connected parts. This can be called as the blind rivet’s grip range.

***Remark:*** In case of material thickness changes in connected parts might lead to other size of blind rivet as joining element!

* clearance: the blind rivet needs some clearance on the blind side, which is the side of mandrel head, when inserted into the holes, before it is applied.
* material: this attribute defines the applied material of the blind rivet body. Generally the applied rivet should be used with connected parts so that the connector rivet element has the same physical and mechanical properties as the components to be joined. (usual materials: Steel, Stainless Steel, Nickel Copper Alloy (Monel) Copper and several grades of Aluminum)

When a blind rivet is going to be applied to join 2 components which have different mechanical properties like one of them is thinner than the other or one of them is softer that the other, then the normal direction element will become more important to show the proper setting direction of the rivet as seen in the picture below:



Figure 11: Thick and Thin Assembling



Figure 12: Fastening Soft and Hard

**Example:**

<connection\_0d label="RVT\_2123921">

<rivet shaft\_diameter="3.35" head\_diameter="5.5" head\_type="dome" length="4">

<blind min\_grip="3" max\_grip="3.2" clearance="4.5" material="Steel"/>

<normal\_direction x="0.0" y="1.5" z="3.0"/>

</rivet>

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

For further information about the Blind rivets you can check the following document:

<http://www.stanleyengineeredfastening.com/brands/pop/rivets>

### Self-Piercing Rivets

A self-piercing rivet is a special kind of rivet which does not need a pre-drilled hole. Originally a hollow cylinder with a cap on one end, it deforms together with the material it is pushed into like sketched in following figure:





Figure 13: Cross Section of a Self-Piercing Rivet



*Source of image:* <http://www.google.com/patents/US7810231>

Figure 14: Self-piercing rivet setting apparatus

There is a wide range of such rivets available on the market. They can be used with different rivet dollies or dies (**30**) on the opposite side. Such combinations have to be chosen in accordance to the materials of the flange partners. Which combinations have been validated successfully is 3rd party intellectual property and hence cannot be part of χMCF definition. It is referred to by string attributes for rivet and die parameters. Possible values of these attribute are *not* subject of standard: In general, they are very OEM specific. However, to provide a minimum amount of information, some general geometric information is given by according attributes.

A self-piercing rivet is denoted by a nested element ***<***se***lf\_piercing/>*** within ***<rivet/>***. This element is described completely by its attributes and those of ***<rivet>***. In especially, attributes "length", "head\_diameter" and "shaft\_diameter" are inherited from ***<rivet>***.

XML specification of ***<self\_piercing/>*** element:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| head\_label | Alphanumeric | Alphanumeric | Optional | - |
| shaft\_label | Alphanumeric | Alphanumeric | Optional | - |
| die\_label | Alphanumeric | Alphanumeric | Optional | - |
| die\_diameter | Floating point | > 0.0 | Optional | - |
| die\_depth | Floating point | > 0.0 | Optional | - |

Table 44: Attributes of element *<self\_piercing/>*

All attributes of this connection are optional for import to CAD or CAE processors. However, specific FE solvers may declare some of them to be mandatory.

The head, shaft and die labels are very OEM specific. However, to provide a minimum amount of information, diameters of them plus depth of die are given.

Attribute die\_label can be used to refer to a catalog entry. Then die\_diameter and die\_depth can be omitted in χMCF file, if their values are given in catalog.

One level higher, the entire rivet can refer to an item via attribute which refers to an item that is being used in OEM Specific PDM system. In this case, subtype definition is used from catalog, too, if present. The ***<rivet/>*** in χMCF file *must not* specify another subtype than the referred item from the PDM system!

General defaults for attributes are: 0 for numeric values, "" for strings. However, these defaults are not always useful for CAE.

Example:

<connection\_0d label="RVT\_2123921">

**<rivet shaft\_diameter="3.35" head\_diameter="5.5" length="4" hardness="410">**

**<normal\_direction x="0" y="0" z="3"/>**

**<self\_piercing head\_label="N000000002651" shaft\_label="C"**

**die\_depth="2.5" die\_label="DZ11x2,5-0,50" die\_diameter="11" />**

**</rivet>**

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

### Solid Rivets

Solid rivets require a pre-drilled hole. They can be found in many similar forms, with a cap on one end. The other end deforms when it is pushed from the other side.

The shafts of solid rivets are typically solid, but for all rivets that have similar shapes, this type will be used:

|  |  |  |  |
| --- | --- | --- | --- |
| Solid rivet | Semi Tubular rivet | Shoulder rivet | Split rivet |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

*Source of image*: <http://www.rivet.com/Catalog_CompleteVersion/ImpactOnly-2-03-12.pdf>

Table 45: Pictures of all Solid Rivets

The dimensions of all these rivets generalize into the following diagram:



Figure 15: Dimensions of Solid Rivets

A solid rivet is denoted by a nested element ***<solid/>*** within ***<rivet/>***. This element is described completely by its attributes and those of ***<rivet/>***.

XML specification of ***<solid/>*** element:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| min\_grip | Floating point | > 0.0 | Optional | - |
| max\_grip | Floating point | > 0.0 | Optional | max\_grip ≥ min\_grip |
| hole\_diameter | Floating point | > 0.0 | Optional | - |
| hole\_depth | Floating point | > 0.0 | Optional | - |
| shoulder\_diameter | Floating point | > 0.0 | Optional | - |
| shoulder\_length | Floating point | > 0.0 | Optional | - |
| tennon\_diameter | Floating point | > 0.0 | Optional | - |
| tennon\_length | Floating point | > 0.0 | Optional | - |

Table 46: Attributes of element *<solid/>*

Recommendations:

1. hole\_diameter is defined with hole\_depth and vice versa.
2. tennon\_diameter exist only if shoulder\_diameter is defined and vice versa.

The pictures above describe what the attributes of ***<rivet>*** and ***<solid>*** correspond to:

* min\_grip, max\_grip: these two attributes collectively describe the effective grip range.
* hole\_diameter: this is the diameter of the hole of the tube. This value is provided in a supplier standard normally.
* hole\_depth: this is a measure of the hole of the tube. There is no exact relation between hole\_depth and grip range. Based on the supplier it might be a length calculation that could be result in an advised clinch allowance based on the work thickness calculated by the sum of the thicknesses of connected parts.



Figure 16: Clinch allowance of solid rivet

* shoulder\_diameter, shoulder\_length: the rivet's shoulder sizes. Note that shoulder length is typically measured next under the head.
* tennon\_diameter, tennon\_length: these attributes describe the secondary smaller shoulder sizes. A tennon\_diameter should not exist without a primary shoulder\_diameter.

If a head\_height exists, sink\_size will be 0, and vice versa. But there is no constraint in χMCF.

Example:

<connection\_0d label="RVT\_2123921">

<loc> 1645.83 821.145 616.585 </loc>

<rivet shaft\_diameter="3.35" head\_diameter="5.5" head\_height="0.4" length="4">

<solid min\_grip="3" max\_grip="3.2" hole\_depth="0.8"

shoulder\_diameter="3.8" shoulder\_length="1.2"/>

<normal\_direction x="0" y="1.5" z="3"/>

</rivet>

<appdata>

...

</appdata>

</connection\_0d>

### Swop Rivets

"SWOP" stands for "Sheet Weld Opposed Plug". The method is used to connect parts with spot welds in cases where one component material is not suitable to create any alloy with the other part’s material. Typically it is the case when aluminum and steel parts are going to be connected.



|  |  |  |  |
| --- | --- | --- | --- |
| 1 - | Connected part A | 5 - | Insert Body |
| 2 - | Connected Part B | 6 - | Enlarged head |
| 3 - | Hole on insert side | 7 - | Stop surface |
| 4 - | Insert (plug or rivet) | 8 - | Electrodes |
| D - | Spot weld diameter | d - | Hole diameter |
| w - | Spot weld nugget | c - | Core and Heat Affected Zone (HZA) |

*Source of image:* <https://www.google.com.ar/patents/EP0967044A2?cl=en&hl=de>

Figure 17: Cross section of a SWOP Rivet

The following description is quoted from the Patent documented under **EP 0967044 A2**:

"A sheet (**1**) of a material which cannot be electrically welded is connected to a second sheet (**2**) of a weldable material by providing a through hole (**3**) in the first sheet having a transverse dimension substantially greater than the transverse dimension of the tips of the electrodes (**8**) which are used for carrying out the electric welding spot. Within the hole (**3**) there is provided an insert (**4**) of a material which can be electrically welded. The two electrodes (**8**) are applied so as to cause welding of the insert (**4**) to the second sheet (**2**). The insert (**4**) has a stop surface (**7**) which prevents the first sheet (**1**) from separating from the second sheet (**2**) after welding. The difference of the transverse dimensions of the tip of each electrode (**8**) and the insert (**4**) avoids any possible overheating up to the melting point of the material constituting the first sheet (**1**) while welding is carried out."

Based on the description above one can imagine a wide range of insert shapes. Hence, they cannot be part of χMCF definition. The shape is referred by a string attribute insert\_shape. The possible values of this attribute are *not* subject of the standard: in general, this is an entry which is very OEM specific. However, to provide a minimum amount of information some general geometric data are given by the attributes introduced below.

A swop rivet is denoted by a nested element <swop/> within <rivet/>. This element is described completely by its attributes and parent element attributes within <rivet/>. Especially the attributes shaft\_diameter, sink\_size, length, head\_diameter and head\_height are inherited from <rivet/> element. Other rivet parameters (e.g.: length or shaft\_diameter) may be treated meaningless.

XML specification of <swop/> element:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| insert\_shape | Alphanumeric | Alphanumeric | Optional | - |
| insert\_height | Floating point | > 0.0 | Optional | - |
| spotweld\_diameter | Floating point | > 0.0 | Optional | - |
| spotweld\_technology | Selection | resistance  laser  projection  friction | Optional | - |

Table 47: Attributes of element **<swop/>**

All attributes of this connection type are optional for importing it into CAD or CAE application. Although, it can be that some FE pre-processor may declare some of them to be mandatory.

These attributes have the following semantics:

* insert\_shape: Identification of the applied insert shape. (In the illustrated example, the hole is circular, but it may have a polygonal shape in order to prevent relative rotation of the two sheets in case they were connected by a single framing spot.)
* insert\_height: Height of the (unmounted) insert.
* spotweld\_diameter: Diameter of the spot weld, see section 7.2 Spot Welds.
* spotweld\_technology: Technology of the spot weld, see section 7.2 Spot Welds.

The element of <swop/> does not allow any nested elements:

**Example:**

<connection\_0d label="RVT\_2123921">

<loc> 1645.83 821.145 616.585 </loc>

<rivet head\_diameter="8.5" head\_height="0.9" hardness="410" **shaft\_diameter="5.4"**

**sink\_size="0.3" length="1.5"** >

<normal\_direction x="0" y="0" z="3" />

**<swop insert\_shape="cone\_23" insert\_height="1.8"**

**spotweld\_diameter="4.5" spotweld\_technology="resistance" />**

</rivet>

<appdata>

...

</appdata>

</connection\_0d>

## Threaded Connections: Bolts and Screws

### Introduction

Bolts and screws are probably the most well-known connection techniques, even within non-specialists. However, they do need a closer look at their details. This starts, but does not end with the differentiation between screws and bolts[[12]](#footnote-13):

* Bolts are for the assembly of unthreaded components, with the aid of a [nut](https://en.wikipedia.org/wiki/Nut_(hardware)" \o "Nut (hardware)).
* Screws are used in components which contain their own thread, and the screw may even cut its own internal thread into them.

|  |  |
| --- | --- |
|  |  |
| Bolt Representation | Screw Representation |

Figure 18: Bolts and Screws



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Button head | Pan head | Round head | Truss head | Countersunk | Countersunk (oval) Raised |

*Source of image:* [*http://commons.wikimedia.org/wiki/File:Screw\_head\_types.svg*](http://commons.wikimedia.org/wiki/File:Screw_head_types.svg).  
*Author published it under the "under the* [*Creative Commons*](http://en.wikipedia.org/wiki/en:Creative_Commons)[*Attribution-Share Alike 3.0 Unported*](http://creativecommons.org/licenses/by-sa/3.0/deed.en) *license".*

Figure 19: Different Screw Forms



Figure 20: Definition of Length and Head Sizes



*Source of image:* [*http://upload.wikimedia.org/wikipedia/commons/0/00/Lead\_and\_pitch.png*](http://upload.wikimedia.org/wikipedia/commons/0/00/Lead_and_pitch.png)*.*

Figure 21: Definition of lead, pitch and starts of a thread.

### Contacts and Friction

Self-loosening of screws and bolts has to be prevented. Static friction, together with pretension, is a major means against self-loosening. However, kinetic (or dynamic) friction also has some meaning in CAE processes. Hence, both friction types need to be supported by χMCF.

Friction occurs between any two objects in contact. In case of bolts and screws, these contacts are usually obtained between:

1. head and washer (if there is a "loose" washer, i.e. a washer not being fixed to the head or shaft)
2. washer (if there is one) and first connected part, or else
3. head and first connected part
4. between the connected sheets
5. last connected part and "loose" washer (if there is one)
6. washer (if there is one) and nut, or else
7. last connected partand nut
8. screw and cut thread, or bolt thread and nut thread

Consequently, χMCF assigns friction attributes to

1. heads and nuts, applying to their contacts to either washers or adjacent parts,
2. washers, applying to their contacts to adjacent parts (*not* to head or nut),
3. any contact between each two adjacent parts,
4. the thread.

For heads (as a constituent part of a screw or bolt), nuts and washers, there are specific XML elements in χMCF. Corresponding friction attributes are located, there.

Case c. above, of inter-part contacts, is addressed by sections 5.3.2 (Global Contact Properties) and 5.3.2.5 (Local Contact Properties).

Case d. above, of the thread contact, is addressed in section 7.5.3.







**Example A (**with washers**):**

<connection\_group id="1">

<connected\_to>

<part index="1" label="PART\_7000400"/>

<part index="2" label="PART\_7100100"/>

<part index="5" label="PART\_5000300"/>

<part index="6" label="PART\_5000800"/>

</connected\_to>

<connection\_list>

<connection\_0d label="BOLT\_135"> <!-- bolt with washers -->

<loc> 84 60 10 </loc>

<!-- Friction is "head to washer": -->

<threaded\_connection length="50"

static\_friction="0.8"

thread\_static\_friction="0.8">

<normal\_direction x="0" y="0" z="-10"/>

<!-- Washer next to head with its friction to 1st part -->

<washer outer\_diameter="20" attached="false" static\_friction="0.8" />

<bolt>

<!-- Friction is "nut to washer" -->

<nut diameter="16." static\_friction="0.8">

<!-- Washer next to nut with its friction to last part -->

**<washer outer\_diameter="25" attached="false" static\_friction="0.8" />**

</nut>

</bolt>

</threaded\_connection>

**<contact\_list>** <!-- Local Contact definition, according to **5.3.2.5** -->

**<contact>**

<partner part\_index="1"/>

<partner part\_index="2"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**<contact>**

<partner part\_index="2"/>

<partner part\_index="5"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**<contact>**

<partner part\_index="5"/>

<partner part\_index="6"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**</contact\_list>**

</connection\_0d>

</connection\_list>

</connection\_group>

**Example B (**without washers**):** with global & local contact definition, and thread contact. Local contacts override global contacts.

<connection\_group id="1">

<connected\_to>

<part index="1" label="PART\_7000400"/>

<part index="2" label="PART\_7100100"/>

<part index="5" label="PART\_5000300"/>

<part index="6" label="PART\_5000800"/>

</connected\_to>

**<contact\_list>** <!-- Global Contact Properties, for the whole connection\_group -->

**<contact>**

<partner part\_index="1"/>

<partner part\_index="2"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**<contact>**

<partner part\_index="2"/>

<partner part\_index="5"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**<contact>**

<partner part\_index="5"/>

<partner part\_index="6"/>

<coefficients static\_friction="0.8"/>

**</contact>**

**</contact\_list>**

<connection\_list>

<connection\_0d label="BOLT\_135"> <!-- bolt without washers -->

<loc> 84 60 10 </loc>

<!-- Friction "head to first part" and "thread to nut": -->

<threaded\_connection length="50"

static\_friction="0.8"

thread\_static\_friction="0.8">

<bolt>

<!-- Friction is "nut to last part" -->

<nut diameter="16." static\_friction="0.8"/>

</bolt>

</threaded\_connection>

**<contact\_list>** <!-- Local Contact definition, according to **5.3.2.5** -->

**<contact>**

<partner part\_index="1"/>

<partner part\_index="2"/>

<coefficients static\_friction="**0.9**"/>

**</contact>**

**</contact\_list>**

</connection\_0d>

</connection\_list>

</connection\_group>

### Definition of element *<threaded\_connection/>*

Due to its similar characters, bolts and screws share a couple of common attributes. Hence, in order to reduce redundancy, they are subsumed beneath a common, more abstract XML element ***<threaded\_connection/>.***

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| threaded\_connection | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 50: Nested elements of <connection\_0d/> for **<threaded\_connection/>**

##### Element "loc"

The syntax of this element is described in the corresponding section 7.1.2 Location.

Element "appdata"

This follows the same syntax as defined in section 5.2.1 User Specific Data <appdata>.

Element "femdata"

This follows the same syntax as defined in section [5.2.2 Finite Element Specific Data <femdata>](#_Finite_Element_Specific).

***Element "*** ***threaded\_connection"***

XML specification of ***<threaded\_connection/>*** element with the following attributes***:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| diameter | Floating point | > 0.0 | Optional |  |
| length | Floating point | > 0.0 | Optional | - |
| thread\_length | Floating point | > 0.0 | Optional | length ≥ thread\_length |
| head\_diameter | Floating point | > 0.0 | Optional | - |
| head\_height | Floating point | ≥ 0.0 | Optional | If at least one of them is specified,  *head\_height + sink\_size > 0*  is required. |
| head\_type | Alphanumeric | Alphanumeric | Optional | - |
| sink\_size | Floating point | ≥ 0.0 | Optional | Usually, sink\_size > 0 implies no washer. |
| pitch | Floating point | > 0.0 | Optional | Not to be confused with "lead". |
| lead | Floating point | > 0.0 | Optional | In case of single-start threadform pitch is equal to lead. Default value is equal to pitch attribute! |
| torque | Floating point | > 0.0 | Optional | - |
| angle | Floating point | > 0.0 | Optional | - |
| pretension | Floating point | > 0.0 | Optional | - |
| static\_friction | Floating point | > 0.0 | Optional |  |
| kinetic\_friction | Floating point | > 0.0 | Optional | - |
| thread\_static\_friction | Floating point | > 0.0 | Optional |  |
| thread\_kinetic\_friction | Floating point | > 0.0 | Optional |  |
| strength\_property\_class | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | - |

Table 51: Attributes of element *<threaded\_connection/>*

These attributes have following semantics:

* diameter: the diameter of the bolt or screw. It should be provided, since e. g. only few CAE simulation types can live without it.
* length: the length of the bolt or screw. Refer to Figure 20: Definition of Length and Head Sizes.
* thread\_length: the length of the thread of the bolt or screw. Only needed in case of a partial-thread screw. In case of a full-thread screw, thread continues from tip to head, without a non-threaded area. Then, *thread\_length = length – sink\_size*.
* head\_diameter: the diameter of the head of the bolt or screw
* head\_height: the height of the head.
* head\_type: Type of screw head, e. g. "outer hexagonal", "flanged-hex/Phillips-head combi", "external torx plus ". Since there is a wide variety and ever increasing of screw head types, alphanumeric type is appropriate for this attribute.
* sink\_size: the size of the head that is sunk (for countersunk screws).
* pitch: is the distance from the crest of one thread to the next.[[13]](#footnote-14)
* lead: is the distance along the screw's axis that is covered by one complete rotation of the screw (360°). Lead and pitch are parametrically related, and the [parameter](https://en.wikipedia.org/wiki/Parameter) that relates them, the number of starts (number of single thread), very often has a value of 1, in which case their relationship becomes equality. In general, lead is equal to S times pitch, in which S is the number of starts.
* torque: The torque which should be applied when fastening the bolt or screw.
* angle: The turning angle which should be applied when fastening the bolt or screw.
* pretension: The pretension which is generated within the bolt or screw when fastening.
* static\_friction: The static friction between head and adjacent washer or part.
* kinetic\_friction: The kinetic friction between head and adjacent washer or part.
* thread\_static\_friction: The static friction between screw and cut thread, or bolt thread and nut thread.
* thread\_kinetic\_friction: The kinetic friction between screw and cut thread, or bolt thread and nut thread.
* strength\_property\_class: Strength according to applied standard within a unique part supplier or OEM.
* part\_code: the part code of the bolt or screw, as used e. g. in a PDM system. Frequently, it may be convenient to use the screw norm (according to ISO, EN, BSW, DIN, …) as part code.

Torque, pretension and angle interact as follows:

* Torque is only applied, if no pretension is given.
* Angle is only applied, if torque is given and no pretension is present.

For bolts as well as screws, it is recommended to provide the direction of fixation. Hence ***<threaded\_connection/>*** offers following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |
| bolt screw | 1 | Required | Exactly one of these elements. |
| washer | 1 | Optional | - |

Table 52: Nested elements of element *<threaded\_connection/>*

##### Element "normal\_direction"

The direction of the bolt or screw is described by the element <normal\_direction/> in form of an orientation vector. This is necessary to define the orientation of the bolt or screw and hence which end is considered to be the connection’s head-side. The orientation sense of the bolt is *from head to nut* and of the screw is *from head to point*.

Refer to section 7.1.3 for syntax of element <normal\_direction/>.

Elements ***<bolt/>***, ***<screw/>*** and ***<washer/>*** are described in the following sections.

The nested element ***<washer/>*** refers to the washer next to the head of a screw or bolt.

All attributes of threaded connections are optional for import to CAD or CAE processors. However, specific FE solvers may declare some of them to be mandatory.

General defaults are: 0 for numeric values, "" for strings. However, these defaults are not always useful for CAE.

### Washer

Bolts and screws are frequently combined with washers. Hence, we define the XML element ***<washer/>***.

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| outer\_diameter | Floating point | > 0.0 | Optional | - |
| inner\_diameter | Floating point | > 0.0 | Optional | Usually NO inner diameter, if attached. |
| thickness | Floating point | > 0.0 | Optional | - |
| attached | Boolean | "false" (default), "true" | Optional | - |
| static\_friction | Floating point | > 0.0 | Optional | - |
| kinetic\_friction | Floating point | > 0.0 | Optional | - |
| strength\_property\_class | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | NO part code, if attached. |

Table 53: Attributes of element *<washer/>*

These attributes have following semantics:

* outer\_diameter: the outer diameter of the washer. If a washer is used at all, at least its diameter must be specified.
* inner\_diameter: the inner or hole diameter of the washer
* thickness: the thickness of the washer
* attached: true, if and only if the washer is firmly attached to the screw head or nut, rsp.
* static\_friction: the static friction between this washer and its adjacent part (not head or nut)
* kinetic\_friction: the kinetic friction between this washer and its adjacent part (not head or nut)
* strength\_property\_class: Strength according to applied standard within a unique part supplier or OEM.
* part\_code: the part code of the washer, as used e. g. in a PDM system. Frequently, it may be convenient to use the washer norm as part code.

The element ***<washer/>*** does not allow for any nested elements.

### Nut

Any bolt requires a nut. But since nuts may have a number of own attributes, it is worth to define a separate XML element for them.

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraints / Remarks*** |
| --- | --- | --- | --- | --- |
| diameter | Floating point | > 0.0 | Optional | - |
| height | Floating point | > 0.0 | Optional | - |
| torque | Floating point | > 0.0 | Optional | - |
| angle | Floating point | > 0.0 | Optional | - |
| static\_friction | Floating point | > 0.0 | Optional | - |
| kinetic\_friction | Floating point | > 0.0 | Optional | - |
| clipped\_to | Integer | > 0 | Optional | - |
| fixed\_to | Integer | > 0 | Optional | - |
| strength\_property\_class | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | - |

Table 54: Attributes of element **<nut/>**

These attributes have following semantics:

* *diameter*: the diameter of the nut
* height: the height of the nut.
* torque: The torque which should be applied when fastening the nut.
* angle: The turning angle which should be applied when fastening the nut.
* static\_friction: The static friction between nut and adjacent washer or part.
* kinetic\_friction: The kinetic friction between nut and adjacent washer or part.
* clipped\_to: The nut is fixed with a clip or it is a clip itself. It is clipped to the flange partner with this index (see section 5.3.1.1). If attribute is missing, nut is not clipped. Nut and clip share a common part code, i. e. they are regarded to be one single part.
* fixed\_to: The nut is firmly fixed (e.g. welded) to the flange partner with this index (see section 5.3.1.1). If attribute is missing, nut is not fixed.
* strength\_property\_class: Strength according to applied standard within a unique part supplier or OEM.
* part\_code: the part code of the nut, as used e. g. in a PDM system. Frequently, it may be convenient to use the nut norm (according to ISO, EN, BSW, DIN, …) as part code.

Usually nut fixed\_to prohibits nut clipped\_to and vice versa.

Usually nut clipped\_to or fixed\_to prohibits bolt clipped\_to or fixed\_to and vice versa.

There are other means of fixating nuts to sheets, as well, e.g. punching or riveting.

The element ***<nut/>*** allows following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| washer | 1 | Optional | - |

Table 55: Nested elements of element *<nut/>*

The nested element ***<washer/>*** refers to the washer next to the nut of the bolt.

### Bolt

A bolt connection is denoted by an element ***<bolt/>***. This element is described completely by its attributes and nested elements.

##### Element "bolt"

For the ***<bolt/>*** element, the following attributes are allowed:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| clipped\_to | Integer | > 0 | Optional | - |
| fixed\_to | Integer | > 0 | Optional | - |

Table 56: Attributes of element *<bolt/>*

* ***clipped\_to***: The head of the bolt is fixed with a clip to the flange partner with this index (see section 5.3.1.1). If attribute is missing, bolt is not clipped. Bolt and clip share a common part code, i.e. they are regarded to be one single part.
* fixed\_to: The head of the bolt is fixed (eg. welded) to the flange partner with this index (see section 5.3.1.1). Also applies if there is no screw head at all, e.g. this bolt actually is stay bolt or stud. If attribute is missing, bolt is not fixed.

There is no "base" attribute for bolts, since this information can be derived from connection direction.

Usually bolt fixed\_to prohibits bolt clipped\_to and vice versa.

The element ***<bolt/>*** allows following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| nut | 1 | Optional |  |

Table 57: Nested elements of element **<bolt/>**

The nested element ***<nut/>*** refers to the bolt’s nut. This, in turn, may contain a nested element ***<washer/>***.

The nested element ***<nut/>*** is required by definition of ***<bolt/>***. The nut itself (rsp. its part\_code or property) must *not* be mentioned in element ***<connected\_to>*** of the ***<connection\_group/>*** containing the ***<bolt/>***. This allows keeping other connection types (glue, rivets …) in the same ***<connection\_group/>***.

Example A:

<connection\_0d label="BOLT\_100532">

<threaded\_connection diameter="10.0" length="50.0"

head\_diameter="16.0" head\_height="5" sink\_size="3">

<normal\_direction> x="3.0" y="0.0" z="0.0"/>

<!--magnitude is irrelevant, direction sense is from head to nut-->

<bolt>

<nut diameter="16." height="5">

<washer outer\_diameter="20"/>

</nut>

</bolt>

<washer outer\_diameter="20">

</threaded\_connection>

<loc> 1500.3 838.7 730.6 </loc>

<appdata>

...

</appdata>

</connection\_0d>

Example B:

<connection\_0d label="BOLT\_135">

<threaded\_connection diameter="10.0" length="50.0"   
 head\_diameter="16.0" head\_height="5" thread\_length="35"   
 torque="80" angle="30" pretension="1200" part\_code="M10x50 12.9" >

<normal\_direction x="0" y="0" z="-10"/>

<!-- Washer next to head -->

<washer outer\_diameter="20" inner\_diameter="10.3" thickness="1.5"   
 attached="false" part\_code="M10x20x1.5"/>

<bolt fixed\_to="1" >

<nut diameter="16." height="5" static\_friction="0.8">

<!-- Washer firmly attached to nut -->

<washer outer\_diameter="25" thickness="1.5" attached="true"/>

</nut>

</bolt>

</threaded\_connection>

<loc> 1500.3 838.7 730.6 </loc>

<appdata>

...

</appdata>

</connection\_0d>

Example C:

<connection\_0d label="BOLT\_135">

<threaded\_connection length="50" diameter="10"   
 head\_diameter="16" head\_height="5" thread\_length="35"   
 torque="80" angle="30" pretension="1200" part\_code="M10x50 12.9">

<normal\_direction x="0" y="0" z="-10"/>

<!-- Washer is part of the head, so it cannot have part code -->

<washer outer\_diameter="20" inner\_diameter="10.3" thickness="1.5"   
 attached="true"/>

<bolt>

<nut diameter="16." height="5" static\_friction="0.8" clipped\_to="4"/>

</bolt>

</threaded\_connection>

<loc> 1500.3 838.7 730.6 </loc>

<appdata>

...

</appdata>

</connection\_0d>

Example D (using every attribute, as many as possible):

<?xml version=**"1.0"** encoding=**"iso-8859-1"** standalone=**"no"**?>

<xmcf xmlns:xsi=**"http://www.w3.org/2001/XMLSchema-instance"**   
xsi:noNamespaceSchemaLocation=**"xmcf\_3\_0\_1.xsd"**>

<version>3.0.1</version>

<date> **2016-01-08** </date>

<units length="mm" angle="deg" mass="kg" force="N" torque="Nm" time="s"/>

<connection\_group id=**"1"**>

<connected\_to>

<part index=**"1"** label=**"PART\_7000400"/**>

<part index=**"2"** label=**"PART\_7100100"/**>

<part index=**"5"** label=**"PART\_5000300"/**>

<part index=**"6"** label=**"PART\_5000800"/**>

</connected\_to>

<connection\_list>

<connection\_0d label=**"BOLT\_135"**><!-- bolt with washers -->

<loc> **84 60 10** </loc>

<!-- Friction between "head to washer" and " thread and nut ": -->  
<threaded\_connection diameter=**"10"** length=**"50"** thread\_length=**"26"**   
head\_diameter=**"16"** head\_height=**"6.4"** head\_type=**"hexagonal"**   
sink\_size=**"0"** pitch=**"0.75"** lead=**"1.5"**  
 **torque="20" angle="35"** pretension=**"180"**   
 static\_friction=**"0.8"** kinetic\_friction=**"0.6"**

thread\_static\_friction="0.6" strength\_property\_class=**"8.8"** part\_code=**"M10x50 8.8"**>

<normal\_direction x=**"0"** y=**"0"** z=**"-10"/**>

<!-- Washer next to head with its friction to 1st part -->

<washer outer\_diameter=**"20"** inner\_diameter=**"10.4"** thickness=**"1.25"**   
attached=**"false"**   
 static\_friction=**"0.8"** kinetic\_friction=**"0.6"**  strength\_property\_class=**"8.8"** part\_code=**"W20/10.4x1.25 8.8"/**>

<bolt>

<!-- No Friction nut to washer, since washer is attached! -->

<nut diameter=**"16."** height=**"6.4"**   
torque=**"20"** angle=**"35"**  
 clipped\_to=**"6"**  strength\_property\_class=**"8.8"** part\_code=**"N10 8.8"**>

<!-- Washer attached to nut with its friction to last part -->

<washer outer\_diameter=**"25"** attached=**"true"** static\_friction=**".8"/**>

</nut>

</bolt>

</threaded\_connection>

<contact\_list> <!-- friction between adjacent flange partners -->

<contact>

<partner part\_index="1"/>

<partner part\_index="2"/>

<coefficients static\_friction="0.8"/>

</contact>

<contact>

<partner part\_index="2"/>

<partner part\_index="5"/>

<coefficients static\_friction="0.8"/>

</contact>

<contact>

<partner part\_index="5"/>

<partner part\_index="6"/>

<coefficients static\_friction="0.8"/>

</contact>

</contact\_list>

</connection\_0d>

</connection\_list>

</connection\_group>

</xmcf>

#### Possible Bolt and Screw Assemblies

Altogether, there are following cases of assembly:

1. Bolt with welded nut (to the bottom sheet):



Figure 22: Bolt with welded nut

Example:

<connection\_0d label="BOLT\_135">

<threaded\_connection diameter="10.0" length="50.0"   
 head\_diameter="16.0" head\_height="5" thread\_length="35"   
 torque="80" angle="30" pretension="1200" part\_code="M10x50 12.9" >

<normal\_direction x="0" y="0" z="-10"/>

<!--No Washer in this case-->

<bolt>

<nut diameter="16." height="5" fixed\_to="3" />

</bolt>

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

1. Bolt with clipped nut (clipped to the bottom sheet): This is the *same*, only fixed\_to is replaced by clipped\_to.
2. Bolt with free nut (not clipped, nor welded to the bottom sheet):



Figure 23: Bolt with free nut

(Since both, the screw and the nut are free, there is *no* **fixed\_to** nor **clipped\_to** attribute)

1. Screw (screwed to the last sheet):

****

Figure 24: Screw

Example:

<connection\_0d label="SCREW\_139">

<threaded\_connection diameter="10.0" length="50.0"   
 head\_diameter="16.0" head\_height="5" thread\_length="35"   
 torque="80" angle="30" pretension="1200" part\_code="M10x50 12.9" >

<normal\_direction x="0" y="0" z="-10"/>

<screw base="3"/>

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

1. Welded stud (with a free nut, of course):



Figure 25: Welded stud with free nut

Example:

<connection\_0d label="BOLT\_135">

<threaded\_connection diameter="10" length="50" head\_diameter="16" head\_height="5" thread\_length="35" torque="80" angle="30" pretension="1200"

part\_code="M10x50 12.9">

<normal\_direction x="0" y="0" z="-10"/>

<!--No Washer in this case-->

<bolt fixed\_to="1" >

<nut diameter="16." height="5" />

</bolt>

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

1. Plain stud (with a nut on one end, screwed into a part on the opposite end):



Figure 26: Plain stud

These studs are not a feature of χMCF version 3.0. They can be modeled according to case 4, but may become a topic of version 3.1.

In all cases, the ***<connected\_to/>*** element contains only the assemblies, part codes or property IDs of the connected sheets.

### Screw

A screw connection is denoted by an element ***<screw/>***. This element is described completely by its attributes and nested elements.

##### Element "screw"

For the ***<screw/>*** element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| base | Integer | > 0 | Optional | - |

Table 58: Attributes of element *<screw/>*

* base: the index (see section 5.3.1.1) of the flange partner, which is carrying the thread. If attribute is missing, the threaded part has to be derived from connection direction.

Specific subtypes of screws are defined by adding according nested elements, listed in following table:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| flow\_drilled | 1 - \* | Optional | - |

Table 59: Nested elements of element **<screw/>**

The subtypes are described in detail in sections below.

**Example A (**screw with no attributes**):**

<connection\_0d label="SCREW\_100532">

**<**threaded\_connectionlength="50." diameter="10"

head\_diameter="16." head\_height="3" sink\_size="4">

<normal\_direction x="3.0" y="0.0" z="0.0" />

<!-- magnitude is irrelevant, direction sense is from head to point -->

**<screw />** <!-- Screw may come without any attributes -->

<washer outer\_diameter="20"/>

**</**threaded\_connection**>**

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

Example B (screw with "base" attribute with washer):

<connection\_0d label="SCREW\_100532">

<threaded\_connection length="50" diameter="10"

head\_diameter="16" head\_height="5" thread\_length="35">

<normal\_direction x="0" y="0" z="-10"/>

<washer outer\_diameter="20" inner\_diameter="10.3"/> <!--Washer next to head-->

**<screw base="5" />**

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

Example C (screw with no attributes without washer):

<connection\_0d label="SCREW\_100532">

<threaded\_connection length="50" diameter="10"

head\_diameter="16" head\_height="5" sink\_size="1" thread\_length="35" >

<normal\_direction x="0" y="0" z="-10"/>

**<screw base="5" />**

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

#### 7.5.7.1 Flow Drilled Screws (FDS)

Flow drilled screws are applied by a process called "friction drilling". For details, see e.g. <http://en.wikipedia.org/wiki/Friction_drilling>

and

<http://www.unique-design.co.uk/flow-drilling/>



|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Placing screw | Heating of material  (speed/pressure) | Forming material | Forming thread  (chipless) | Tightening screw  (torque, depth angle) |

Figure 27: Process of Flow Drill Screwing



*Source of image*: <http://www.ejot-avdel.se/sites/default/files/product/files/Brochure_EJOT_FDS_en.pdf>

Figure 28: Measures of applied FDS

The application of such a connector element can be seen in the following video: <https://www.youtube.com/watch?v=bnPBpN2y2FA>

The basic steps in the flow drill screw process consist of:

1. Applying rotational velocity and pressure.
2. Tool heats target sheet metal (or without pre-punching both sheet component) and melts through it.
3. Screw thread tapping.
4. Tightening the screw and applying proper torque to create the desired connection.

The FDS combines the tool with the screw: The screw itself drills its hole and shapes its thread.

##### Element "flow\_drilled"

For the <flow\_drilled/> element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| pre\_machined\_hole\_diameter | Floating point | ≥ 0.0 | Optional | - |
| pre\_machined\_hole\_index | Integer | > 0 | Optional | Exists only if <connected\_to> properly filled out with parts to be connected. |
| pilot\_hole\_diameter | Floating point | ≥ 0.0 | Optional | Its definition depends on the applied FDS type. |

Table 60: Attributes of element **<flow\_drilled/>**

* pre\_machined\_hole\_diameter: In order to facilitate the penetration in the metal sheet of the tip of the Flow Drill Screw, a small hole may be machined in the sheet metal. Besides, when the penetration happens in the phase of material forming, a small portion of the formed part is flowing opposite to the fastening direction and creating a bulge (dW) that has to be accommodated by the upper part‘s clearance-hole (dD). Default value is 0.0, which means "no pre-machined hole or clearance hole".



Figure 29: Pre-machined or clearance hole in FDS connection

* pre\_machined\_hole\_index: If pre\_machined\_hole\_diameter > 0.0, then the hole is in the flange partner with index pre\_machined\_hole\_index (see section 5.3.1.1). If attribute is missing, this information is not (yet) available.
* pilot\_hole\_diameter: This hole diameter (dV) is defined in case of the applied FDS type requires a drilled hole on the sheet metal that is going to be formed during the process.



Figure 30: Pilot hole on sheet metal

The element <flow\_drilled/>does not allow for any nested elements.

Example:

<connection\_0d label="FDS\_96930">

<threaded\_connection length="50" diameter="10"

head\_diameter="16" head\_height="5" sink\_size="1" thread\_length="35" >

<normal\_direction x="0" y="0" z="-10"/>

<screw base="1">

<flow\_drilled pre\_machined\_hole\_diameter="18.0"

pre\_machined\_hole\_index="1" pilot\_hole\_diameter="12.0" />

</screw>

</threaded\_connection>

<loc> 1500.3809 838.75885 730.6529 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Gum Drops

A gum drop, or adhesive point, is denoted by an element <***gumdrop/>***. This element is described completely by its attribute and nested elements.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| gumdrop | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 61: Nested elements of **<connection\_0d> for** <gumdrop/>

XML specification of ***<gumdrop/>*** with following attributes***:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| diameter | Floating point | >= 0.0 | Optional | - |
| mass | Floating point | >= 0.0 | Optional | - |
| material | Alphanumeric | Alphanumeric | Optional | - |

Table 62: Attributes of element *<gumdrop/>*

* diameter: The diameter of a gumdrop is specified by the attribute *diameter* for the child element of ***<connection\_0d>***. It specifies the diameter of the adhesive material *after* manufacturing.
* mass: This is the mass of the glue attached.
* material: the name of the adhesive material according to CAD/PDM. For CAE applications, another label from a reduced data base may be applicable. This is to be stored in <appdata/>.

Example:

<connection\_0d label="DROP\_2123921">

<!-- Assumed Unit system with mass attribute with value="kg" -->

**<gumdrop diameter="5.0" mass="0.0033" material="CAD\_Material" />**

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Clinches

Clinching is a mechanical, cold forming fastening method to join sheet metal without additional components, using special tools to plastically form a mechanical interlock between the sheets.[[14]](#footnote-15)

In general, clinching is applied in case of lightweight metals because of they can be welded in poor quality or not at all. This joining technique can be cost-effective alternative to spot welding for specific steel structures. Such joints can be found on Air Conditioning Tube fixation or Air Bag Assemblies.

As result, the cross section of a clinch may look like this:



Figure 31: Schematic representation of the clinching operation





Figure 32: Clinch Joint Dimensions



Figure 33: TOX (left) and BTM’s Tog-L-Loc system[[15]](#footnote-16)

One can imagine this cross section rotated around its vertical axis, giving a pan-shaped round clinch in 3 dimensions. Alternatively, this cross section could be the look at an open edge of two stacked sheets. The shape’s height reduces, as we proceed "behind the paper", resulting in a wedge-shaped 3 dimensional contour.

Obviously, a wide range of geometrical shapes, produced by as many different tools, is possible. Hence, we cannot define an enumeration of all clinches, but must describe them by OEM specific alphanumeric names. Same is valid for the strength of the clinch, in terms of its strength class.

A clinch is denoted by an element <clinch/>. This element is described completely by its attributes and nested elements.

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| clinch | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 63: Nested elements of **<connection\_0d/>** for **<clinch/>**

XML specification of <clinch/> element**:**

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| clinch\_type | Alphanumeric | Alphanumeric | Optional | - |
| strength\_class | Alphanumeric | Alphanumeric | Optional | It is dependent from the applied punch diameter and part materials |
| shear\_strength | Floating point | > 0.0 | Optional | - |
| peel\_strength | Floating point | > 0.0 | Optional | - |
| button\_diameter | Floating point | > 0.0 | Optional | Dependent of punch diameter and sheet thicknesses |
| die\_type | Alphanumeric | Alphanumeric | Optional | "round" or "rectangular" |

Table 64: Attributes of element **<clinch/>**

* clinch\_type: the alphanumeric name of the clinch. In this standard we will introduce and use for joint definition the 2 main systems which are TOX and BTM’s Tog-L-Loc or Lance-N-Loc[[16]](#footnote-17) system. The main difference is that the TOX system uses a fixed die whereas the BTM system employs an extending die (see Figure 33).

***Remark:*** For further consideration the sub-process shape definitions can be introduced in this document that can be based on the data from:

<http://www.tox-uk.com/uk/products/joining-systems/tox-clinch-procedure.html>

* strength\_class: the strength class name of the clinch. Due to the fact that the manufacturer of the applied clinching process has a specific tooling die diameter it can be defined the strength as 3 different classes. Such as:
  + Heavy Duty (HD) punches are 6.4mm/0.25" Ø and are used for thick material up to 0.35mm/0.135" thick. A HD joint is typically twice as strong as an equivalent MD joint.
  + Medium Duty (MD) punches are the most common and are approx. 4.6mm/0.18" Ø and are 15 used for materials 0.20mm/0.075" to 0.025mm/0.010" thick.
  + Light Duty (LD) punches are 3.0mm/0.12" Ø and are used for thin materials up to 0.08mm/0.032" thick. LD joints are typically half as strong as a MD joint.
* shear\_strength: Shear failure where the joint fails by shearing a hole in the punch side material. It is defined as maximum measured force during the test process.
* peel\_strength: Pull failure in peeling test is where the joint pulls apart leaving a "male" and "female" parts. It is defined as maximum measured force during the test process.
* button\_diameter: The applied punch diameter to create this joint. The button diameter of the clinch seen in Figure 32 is shown by BD. The diameter may be defined as the maximum distance between the s-twists of the die side sheetFigure 32. According to its use, another definition may be more appropriate, though. As rule of thumb the following formula can be used: Dbutton = dnom x 1.4. Where dnom is the punch diameter.
* die\_type: The "round" dies (three and four blades) are used for drawable materials (like mild steel and aluminum). The "rectangular" dies (two blades) are used for hard materials (materials that do not draw very well) such as stainless steel.

If possible, a clinch should know the direction of fixation, i.e. possess a nested element <normal\_direction/>. However, this is not mandatory in order to allow for importing incomplete data. Direction sense of <normal\_direction/>is from punch to die, i.e. the direction in which metal

is displaced. The element’s definition can be found in section 7.1.3.

There is no "base" attribute for clinches, since this information can be derived from connection direction.

The element <clinch/>allows for following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |

Table 65: Nested elements of element **<clinch/>**

Example:

<connection\_0d label="CLINCH\_left\_2123521">

<!-- Unit definition and connected to is important for clinch -->

<clinch clinch\_type="TOX" button\_diameter="3.0"

strength\_class="HD" shear\_strength="890" peel\_strength="356">

<normal\_direction x="0" y="0" z="-10"/>

</clinch>

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Heat Stakes / Thermal Stakes

Heat stakes are well known techniques to connect a shell-type part with a thermoplastic other part.

For this reason, the thermoplastic part is manufactured with appropriate stakes.



*Source of image*: <http://www.bartec-dt.com/images/heat2.png>



*Source of image*:

<http://www.emersonindustrial.com/en-US/documentcenter/BransonUltrasonics/Plastic%20Joining/Non-Ultrasonics/Thermal%20Staking%20Design%20Guide%20pgs.pdf>

Figure 34: Cross Section of a Heat Stake

One can imagine this cross section rotated around its vertical axis, giving a round shape in 3 dimensions. This shape is most common, though not mandatory. Obviously, a wide range of geometrical shapes, produced by as many different tools, is possible.

Hence, we cannot define an enumeration of all heat stakes, but must describe them by OEM specific alphanumeric names (e.g.: flared, domed, knurled, hollow, flush etc.). Same is valid for the strength of the connection, in terms of its force-displacement diagram.

Heat stakes cannot be disassembled without irreversible damage to (at least) the thermoplastic part.

The element <heat\_stake/> is described completely by its attributes and nested elements.

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| heat\_stake | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 66: Nested elements of **<connection\_0d/>** for **<heat\_stake/>**

XML specification of <heat\_stake/>element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| heat\_stake\_type | Alphanumeric | Alphanumeric | Optional | - |
| strength | Floating point | > 0.0 | Optional | - |
| diameter | Floating point | > 0.0 | Optional | - |
| head\_diameter | Floating point | > 0.0 | Optional | diameter < hole\_diameter |
| head\_height | Floating point | ≥ 0.0 | Optional | - |
| void\_diameter | Floating point | ≥ 0.0 | Optional | void\_diameter < diameter |
| hole\_diameter | Floating point | > 0.0 | Optional | hole\_diameter < head\_diameter |

Table 67: Attributes of element **<heat\_stake/>**

* heat\_stake\_type: the alphanumeric name of the heat stake. (e.g.: domed, flared etc.)
* strength: the strength of the heat stake.
* diameter: The diameter of the heat stake, assuming a round/cylindrical shape.
* head\_diameter: The diameter of the head of the heat stake after thermal forming, assuming the final shape is a round.
* head\_height: the height of the head, created by the tool.
* void\_diameter: The tool may form a hole/void within the stake. This is its diameter, assuming cylindrical shape.
* hole\_diameter: Diameter of the hole(s) in the non-thermoplastic part(s).

If possible, a heat stake should know the direction of fixation, i. e. possess a nested element <normal\_direction/>. However, this is not mandatory in order to allow for importing incomplete data. Direction sense of <normal\_direction/>is from tool to thermoplastic part. The element’s definition can be found in section 7.1.3.

There is no "base" attribute for heat stakes, since this information can be derived from connection direction.

The initial height of the stake (above base part) is not represented in χMCF: Before tool application, it can be derived from CAD data. After tool application (in final shape of the heat stake), this height has vanished.

Example:

<connection\_0d label="HEAT\_STAKE\_521">

<heat\_stake heat\_stake\_type="domed" diameter="3.0"

head\_diameter="6.0" head\_height="2.25">

<normal\_direction x="0" y="0" z="-10"/>

</heat\_stake>

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Clips/Snap Joints

In general, a clip is a fastener with an elastic component. Pushed onto a firm counterpart, this elastic component causes the clip to hook onto that part. It depends on the type of the clip, whether it can be removed without being destroyed.

A wide and ever increasing variety of clinches is in practical use.

Examples:

* A so-called "Terry Clip" consists of a cylindrical metal band with a gap. Opening the gap, it snaps onto a tube. Frequently, there are means for fastening a screw etc. on the opposite side of the gap.
* A "Hairpin Clip" is similar to a "Terry Clip", but uses some wire instead of a metal band.
* An "R-Clip" is similar to a "Hairpin Clip". One of its legs is straight and suitable for inserting into a drilled hole of an axle.
* Circlips (also known as a C-Clip, Seeger ring, snap ring or Jesus clip) are used to secure some item against sliding on an axle.
* Another sort of clips is snapped into a hole in a sheet metal. Its other side is shaped to hold a certain item, such as a cable, a panel etc.
* Other clips slide onto a flat surface.

[](https://upload.wikimedia.org/wikipedia/commons/0/03/Hairpin_clip.png)

*Source of image*: <http://en.wikipedia.org/wiki/File:Hairpin_clip.png>

Figure 35: A "Hairpin Clip"



*Source of image*: <http://commons.wikimedia.org/wiki/File:Circlips_interieur.png>

Figure 36: Internal and External Circlips

 

*Source of images: Ford Werke GmbH*

Figure 37: Clips Pushed into a Hole

 

*Source of images: Ford Werke GmbH*

Figure 38: Clips Sliding onto a Flat Surface

A clip is denoted by an element <clip/> and described completely by its attributes and nested elements.

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| clip | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 68: Nested elements of **<connection\_0d/>** for **<clip/>**

XML specification of <clip/>element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| clip\_type | Alphanumeric | Alphanumeric | Optional | - |
| attachment\_type | Alphanumeric | Alphanumeric | Optional | - |
| hole\_diameter | Floating point | ≥ 0.0 | Optional | - |
| hole\_length | Floating point | ≥ 0.0 | Optional | hole\_length > 0 implies  hole\_diameter > 0 |
| pin\_diameter | Floating point | ≥ 0.0 | Optional | - |
| pin\_width | Floating point | ≥ 0.0 | Optional | pin\_width > 0 implies  pin\_diameter > 0 |
| pin\_length | Floating point | ≥ 0.0 | Optional | - |
| strap\_length | Floating point | ≥ 0.0 | Optional | - |
| clipped\_to | Integer | > 0 | Optional | - |
| material | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | - |

Table 69: Attributes of element **<clip/>**

* clip\_type: the alphanumeric name of the clip, e.g. at FORD: "STRAP 5-45X8X.9-4.1 PNL".
* attachment\_type: the description, how the clip is fastened, e. g. "push into round hole".
* hole\_diameter: If the clip is pushed into a hole, this attribute describes the diameter of that mating hole. If the hole is not round, the minimum diameter is meant. Default value is 0.0, which means "no hole".
* hole\_length: If the clip is pushed into a *non-*round hole, this attribute describes the maximum diameter of that hole. Default value is 0.0, which means "no hole or round hole".
* pin\_diameter: If the clip is pushed into a hole, this attribute describes the diameter of the clip’s pin. If the hole is not round, the minimum diameter is meant. Default value is 0.0, which means "no hole".
* pin\_width: If the clip is pushed into a *non-*round hole, this attribute describes the maximum diameter of the clip’s pin. Default value is 0.0, which means "no hole or round hole".
* pin\_length: If the clip is pushed into a hole, this attribute describes the length of the clip’s pin. Default value is 0.0, which means "no hole".
* strap\_length: If the clip carries a strap (cf. to Figure 37: Clips Pushed into a Hole, left picture.), this attribute describes the length of that strap. Default value is 0.0, which means "no strap".
* clipped\_to: The clip is clipped to the flange partner with this index (see section 5.3.1.1). If attribute is missing, this information is not (yet) available.
* material: the material of the clip.
* part\_code: the part code of the clip, as used e. g. in a PDM system.

There is no base attribute for clips, since this information is hold by attribute clipped\_to.

If possible, a clip should know the direction of fixation, i. e. possess a nested element <normal\_direction/>. However, this is not mandatory in order to allow for importing incomplete data. Direction sense of <normal\_direction/>is from tool to the flange partner given by attribute clipped\_to.

Element <tangential\_direction/>denotes direction of (one) maximum clip diameter, perpendicular to <normal\_direction/>***.*** This gives the local x axis. The <normal\_direction/>and <tangential\_direction/>elements are described in section 7.1.3.

The element <clip/>allows for following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |
| tangential\_direction | 1 | Optional | - |

Table 70: Nested elements of element **<clip/>**

Example:

<connection\_0d label="CLIP\_1001">

**<clip clipped\_to="1" attachment\_type="push into round hole" hole\_diameter="8.0" hole\_length="12.0" pin\_diameter="10.0" pin\_length="10.0" material="polyamid">**

<normal\_direction x="0" y="0" z="-10"/>

<tangential\_direction x="0" y="10" z="0"/>

</clip>

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

## Nails

Nailing is a rather old joining method. However, with optimized nail shapes and high velocity application, it still addresses modern requirements, especially if non-steel materials are involved.



*Source of image*: <http://www.boellhoff.de/files/jpg2/RIVTAC-Alu-Hybrid-low.jpg>

Figure 39: RIVTAC® Nail

The components, which are connected by this type of connector, may consist of steel, aluminum, magnesium or plastic.



***Source of image*:** [**http://www.boellhoff.de**](http://www.boellhoff.de)

Figure 40: Cross Section of a Nail, Connecting Two Sheets

A nail is denoted by an element <nail/>. This element is described completely by its attributes and nested elements.

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| nail | 1 | Optional | - |
| loc | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 71: Nested elements of **<connection\_0d/>** for **<nail/>**

XML specification of <nail/>element:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| nail\_type | Alphanumeric | Alphanumeric | Optional | - |
| shaft\_diameter | Floating point | > 0.0 | Optional | - |
| length | Floating point | > 0.0 | Optional | - |
| cylinder\_length | Floating point | > 0.0 | Optional | - |
| head\_diameter | Floating point | > 0.0 | Optional | - |
| head\_height | Floating point | > 0.0 | Optional | - |
| shear\_strength | Floating point | > 0.0 | Optional | Dependency from sheet thicknesses |
| peel\_strength | Floating point | > 0.0 | Optional | Dependency from sheet thicknesses |
| material | Alphanumeric | Alphanumeric | Optional | - |
| part\_code | Alphanumeric | Alphanumeric | Optional | - |

Table 72: Attributes of element **<nail/>**

* nail\_type: the alphanumeric name of the nail[[17]](#footnote-18). (Naming convention based on supplier nail codes)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| a, | b, | c, | d, | e, |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| f, | g, | h, | i, |  |

* shaft\_diameter: the diameter of the shaft of the (unmounted) nail.
* length: is the overall length of the nail.
* cylinder\_length: the length of the cylindrical part of the nail shaft.
* head\_diameter: the diameter of the head of the nail.
* head\_height: the height of the nail head.
* shear\_strength: Shear failure where the joint fails by shearing a hole in the cover part side material. It is defined as maximum measured force during the test process.
* peel\_strength: Pull failure in peeling test is where the joint i.e. nail and cover sheet pull apart leaving the base sheet part. It is defined as maximum measured force during the test process.
* material: the material of the nail.
* part\_code: the part code of the nail, as used e. g. in a PDM system. Frequently, it may be convenient to use the nail norm (according to ISO, EN, BSW, DIN etc.) as part code.

There is no "base" attribute for nails, since this information can be derived from connection direction.

If possible, a <nail/> should know the direction of fixation, i.e. possess a nested element <normal\_direction/>. However, this is not mandatory in order to allow for importing incomplete data. Direction sense of <normal\_direction/> is from nail head to tip. The element’s definition can be found in section 7.1.3.

The element <nail/>allows for following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| normal\_direction | 1 | Optional | - |
| tangential\_direction | 1 | Optional | - |

Table 73: Nested elements of element **<nail/>**

Example:

<connection\_0d label="NAIL\_100">

**<nail shaft\_diameter="10.0" length="26.0" head\_diameter="15.0" material="steel" shear\_strength="5.20" peel\_strength="5.0"> <!-- unit def. for Force is kN -->**

<normal\_direction x="0" y="0" z="-10"/>

</nail>

<loc> 1645.83 821.145 616.585 </loc>

<appdata>

...

</appdata>

</connection\_0d>

# 1D connections

## Generic Definitions

### Identification

For identifying 1D connections, the same rules apply as for 0D connections, see section 7.1.1 identification.

### Location

The definition of the connection line is described as a series of points and thus split into segments. All other curves can also be represented with this type of representation by adding necessary points and thus approximating to the needed accuracy.

The connection line may consist of more than one section. The sections need not be joined to each other. This is to simulate gaps along the application of a seam or an adhesive, due to crossing another weld, or an obstacle, like a hole in the connected sheets.

##### This feature could also be used in cases where a seam weld changes its ***<subtype/>***, seen in Figure 41: Weld Line Changing from Y-Joint to Overlap-Joint.

The χMCF specifies the order of line sections, as well as the order of the locations within each section.

##### Element "loc\_list"

The list of locations for the definition of the connection line is stored in the element <loc\_list>. This element contains nested elements <loc/> defining the location of a point of the connection line in space. These locations have to be ordered so that the line defined by the ordered list of locations specifies the connection line.

The attributes associated to the element <loc\_list/> are:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint*** |
| index | Integer | Optional | Required only if there are more than one loc\_list elements in the connection\_1d |

Table 74: Attributes of element **<loc\_list/>**

A stepped connection line, or a connection line with sharp corners[[18]](#footnote-19), can be expressed by a series of <loc\_list> elements. In this case, the <loc\_list> order is indicated by the index attribute.

The <loc\_list> element has the following nested elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| loc | 1-\* | Required | - |

Table 75: Nested elements of **<loc\_list>**

##### Element "loc"

Each location specified by the element <loc/> contains three values specifying the x, y and z coordinates of the location.

The attributes associated to the element <loc/> are:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint*** |
| v | Floating point | Required | - |

Table 76: Attributes of element **<loc/>**

The attribute v is used as surrogate index to ensure proper ordering. The values are NOT related to the attribute u used in the <weld\_position/> element.

The <loc/> with the minimum value of "v" marks the start of a seam weld and max(v) is used to mark the end. The reason for that is some manufacturing techniques are not "symmetric" regarding both ends of a connection line.

Example A (a connection line with a single section):

<loc\_list>

**<loc v="0" > 2581.21 -708.408 31.6532 </loc>** <!-- first point -->

**<loc v="0.1" > 2581.42 -708.357 35.2816 </loc>**

**<loc v="2.22"> 2581.05 -708.302 39.0643 </loc>** <!-- last point -->

</loc\_list>

Example B (a connection line consisting of two disjoint sections):

<loc\_list index="1"> <!-- first section -->

<loc v="0" > 2581.21 -708.408 31.6532 </loc> <!-- first point -->

<loc v="1" > 2581.42 -708.357 35.2816 </loc>

<loc v="2.22"> 2581.05 -708.302 39.0643 </loc> <!-- last point -->

</loc\_list>

<loc\_list index="2"> <!-- second section -->

<loc v="1" > 2581.05 -708.302 40.3340 </loc> <!-- first point -->

<loc v="2.1"> 2581.05 -708.302 48.5300 </loc> <!-- last point -->

</loc\_list>

### Type Specification

Each connection is identified by its type. The XML definitions of all 1D connections are containing the following elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| seamweld | 1 | Optional | - |
| adhesive\_line | 1 | Optional | - |
| hemming | 1 | Optional | - |
| sequence\_connection\_0d | 1 | Optional | - |
| contact\_list | 1 | Optional | See section 5.3.2.5. |
| stacking | 1 | Optional | See section 5.3.1.3 |

Table 77: Nested elements of element *<connection\_1d/>*

***Note***: Only *one* of the elements (seamweld, adhesive\_line, hemming, sequence\_connection\_0d) must exist in a <connection\_1d>. If none of the type elements exist, then this will default to <seamweld/>.

## Seam Welds

### Description and Modeling Parameters

To be able to use the χMCF file as a description for seam welds in the process it is necessary to use the modeling described in this document.

The description of seam welds made up from different modeling types is handled in the way that these welds are split up into separate seam welds each of them containing the specific information representing the intended modeling.



Figure 41: Weld Line Changing from Y-Joint to Overlap-Joint

This assures that a seam weld definition only represents one cross section with the welding parameters for all the welded sides.

There is a demand for handling weld lines exceeding the actual contact polygon of the involved parts, which is presented in the following figure:



*Source of image: Dr. Thomas Bruder, BMW Group.*

Figure 42: Longitudinal stiffener, top view

Standard conform polygons may well exceed the contact area. However, χMCF version 3.0 does not state anything about the physical meaning or the implications for CAE and CAM. Hence, later versions of χMCF may specify details about what should happen with exceeding parts of a weld line in CAE and CAM. In CAE, for example, hexahedron or tetrahedron could be generated on the exceeding polygons, if their height or thickness is provided.

***Remark***:It is well known that several welding technologies produce material structures which are oriented. In especially, there is a difference between the start and the end of a weld line. χMCF knows about the orientation of a weld line and hence can distinguish between start and end. But it does not yet provide means to transport details about what is the difference between both, neither for CAE nor CAM.

### Seam Weld Definition Overview

The weld definition depends on the type of the weld. For each of the different types the parameters and their meaning can be different. The detailed description can be found in the next sections describing each weld type separately.

The table shown below provides an overview over the current seam weld types and their parameters.

For each of the weld types it provides the following information:

* + Type of the weld
  + Number of weld positions for the type
  + Supported technology
  + Valid weld sections
  + Required parameters
  + Optional parameters with their default values
  + Section drawing related to the weld type

For the given combinations of weld type, technology and section the parameters and the section drawings are provided. The section drawings do not show the specific sections possible for a technology.

The sheet parameters describing the sheet thickness in the following document sections are not part of the χMCF file contents. They are used in the weld specific sections to describe parameters stored in the χMCF file and their relations.

The variety is to be handled by the application using the χMCF file inside the process. All the information stored for the weld together with the model is sufficient to determine the specific type of connection.



Figure 43: Seam weld types and attributes

### Specific XML Realization

This part of the XML structure describes the data stored for each of the seam welds. This includes the details necessary to describe each connection in depth.

Inside the XML definition of the seam weld each of the welds related to a connection is stored in a separate weld position inside the specific subtype definition.



Figure 44: χMCF Structure of a Seam Weld (*connection\_1d*)

### Generic Seam Weld Definition

#### Identification

Each seam weld is optionally identified by its *label*. The XML definition at ***connection\_1d*** level contains the following attributes:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| label | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 78: Attributes of element **<connection\_1d/>**

##### Attribute "label"

The label defines the human readable identification of the seam weld connection.

Example:

<connection\_list>

**<connection\_1d label="SEAM\_1780">**

<loc\_list>

...

</loc\_list>

<seamweld>

...

</seamweld>

<appdata>

...

</appdata>

**</connection\_1d>**

</connection\_list>

#### Type Specification

Each seam weld is identified by main type of the weld and described more precisely by its subtype. This means there is a general category that includes several subcases. Detailed information can be seen under definition of element main type and subtype.

##### Definition of main type

The element main type for seam welding always has the value seamweld. This is located directly below the <***connection\_1d/>*** element. It is used to define the connection as general as it can be.

The XML definition of seam weld main type contains the following nested elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| butt\_joint | 1 | Optional | - |
| corner\_weld | 1 | Optional | - |
| edge\_weld | 1 | Optional | - |
| i\_weld | 1 | Optional | - |
| overlap\_weld | 1 | Optional | - |
| y\_joint | 1 | Optional | - |
| k\_joint | 1 | Optional | - |
| cruciform\_joint | 1 | Optional | - |
| flared\_joint | 1 | Optional | - |

Table 79: Nested elements of element *<seamweld/>*

Example A (main type as *seamweld*):

<connection\_1d>

**<seamweld>**

**...**

**</seamweld>**

</connection\_1d>

**Note:** The differentiator for the specific seam weld is stored as value in the subtype element which is described below.

##### Definition of subtype

Different kinds of welds are distinguished through the definition of a subtype of the seam weld.

Valid values for the subtype element are:

* butt\_joint
* corner\_weld
* edge\_weld
* i\_weld
* overlap\_weld
* y\_joint
* k\_joint
* cruciform\_joint
* flared\_joint

Each subtype element can contain the following attributes:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| base | Integer | > 0 | Optional | - |
| technology | Selection | resistance arc laser friction brazing | Optional | - |

Table 80: Attributes of element *<subtype/>*

Each subtype element contains the following nested elements:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| weld\_position | 1 - \* | Optional | - |
| sheet\_parameter | 1 - \* | Optional | - |

Table 81: Nested elements of element *<subtype/>*

**Note:** The number of elements of <weld\_position/> is dependent on the specific subtype.

##### Attribute "base"

The attribute base defines the index of the base sheet for the weld. It references the attribute index inside the element <part> of the <connected\_to> element. This could be useful when the angle of the weld itself is not symmetrical between the welded sheet and the base sheet. That means it is crucial to be identified to which sheet part the angle is being measured.

##### Attribute "technology"

The technology used to weld the connection can be specified for each of the welds of a connection separately.

This technology can be one of

* Resistance welding
* Arc welding
* Energy beam welding (e.g. laser)
* Friction welding
* Brazing (Not allowed for I-Welds, for technical reasons.)

Additionally to the technology there is a specification for each of the weld positions whether the welding introduces additional material (attribute filler).

The attribute technology defines the welding technology used for its subtype.

Possible values are:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

Example A (main type as *seamweld* and subtype as *butt\_joint*):

<connection\_1d>

**<seamweld>**

**<butt\_joint base="1" technology="resistance">**

**...**

<weld\_position ... />

**<sheet\_parameter ... />**

**...**

**</butt\_joint>**

**</seamweld>**

</connection\_1d>

#### Weld Position and Sheet Metal Parameters

We have to collect and put into separate groups the parameters that can be observed in terms of welding processes. Some of the used and measured parameters are related to the involved sheet metal parts, describing the thickness of the sheet and the applied sheet angle between to sheet metal parts.

On the other hand, we can distinguish the parameters that are mentioned in terms of the welding process has been made i.e. the weld itself is present. The detailed description of these parameters can be seen for Sheet Parameters in chapter 8.2.4.3.1 and for Weld Position Parameters in chapter 8.2.4.3.2.



Figure 45: Sheet Parameters vs. Weld Position Parameters

#### Parameters Assigned to a Specific Sheet of the Flange

##### In a welded connection there are different kinds of parameters that have to be assigned to either welded sheet metal or the created weld itself. Thus we can group and put all those parameters under two elements directly under the parent subtype element. These are the <sheet\_parameter/> and the <weld\_position/>.

##### Element "sheet\_parameter"

The element <sheet\_parameter/> describes the sheet in order to identify the correct sheet when multiple sheets are connected. Furthermore it defines as attributes the corresponding gap applied between the welded sheet and the base sheet, i.e. in general the applied gap between the welded sheets involved in the welding process.

It is defined using the following attributes:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating point | Optional | Default value is 0 |
| sheet\_thickness | Floating point | Optional | - |
| sheet\_angle | Floating point | Optional | - |

Table 82: Attributes of element *<sheet\_parameter/>*

##### Attribute "index"

The value of the attribute index must be referenced to the Part index. The *index* needs to be unique only within the parent element ***<connected\_to>.*** For specific connections, it is used as the matching index for the subjected welded sheet.

##### Attribute "gap"

The value of the attribute gap is numerical in the range [0, **∞**). It defines the distance between the base and the connected sheet.

##### Attribute "sheet\_thickness"

The value of the attribute ***sheet\_***thickness is numerical in the range (0, **∞**). It defines the CAD related input for the thickness measure of the connected sheet (in the example in Figure 45 this is t2). In case of more than 1 welded sheet exist see the definition example in 8.2.11.5.

##### Attribute "sheet\_angle"

The value of the attribute sheet\_angle is numerical in the range [0, 360). It defines the angle between the base sheet and the connected sheet middle lines.

Example A (within each *attribute*):

<connection\_1d>

<seamweld>

<corner\_weld base="1" technology="resistance">

<weld\_position .../>

**<sheet\_parameter index="2" gap="1.0" sheet\_thickness="1.5" sheet\_angle="90"/>**

</corner\_weld>

</seamweld>

</connection\_1d>

#### Welding Position

The position of the welding on the seam weld is specified by an orientation vector pointing from the weld root into the side where the welding takes place (see Figure 46).

The origin of this orientation vector is located directly on the connection line. The position on the connection line is determined by a fraction in the range [0, 1] of the complete line. The fraction is applied to the length of the connection line measured as sum of all segment lengths in space.

A connection can be welded at different positions. This is depending on the seam weld type and can be between two and five positions (by combing K-Joint with a Y-Joint). Each position represents a welding performed from one side of the structure.

Details for each seam weld type are described inside the specific chapter (e.g. see 8.2.5).



Figure 46: Welding Position of a Y-Joint

##### Primary and Secondary Sides

For weld definitions needing a specific side the orientation vector defines the primary side. All other sides are named secondary side not specifying any precedence on them.

##### Element "weld\_position"

The element <weld\_position/> describes the location of the weld relative to the connection line specified in loc\_list. It is defined using the following attributes:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| base | Integer | Optional | Value only for specific weld types |
| u | Floating Point | Required | 0 ≤ u ≤ 1 |
| x | Floating Point | Required | - |
| y | Floating Point | Required | - |
| z | Floating Point | Required | - |
| reference | Boolean | Optional | "false" |
| section | Selection | Optional | - |
| thickness | Floating Point | Optional | Value only for specific weld types |
| width | Floating Point | Optional | Value only for specific weld types |
| angle | Floating Point | Optional | - |
| filler | Selection | Optional | - |
| filler\_material | Alphanumeric | Optional | - |
| shape | Selection | Optional | - |
| penetration | Floating Point | Optional | 0 ≤ penetration ≤ 1 |

Table 83: Attributes of element *<weld\_position/>*

Depending on subtype the attributes of the element ***<weld\_position/>*** are different. Each of the subtype is supporting its specific combination of attributes. Description of the specific combination can be found in the specific weld section below.

Example A (within each *attribute*):

<connection\_1d>

<seamweld>

<corner\_weld base="1" technology="resistance">

**<weld\_position u="0.2" x="1" y="0" z="1"**

**reference="true"**

**section="HV"**

**thickness="0.5"**

**angle="45"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight"**

**penetration="0.6"/>**

<sheet\_parameter index="2" gap="1.0"/>

</corner\_weld>

</seamweld>

</connection\_1d>

##### Attributes "u", "x", "y", "z"

The attribute u specifies the relative location on the connection line defined in loc\_list. Value u=0 represents the first location of the connection line matching the element loc specified with the lowest value for the attribute u. Value u=1 represents the last location of this line matching the element loc with highest value for the attribute value u. Values in between are specifying the point located at the specified fraction of the line measure in summed up lengths of the segments of the connection line in space.

The attributes x, y, z are specifying the direction vector in global coordinate system into the quadrant of the welding. The origin of this vector is defined by u and the loc\_list.

The length of the vector has no specific meaning, only the direction is used. However, it should be sufficiently long to be unambiguous as it is presented in Figure 47.



Figure 47: Welding Position vector direction and length

##### Attribute "reference"

The attribute reference specifies this weld position to be the reference for welds that need such a reference. In case of butt-welds or cruciform joints this is needed to specify a specific side for one of the attributes (see there).

##### Attribute "section"

The attribute section defines the geometry section of the weld. The different section types that can be used inside the definition of seam welds are listed here. The description here denotes the principles of the sections. Details of the interpretation on the different weld type can be found in the corresponding section for each of the weld types.

In most cases the sections "Fillet", "HV" and "HY" are used in seam weld connections when the head of a sheet is welded on a base sheet. Connections putting two sheet heads together are mostly using the section types "I", "V", "X" and "Y".

Allowed values are:

* I
* V
* U
* X
* Y
* HV
* HY
* Fillet
* Radius

##### Section "I"

The section "I" describes the filling of the weld normally on the head sides of a connection. The section is filled completely and may be welded from one or two sides.

##### Section "V"

The section "V" describes the one-sided filling of the weld with welding material looking like a "V". The weld filling provides full penetration.

##### Section "U"

The section "U" describes the one-sided filling of the weld with welding material looking like a "U". The penetration in most cases is less than full penetration.

##### Section "X"

The section "X" describes the filling of a two-side weld with welding material looking like an "X". The weld filling provides full penetration.

##### Section "Y"

The section "Y" describes the one-sided filling of the weld with welding material looking like a "v". Only a part of the gap between the welded sheets is filled thus there is no full penetration.

##### Section "HV"

The section "HV" describes the filling of a one-sided weld with a full penetration. The welded sheet is normally be phased to take full advantage of the full penetration.

##### Section "HY"

The section "HY" describes again a filling of a one-side weld but the penetration is only partial. In common cases the welded sheet is phased partially to take again advantage of the penetration at that area.

##### Section "Fillet"

The section "Fillet" describes a one-sided welding placed on the outside of the welded sheets. Depending on the sheet thicknesses there might be a penetration.

##### Section "Radius"

The section "Radius" describes a special case where the welding material looks like a circle but not filling the complete gap between the welded sheets. In most cases there is no full penetration.

##### Attribute "thickness"

The value of the attribute thickness is a numerical value in the range of (0, **∞**). It describes the distance between the weld root and the weld surface. It is used for to describe the throat thickness of the weld.

##### Attribute "width"

The value of the attribute width is a numerical value in the range of (0, **∞**).

##### Attribute "angle"

The value of the attribute angle is a numerical value. This attribute of the ***<weld\_position/>*** element describes the angle between the weld face and the base sheet face.

##### Attribute "filler"

The attribute filler specifies whether the welding is performed using filling material. This is the case for resistance or arc welding but not for laser welding.

The allowed values are:

* yes
* no

According to above rule on filling material, the default values are depending on the attribute value of technology of the element subtype:

| ***Attribute value "technology"*** | ***Default value "filler"*** |
| --- | --- |
| resistance | Yes |
| arc | Yes |
| laser | No |

Table 84: Default values of attribute "filler", dependent from attribute "technology"

##### Attribute "filler\_material"

##### The attribute filler\_material specifies the applied material during the welding process.

##### Attribute "shape"

The attribute shape defines the shape of the weld throat. Allowed values are:

* straight
* convex
* concave

Independent of the shape, the weld position attributes (a-measure, weld angle etc.) are taken with respect to the *straight* line. In fact, the shape is just a hint to specific solvers. It does *not* provide an exact definition whether convex or concave mean e.g. "segment of a circle", "parabolic" etc., nor how big the deviation from straight shape is.

##### Attribute "penetration"

The value of the attribute penetration is a numerical value in the range [0; 1]. The value describes the ratio between the thickness and the penetration of the sheets. Value of 0 means no penetration, value of 1 represents complete penetration.

***Note:*** *The attribute* penetration *of a* <weld\_position/> *holds for all sheets connected by this* <weld\_position/> *(e.g. important for K-joints).*

**Note:** If all <weld\_position/> at the same welded sheet have a sum of penetration ≥ 1 there is no open (unfilled) gap between the base sheet and the welded sheet.

### Butt Joint

The principles of the modeling of Butt Joints for χMCF are described in this section. A Butt Joint describes a connection between two sheets welded at their forehead side.

The XML definition of a Butt Joint supports up to two weld positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Sheet Parameters

The parameters to describe the connection are:



Figure 48: Butt Joint Sheet Layout

* tB Thickness of base sheet
* t1 Thickness of welded sheet

#### Weld Parameters



Figure 49: Butt Joint Weld parameters

The parameters of the weld are described below:

* b1 Width of the weld at primary side
* b2 Width of the weld at secondary side
* e1 Reinforcement of the weld at primary side
* e2 Reinforcement of the weld at secondary side

Inside the χMCF File the following parameters can be specified:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| B | width | 1 – 2 | ≥ 0 | Optional | - |
| E | - | (1 – 2) | (≥ 0) | (Optional) | (0) |

Table 85: Parameters of Butt Joint Weld

**Note:** The reinforcement is currently not defined as ***attribute*** in the version 3.0 document!

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/>, the following attributes can be specified for the Butt Joint:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| U | Floating Point | Required | 0 ≤ u ≤ 1 |
| X | Floating Point | Required | - |
| Y | Floating Point | Required | - |
| Z | Floating Point | Required | - |
| reference | Boolean | Optional | "false" |
| section | Selection | Optional | - |
| width | Floating Point | Optional | - |
| filler | Selection | Optional | - |
| filler\_material | Alphanumeric | Optional | - |

Table 86: Attributes of element *<weld\_position/>* for Butt Joint

##### Attributes "u, x, y, z, reference"

Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "section"

Valid values for the attribute section of a Butt Joint are:

* I
* U
* V
* X
* Y
* Radius

##### Attribute "width"

The attribute value width specifies the width of the weld.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can be different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within only necessary *attributes*):

<seamweld>

<butt\_joint base="1" technology="arc">

***<weld\_position u="0.2" x="1" y="0" z="1"*/>**

<sheet\_parameter ... />

</butt\_joint>

</seamweld>

Example B (within every *attribute*):

<seamweld>

<butt\_joint base="1" technology="arc">

***<weld\_position u="0.2" x="1" y="0" z="1"***

**reference="true"**

**section="X"**

**width="1.5"**

**filler="yes"**

**filler\_material=" E7018-X"/>**

<sheet\_parameter ... />

</butt\_joint>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Butt Joint:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| Gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 87: Attributes of element *<sheet\_parameter/>* for Butt Joint

Example A (within only required *attributes*):

<seamweld>

<butt\_joint base="1" technology="arc">

*<weld\_position u="0.2" x="1" y="0" z="1"* ... />

**<sheet\_parameter index="2" gap="0" sheet\_thickness="1.5" sheet\_angle="180" />**

</butt\_joint>

</seamweld>

### Corner Weld

The principles of the modeling of corner welds for χMCF are described in this section. A corner weld describes a connection between two or three sheets welded together.

The XML definition of a Corner Weld supports up to four positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Simple Corner Weld



Figure 50: Corner Weld Sheet Layout

##### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1  Thickness of welded sheet
* c Gap between base sheet and welded sheet
* v Misalignment of welded sheet

##### Weld Parameters

The parameters of the welds are the same for all of the potential welds on the connection:



Figure 51: Corner Weld Parameters

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

For the penetration, the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where variable *i* is specifying the weld index and variable *j* is defined by the sheet index of the welded sheet related to the weld. (αj in case of a Corner Weld is 90° and therefore sinαj=1.)

Inside the χMCF File the following parameters can be specified:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| a | thickness | 1 – 2 | ≥ 0 | Optional |  |
| β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 2 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 88: Parameters of Simple Corner Weld

All other parameters are provided by the model itself.

#### Double Corner Weld

##### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1, t2 Thicknesses of welded sheet
* c1, c2 Gaps between base sheet and welded sheet
* v Misalignment of welded sheet

##### Weld Parameters

The parameters of the welds are the same for all the potential welds on the connection:

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

Figure 53: Double Corner Weld Parameters



Figure 52: Corner Weld Sheet Layout

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where variable *i* is specifying the weld index and variable *j* is defined by the sheet index of the welded sheet related to the weld. (αj in case of a Corner Weld is 90° and therefore sinαj=1.)

Inside the χMCF File the following parameters can be specified:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| a | thickness | 1 – 2 | ≥ 0 | Optional |  |
| β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 2 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 89: Parameters of Double Corner Weld

All other parameters are provided by the model itself.

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Corner Weld:

|  |  |  |
| --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** |
| u | Floating Point | Required |
| x | Floating Point | Required |
| y | Floating Point | Required |
| z | Floating Point | Required |
| reference | Boolean | Optional |
| section | Selection | Optional |
| thickness | Floating Point | Optional |
| angle | Floating Point | Optional |
| shape | Selection | Optional |
| penetration | Floating Point | Optional |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |

Table 90: Attributes of element **<weld\_position/>** for Corner Weld

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "section"

Valid values for the attribute section of a corner weld are:

* HV
* U
* Fillet

##### Attribute "thickness"

The attribute thickness specifies the thickness (a-value, throat) of the weld. Depending on the section this is required, optional or not allowed:

|  |  |
| --- | --- |
| ***Attribute value "section"*** | ***Attribute "thickness"*** |
| HV | Optional |
| U | Not allowed |
| Fillet | Required |

Table 91: Values of Attribute **section**

##### Attribute "angle"

The attribute angle specifies the angle of the weld relative to the base sheet. Depending on the section this is optional or not allowed:

|  |  |
| --- | --- |
| ***Attribute value "section"*** | ***Attribute "angle"*** |
| HV | Optional |
| U | Not allowed |
| Fillet | Required |

Table 92: Values of Attribute **angle**

##### Attribute "shape"

The attribute shape defines the shape of the weld throat.

##### Attribute "penetration"

The attribute penetration specifies the degree of penetration resulting from the welding.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*):

<seamweld>

<corner\_weld base="1" technology="resistance">

**<weld\_position u="0" x="0" y="1" z="0"**

**reference="false"**

**section="Fillet"**

**thickness="1.5"**

**angle="30"**

**shape="concave"**

**penetration="0.5"**

**filler="yes"**

**filler\_material=" E7018-X"/>**

<sheet\_parameter ... />

</corner\_weld>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Corner Weld:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 93: Attributes of element *<sheet\_parameter/>* for Corner Weld

Example A (within only required *attributes*):

<seamweld>

<corner\_weld base="1" technology="resistance">

*<weld\_position u="0" x="0" y="1" z="0" ...* />

**<sheet\_parameter index="2" gap="0" sheet\_thickness="1.5" sheet\_angle="90" />**

</corner\_weld>

</seamweld>

### Edge Weld

The principles of the modeling of edge welds for χMCF are described in this section. An Edge Weld describes a connection between two sheets welded at their forehead side.

The XML definition of an Edge Weld supports one position. The weld position is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### EdgeWeld_v2Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1 Thickness of welded sheet
* c Gap between base and welded sheet

Figure 54: Edge Weld Sheet Layout

#### EdgeWeld_v2Weld Parameters

The parameters of the weld are described below:

* b Width of the weld
* e Reinforcement

The following parameters can be specified for the edge weld:

Figure 55: Edge Weld parameters

| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| --- | --- | --- | --- | --- | --- |
| b | width | 1 | ≥ 0 | Optional | - |
| c | gap | 0 – 1 | ≥ 0 | Optional | 0 |
| e | - | 0 – 1 | ≥ 0 | Optional | 0 |

Table 94: Parameters of Edge Weld

**Note:** The reinforcement is currently not defined as ***attribute*** in the version 3.0 document!

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Edge Weld:

| ***Attributes*** | ***Type*** | ***Use*** |
| --- | --- | --- |
| u | Floating Point | Required |
| x | Floating Point | Required |
| y | Floating Point | Required |
| z | Floating Point | Required |
| reference | Boolean | Optional |
| section | Selection | Optional |
| width | Floating Point | Optional |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |

Table 95: Attributes of element *<weld\_position/>* for Edge Weld

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "section"

Valid values for the attribute section of a edge weld are:

* I
* V
* U

##### Attribute "width"

The attribute width specifies the width of the weld.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each optional *attribute*):

<seamweld>

<edge\_weld base="1" technology="arc">

**<weld\_position u="1" x="1" y="1" z="0"**

**reference="false"**

**section="V"**

**width="2"**

**filler="yes"**

**filler\_material=" E7018-X"/>**

<sheet\_parameter ... />

</edge\_weld>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Edge Weld:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 96: Attributes of element *<sheet\_parameter/>* for Corner Weld

Example A (within only required *attributes*):

<seamweld>

<edge\_weld base="1" technology="resistance">

*<weld\_position u="1" x="1" y="1" z="0" ...* />

**<sheet\_parameter index="2" gap="0" sheet\_thickness="1.5" sheet\_angle="90" />**

</edge\_weld>

</seamweld>

### I-Weld

The principles of the modeling of I-welds for χMCF are described in this section. An I-Weld describes a connection between two sheets welded together.

The XML definition of an I-Weld supports one weld position. The weld position is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1 Thickness of welded sheet
* c Gap between base and welded sheet

#### Weld Parameters

The parameters of the weld are described below:

* b Width of the weld



Figure 56: I-Weld Sheet Layout



Figure 57: I-Weld Parameters

The following parameter can be specified for the I-weld:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| b | width | 1 | ≥ 0 | Optional | - |

Table 97: Parameters of I-Weld

All other parameters are provided by the model itself and are partially used to specify parameters of the weld.

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the I-Weld:

| ***Attributes*** | ***Type*** | ***Use*** |
| --- | --- | --- |
| u | Floating Point | Required |
| x | Floating Point | Required |
| y | Floating Point | Required |
| z | Floating Point | Required |
| reference | Boolean | Optional |
| width | Floating Point | Optional |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |

Table 98: Attributes of element **<***weld\_position/>* for I Weld

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "width"

The attribute width specifies the width of the weld.

##### Attribute "filler"

Valid values for the attribute ***filler*** can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*):

<seamweld>

<i\_weld base="1" technology="laser">

**<weld\_position u="0" x="1" y="1" z="1"**

**reference="false"**

**width="1.0"**

**filler="no"**

**filler\_material=" E7018-X"/>**

<sheet\_parameter ... />

</i\_weld>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the I Weld:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 99: Attributes of element <*sheet\_parameter/>* for I Weld

Example A (within only required *attributes*):

<seamweld>

<i\_weld base="1" technology="laser">

*<weld\_position u="0" x="1" y="1" z="1"* ... "/>

**<sheet\_parameter index="2" gap="0" sheet\_thickness="1.5" sheet\_angle="0"/>**

</i\_weld>

</seamweld>

### Overlap Weld

The principles of the modeling of overlap welds for χMCF are described in this section. An Overlap Weld describes a connection between two or three sheets welded together.

The XML definition of an Overlap Weld supports up to three[[19]](#footnote-20) weld positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Simple Overlap Weld

##### OverlapWeld_v2Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1 Thickness of welded sheet
* c Gap between base and welded sheet

Figure 58: Overlap Weld Sheet Layout

##### Weld Parameters

The parameters of the welds are the same for all of the potential welds on the connection:

* a1 Thickness of the weld (a-value, throat)
* d1 Depth of the penetration
* β1 Weld angle

Figure 59: Overlap Weld Parameters

For the penetration, the ratio η1 of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by, where t1 is the thickness of the attached sheet (green in above figure), *not* of the base sheet.

Inside the χMCF File the following parameters can be specified:

| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| --- | --- | --- | --- | --- | --- |
| A | thickness | 1 | ≥ 0 | Optional | - |
| Β | angle | 0 – 1 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 1 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 100: Parameters of Overlap Weld

All other parameters are provided by the model itself and are partially used to specify parameters of the weld.

#### Single Sided Double Overlap Weld

The Single Sided Double Overlap Weld is represented by a stacked welding.

##### Sheet Parameters

The parameters to describe the connection are:

* ******tB Thickness of base sheet
* t1, t2 Thicknesses of welded sheets
* c1, c2 Gaps between base and welded sheets

##### Weld Parameters

Figure 60: Single Sided Double Overlap Weld

The parameters of the welds are the same for all of the welds on the connection:

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

Figure 61: Overlap Weld Parameters

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where index *i* is specifying the weld index and index *j* is defined by the sheet index of the welded sheet related to the weld.

Inside the χMCF File the following parameters can be specified:

| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| --- | --- | --- | --- | --- | --- |
| A | thickness | 2 | ≥ 0 | Optional | - |
| Β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 2 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 101: Parameters of Single Sided Double Overlap Weld

All other parameters are provided by the model itself and are partially used to specify parameters of the weld.

#### Double Sided Double Overlap Weld

A Double Sided Double Overlap Weld can have the welds on both sides of the base sheet.

##### DoubleOverlapWeld2Sides_v2Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1, t2 Thicknesses of welded sheets
* c1, c2 Gaps between base and welded sheets

Figure 62: Double Sided Double Overlap Weld

##### Weld Parameters

The parameters of the welds are the same for all of the welds on the connection:

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

Figure 63: Parameters of Double Sided Double Overlap Weld

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where index *i* is specifying the weld index and index *j* is defined by the sheet index of the welded sheet related to the weld.

Inside the χMCF File the following parameters can be specified:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| A | thickness | 2 | ≥ 0 | Optional | - |
| Β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 2 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 102: Parameters of Double Sided Double Overlap Weld

All other parameters are provided by the model itself and are partially used to specify parameters of the weld.

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Overlap Weld:

|  |  |  |
| --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** |
| Base | Integer | Optional |
| U | Floating Point | Required |
| X | Floating Point | Required |
| Y | Floating Point | Required |
| Z | Floating Point | Required |
| Reference | Boolean | Optional |
| Section | Selection | Optional |
| Thickness | Floating Point | Optional |
| Angle | Floating Point | Optional |
| Shape | Selection | Optional |
| penetration | Floating Point | Optional |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |

Table 103: Attributes of element <*weld\_position/>* for Overlap Weld

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "base"

For this type of weld the base sheet can be specified also inside the element <weld\_position/>. This is necessary in the case of a stacked welding with two welded sheets.

##### Attribute "section"

The only valid value currently for the attribute section of an Overlap Weld is:

* Fillet

**Note:** This value is the default if the ***section*** attribute is not specified.

##### Attribute "thickness"

The attribute thickness specifies the thickness (a-value, throat) of the weld.

##### Attribute "angle"

The attribute angle specifies the angle of the weld relative to the base sheet.

##### Attribute "shape"

The attribute shape defines the shape of the weld throat.

##### Attribute "penetration"

The attribute penetration specifies the degree of penetration resulting from the welding.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*, except *base* within **<weld\_position/>**):

<seamweld>

<overlap\_weld base="1" technology="resistance">

**<weld\_position u="0" x="0" y="0" z="1"**

**reference="false"**

**section="Fillet"**

**thickness="1.5"**

**angle="30"**

**shape="concave"**

**penetration="0.5"**

**filler="yes"**

**filler\_material=" E7018-X"/>**

<sheet\_parameter ... />

</overlap\_weld>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/> the following attributes can be specified for the Overlap Weld:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| Index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| Gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 104: Attributes of element <*sheet\_parameter/>* for Overlap Weld

Example A (within only required *attributes*):

<seamweld>

<overlap\_weld base="1" technology="resistance">

*<weld\_position u="0" x="0" y="0" z="1"/>*

**<sheet\_parameter index="2" gap="1.0" sheet\_thickness="1.5" sheet\_angle="0"/>**

</overlap\_weld>

</seamweld>

### Y-Joint

The principles of the modeling of Y-joints for χMCF are described in this section. A Y-Joint describes a connection between two or three sheets. The Y-Joint defines a connection between a welded sheet and a base sheet. There are two potential welds that can be specified for this type of connection. The parameters for each of the welds can be described separately.

The XML definition of a Y-Joint supports up to three[[20]](#footnote-21) weld positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1 Thickness of welded sheet
* α Sheet angle of welded sheet
* c Gap between base and welded sheet

#### Weld Parameters

The parameters of the welds are the same for all of the four potential welds on the connection:

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle



Figure 64: Y-Joint Sheet Layout



Figure 65: Parameters of Y-Joint Weld

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where index *i* is specifying the weld index and index *j* is defined by the sheet index of the welded sheet related to the weld.

Inside the χMCF File only a subset can be specified:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| A | thickness | 1 – 2 | ≥ 0 | Optional | - |
| Β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 2 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 105: Parameters of Y-Joint

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Y-Joint:

|  |  |  |
| --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** |
| Base | Integer | Optional |
| U | Floating Point | Required |
| X | Floating Point | Required |
| Y | Floating Point | Required |
| Z | Floating Point | Required |
| Reference | Boolean | Optional |
| Section | Selection | Optional |
| Thickness | Floating Point | \* see attribute description |
| Angle | Floating Point | \* see attribute description |
| penetration | Floating Point | \* see attribute description |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |
| Shape | Selection | Optional |

Table 106: Attributes of element <*weld\_position/>* for Y Joint

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "base"

For this type of weld the base sheet can be specified also inside the element <weld\_position/>. This is necessary in the case of a stacked welding with two welded sheets.

##### Attribute "section"

The attribute section can be absent in the case of attribute value technology="laser" inside element subtype.

Valid values for the attribute section (if present) of a Y-Joint are:

* Fillet
* HV
* HY

##### Attribute "thickness"

The attribute thickness specifies the thickness (a-value, throat) of the weld. Depending on the section this is required, optional or not allowed:

|  |  |
| --- | --- |
| ***Attribute value "section"*** | ***Attribute "thickness"*** |
| HV | Optional |
| HY | Not allowed |
| Fillet | Required |

Table 107: Value Dependency of Attribute **thickness**

##### Attribute "angle"

The attribute angle specifies the angle of the weld relative to the base sheet.

##### Attribute "penetration"

The attribute penetration specifies the degree of penetration resulting from the welding.

##### Attribute "shape"

The attribute shape defines the shape of the weld throat.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*, except *base* within **<weld\_position/>**):

<seamweld>

<y\_joint base="1" technology="resistance">

**<weld\_position u="0.5" x="1" y="0" z="1"**

**reference="false"**

**section="HY"**

**thickness="0.5"**

**angle="30"**

**penetration="0.5"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="concave"/>**

**<weld\_position u="0.2" x="-1" y="0" z="1"**

**reference="false"**

**section="HY"**

**thickness="0.5"**

**angle="45"**

**penetration="0.5"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="concave"/>**

<sheet\_parameter ... />

</y\_joint>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Y-Joint:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| Index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| Gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 108: Attributes of element **<***sheet\_parameter/>* for Y-Joint

Example A (within only required *attributes*):

<seamweld>

<y\_joint base="1" technology="resistance">

*<weld\_position u="0.2" x="1" y="0" z="1" ...*/>

**<sheet\_parameter index="2" gap="1.0" sheet\_thickness="1.5" sheet\_angle="180"/>**

</y\_joint>

</seamweld>

### K-Joint

The K-Joint connects two welded sheets from the same side to a base sheet.

There are four[[21]](#footnote-22) potential welds that can be specified for this type of connection. The parameters for each of the welds can be described separately.

****The XML definition of a K-Joint supports up to four weld positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1, t2 Thickness of welded sheet
* α1, α2 Sheet angle of welded sheet
* c1, c2 Gap between base and welded sheet

Figure 66: K-Joint Sheet Layout

#### Weld Parameters

The parameters of the welds are the same for all of the three potential welds on the connection:

Figure 67: Parameters of K-Joint Weld

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where index *i* is specifying the weld index and index *j* is defined by the sheet index of the welded sheet related to the weld.

The following parameters can be specified for the K-Joint:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| A | thickness | 1 – 3 | ≥ 0 | Optional | - |
| Β | angle | 0 – 2 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 3 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 109: Parameters of K-Joint

The penetration of the 3rd weld connection (d3) is assumed to be equal on both welded sheet. There is only one value to be specified.

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the K-Joint:

| ***Attributes*** | ***Type*** | ***Use*** |
| --- | --- | --- |
| Base | Integer | Optional |
| U | Floating Point | Required |
| X | Floating Point | Required |
| Y | Floating Point | Required |
| Z | Floating Point | Required |
| Reference | Boolean | Optional |
| Section | Selection | Optional |
| Thickness | Floating Point | \* see attribute description |
| Angle | Floating Point | \* see attribute description |
| penetration | Floating Point | \* see attribute description |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |
| Shape | Selection | Optional |

Table 110: Attributes of element **<***weld\_position/>* for K Joint

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "base"

For this type of weld the base sheet can be specified also inside the element <weld\_position/>. This is necessary in the case of a stacked welding with two welded sheets.

##### Attribute "section"

The attribute section can be absent in the case of attribute value technology="laser" inside element subtype.

Valid values for the attribute section (if present) of a K-Joint are:

* Fillet
* HV
* HY

##### Attribute "thickness"

The attribute thickness specifies the thickness (a-value, throat) of the weld. Depending on the section this is required, optional or not allowed:

|  |  |
| --- | --- |
| ***Attribute value "section"*** | ***Attribute "thickness"*** |
| HV | Optional |
| HY | Not allowed |
| Fillet | Required |

Table 111: Value Dependency of Attribute **thickness**

##### Attribute "angle"

The attribute anglespecifies the angle of the weld relative to the base sheet. The weld angle of a center weld of a K-Joint is assumed to be parallel to the base sheet (i.e. 0°).

##### Attribute "penetration"

The attribute penetration specifies the degree of penetration resulting from the welding.

##### Attribute "shape"

The attribute shape defines the shape of the weld throat.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*, except *base* within **<weld\_position/>**):

<seamwweld>

<k\_joint base="2" technology="resistance">

**<weld\_position u="1.0" x="2" y="0" z="1"**

**reference="true"**

**penetration="0.5"**

**thickness="1.4"**

**angle="15"**

**section="HV"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

**<weld\_position u="0.0" x="1" y="0" z="2"**

**reference="true"**

**penetration="0.5"**

**thickness="1.1"**

**angle="90"**

**section="HV"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

**<weld\_position u="1.0" x="-2" y="0" z="1"**

**reference="true"**

**penetration="0.6"**

**thickness=".5"**

**angle="30"**

**section="HV"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

<sheet\_parameter ... />

<sheet\_parameter ... />

</k\_joint>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the K Joint:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating Point | Optional | Default value is 0 |
| sheet\_ thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 112: Attributes of element <*sheet\_parameter/>* for K Joint

Example A (within only required *attributes*):

<seamweld>

<k\_joint base="2" technology="resistance">

*<weld\_position u="1.0" x="2" y="0" z="1" .../>*

*<weld\_position u="0.0" x="1" y="0" z="2" .../>*

*<weld\_position u="1.0" x="-2" y="0" z="1" .../>*

**<sheet\_parameter index="1" gap="1.5" sheet\_thickness="1.5" sheet\_angle="45"/>**

**<sheet\_parameter index="3" gap="1.0" sheet\_thickness="1.5" sheet\_angle="30"/>**

</k\_joint>

</seamweld>

### Cruciform Joint

The cross joint connects two welded sheets from different sides to a base sheet.

There are four potential welds that can be specified for this type of connection. The parameters for each of the welds can be described separately.

The XML definition of a Cruciform Joint supports up to four weld positions. Each of the weld positions is specified using the element <weld\_position/> with the corresponding attributes and nested elements inside the subtype definition.

#### CruciformJoint_v2Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1, t2 Thickness of welded sheet
* α1, α2 Sheet angle of welded sheet
* c1, c2 Gap between base and welded sheet

#### Weld Parameters

Figure 68: Cruciform Joint Sheet Layout

The parameters of the welds are the same for all the four potential welds on the connection:

Figure 69: Parameters of Cruciform Joint

* ai Thickness of the weld (a-value, throat)
* di Depth of the penetration
* βi Weld angle

For the penetration the ratio ηi of the penetration depth to the sheet thickness is specified inside the χMCF file.

This is computed by  where index *i* is specifying the weld index and index *j* is defined by the sheet index of the welded sheet related to the weld.

The following parameters can be specified for the Cruciform Joint:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| a | thickness | 2 – 4 | ≥ 0 | Optional | - |
| β | angle | 0 – 4 | ≥ 0 | Optional | 45 [deg] |
| η | penetration | 0 – 4 | 0 ≤ η ≤ 1 | Optional | 0 |

Table 113: Parameters of Cruciform Joint

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Cruciform Joint:

| ***Attributes*** | ***Type*** | ***Use*** |
| --- | --- | --- |
| base | Integer | Optional |
| u | Floating Point | Required |
| x | Floating Point | Required |
| y | Floating Point | Required |
| z | Floating Point | Required |
| reference | Boolean | Optional |
| section | Selection | Optional |
| thickness | Floating Point | \* see attribute description |
| angle | Floating Point | \* see attribute description |
| penetration | Floating Point | \* see attribute description |
| filler | Selection | Optional |
| filler\_material | Alphanumeric | Optional |
| shape | Selection | Optional |

Table 114: Attributes of element **<***weld\_position/>* for Cruciform Joint

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section 8.2.4.3.2 Welding Position.

##### Attribute "base"

For this type of weld the base sheet can be specified also inside the element <weld\_position/>. This is necessary in the case of a stacked welding with two welded sheets.

##### Attribute "section"

The attribute section can be absent in the case of attribute value technology="laser" inside element subtype.

Valid values for the attribute section (if present) of a cross joint are:

* Fillet
* HV
* HY

##### Attribute "thickness"

The attribute thickness specifies the thickness (a-value, throat) of the weld. Depending on the section this is required, optional or not allowed:

| ***Attribute value "section"*** | ***Attribute "thickness"*** |
| --- | --- |
| HV | Optional |
| HY | Not allowed |
| Fillet | Required |

Table 115: Value Dependency of Attribute **thickness**

##### Attribute "angle"

The attribute angle specifies the angle of the weld relative to the base sheet.

##### Attribute "penetration"

The attribute penetration specifies the degree of penetration resulting from the welding[[22]](#footnote-23).

##### Attribute "shape"

The attribute shape defines the shape of the weld throat.

##### Attribute "filler"

Valid values for the attribute filler can be:

* yes
* no

**Note:** Depending on the technology the default value can different (see in Generic Seam Weld Definition section under attribute filler).

##### Attribute "filler\_material"

The attribute filler\_material specifies the applied material during the welding process.

Example A (within each *attribute*, except *base* within **<weld\_position/>**):

<seamweld>

<cruciform\_joint base="1" technology="arc">

**<weld\_position u="0.2" x="1" y="0" z="1"**

**thickness="3.0"**

**penetration="0.8"**

**section="HY"**

**angle="30"**

**reference="true"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

**<weld\_position u="0.4" x="-1" y="0" z="-1"**

**thickness="4.0"**

**penetration="0.4"**

**section="HY"**

**angle="45"**

**reference="true"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

**<weld\_position u="0.6" x="-1" y="0" z="1"**

**thickness="5.0"**

**penetration="0.8"**

**section="HY"**

**angle="50"**

**reference="true"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

**<weld\_position u="0.8" x="1" y="0" z="-1"**

**thickness="6.0"**

**penetration="0.4"**

**section="HY"**

**angle="75"**

**reference="true"**

**filler="yes"**

**filler\_material=" E7018-X"**

**shape="straight" />**

<sheet\_parameter ... />

<sheet\_parameter ... />

</cruciform\_joint>

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Cruciform Joint:

|  |  |  |  |
| --- | --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| gap | Floating Point | Optional | Default value is 0 |
| sheet\_thickness | Floating Point | Optional | - |
| sheet\_angle | Floating Point | Optional | - |

Table 116: Attributes of element **<***sheet\_parameter/>* for Cruciform Joint

Example A (within only required *attributes*):

<seamweld>

<cruciform\_joint base="1" technology="arc">

*<weld\_position u="0.2" x="1" y="0" z="1" .../>*

*<weld\_position u="0.4" x="-1" y="0" z="-1".../>*

*<weld\_position u="0.6" x="-1" y="0" z="1" .../>*

*<weld\_position u="0.8" x="1" y="0" z="-1" .../>*

**<sheet\_parameter index="2" gap="1.5" sheet\_thickness="1.5" sheet\_angle="90"/>**

**<sheet\_parameter index="3" gap="1.0" sheet\_thickness="1.5" sheet\_angle="90"/>**

</cruciform\_joint>

</seamweld>

### Flared Joint



Figure 70: Flared Joint Sheet Layout

##### Sheet Parameters

The parameters to describe the connection are:

* tB Thickness of base sheet
* t1 Thickness of welded sheet
* c Gap between base and welded sheet

##### Weld Parameters



Figure 71: Parameters of Flared Joint Weld

The parameters of the welds are described below:

* b width of the weld

The following parameter can be specified for the Flared Joint:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Parameter*** | ***χMCF-Key*** | ***Multiplicity*** | ***Value Range*** | ***Use*** | ***Default Value*** |
| b | width | 1 | ≥ 0 | Optional | - |

Table 117: Parameters of Flared joint

All other parameters are provided by the model itself and are partially used to specify parameters of the weld.

#### Attributes

##### Attribute "base"

The index for the base sheet is specified using the attribute base.

##### Attribute "technology"

The value for the attribute technology can be specified using the following values:

* resistance
* arc
* laser (Energy beam / Laser)
* friction
* brazing

#### Element "weld\_position"

For the element <weld\_position/> the following attributes can be specified for the Flared-Joint:

|  |  |  |
| --- | --- | --- |
| ***Attributes*** | ***Type*** | ***Use*** |
| U | Floating point | Required |
| X | Floating point | Required |
| Y | Floating point | Required |
| Z | Floating point | Required |
| Reference | Boolean | Optional |
| Width | Floating point | Optional |

Table 118: Attributes of element **<***weld\_position/>* for Flared Joint

##### Attributes "u, x, y, z, reference"

##### Detailed definition can be found in section [Welding Position](#_Welding_Position).

##### Attribute "width"

The attribute width specifies the width of the weld.

Example A (within each *attribute*):

<seamweld>

<flared\_joint base="1" technology="arc">

**<weld\_position u="0" x="1" y="1" z="1"**

**reference="false"**

**width="1.0" />**

<sheet\_parameter ... />

</flared\_joint >

</seamweld>

#### Element "sheet\_parameter"

For the element <sheet\_parameter/>, the following attributes can be specified for the Flared Joint:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| Index | Integer | Required | It must be referenced to ***<part>*** index attribute |
| Gap | Floating point | Optional | Default value is 0 |
| sheet\_thickness | Floating point | Optional | - |

Table 119: Attributes of element **<***sheet\_parameter/>* for Flared Joint

Example A (within only required *attributes*):

<seamweld>

<flared\_joint base="1" technology="arc">

*<weld\_position u="0" x="1" y="1" z="1"* ... "/>

**<sheet\_parameter index="2" gap="0" sheet\_thickness="1.5"/>**

</flared\_joint >

</seamweld>

## Adhesive Lines

An adhesive line is denoted by an element <adhesive\_line/>. This element is described completely by its attributes and nested elements.

XML specification of ***<connection\_1d/>*** with attribute ***label:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| label | Alphanumeric | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 120: Attributes of **<connection\_1d/>**

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| adhesive\_line | 1 | Optional | - |
| loc\_list | 1-\* | Required | See section 8.1.2 loc\_list |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 121: Nested elements of **<connection\_1d/>**

##### Element "adhesive\_line"

For the ***<adhesive\_line/>*** element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| base | Integer | > 0 | Optional | - |
| width | Floating point | >= 0.0 | Optional | - |
| thickness | Floating point | >= 0.0 | Optional | - |
| material | Alphanumeric | Alphanumeric | Optional | - |

Table 122: Attributes of element *<adhesive\_line/>*

* base: the index of the flange partner, which the robot applies the adhesive to, before the flange partners are fitted together.
* width: the width of the adhesive
* thickness: the height of the adhesive
* material: the name of the adhesive material according to CAD/PDM. For CAE applications, another label from a reduced data base may be applicable. This is to be stored in <appdata/>, then.

All attributes of this connection are optional for import to CAD or CAE processors. However, specific FE solvers may declare some of them to be mandatory.

##### General defaults are: 0 for numeric values, "" for strings. However, these defaults are not always useful for CAE.

##### Element "loc\_list"

This follows the same syntax as defined in section 8.1.2 Location.

Element "appdata"

This follows the same syntax as defined in section 5.2.1 User Specific Data <appdata>.

Element "femdata"

This follows the same syntax as defined in section [5.2.2 Finite Element Specific Data <femdata>](#_Finite_Element_Specific).

**Example A (**without base definition**):**

<connection\_1d label="ADH\_100006">

**<adhesive\_line width="5" thickness="2" material="CAD\_Material"/>**   
 <!-- material is optional -->

<loc\_list>

<loc v="1"> 2169.300 -489.495 1773.936 </loc>

<loc v="2"> 2165.593 -480.000 1790.221 </loc>

<loc v="3"> 2165.593 480.000 1790.221 </loc>

<loc v="4"> 2169.302 489.495 1773.937 </loc>

</loc\_list>

<appdata>

...

</appdata>

</connection\_1d>

**Example B (**with base definition**):**

<connection\_1d label="ADH\_1544256">

<adhesive\_line base="2" width="1" thickness="1" material="CAD\_test\_Mat"/>

<loc\_list>

<loc v="0.0"> 501 1.03333 3.33332 </loc>

<loc v="0.5"> 502 1.03333 3.33332 </loc>

<loc v="1.0"> 503 1.03333 3.33332 </loc>

</loc\_list>

<appdata>

...

</appdata>

</connection\_1d>

## Hemming Flanges

### Introduction

A hemming involves rolling over a metal sheet onto itself, to reinforce an edge and improve appearance. In automotive engineering, the hemming process also involves adhering other metal sheets within the rolled one.

A hemming involves a path around which the outer metal sheet is rolled over. This is called the *hemming root.*

The hemming also consists of three regions, where glue is applied and which are compressed during hem formation.



Figure 72: The Three Regions of a Hemming

The solution described below addresses certain features in hemming design:

* The path of the hemming root does not need to coincide with the paths of the adhesive.
* Each region may have a different filling percentage. This is mainly to prevent spillage, but also to maximize contacting overlap.
* Reinforcements may exist in the *Inner Panel*.



Figure 73: Path Changes and Width Changes in Hemming Flanges

Width and path sometimes change to avoid obstacles, like holes.



Figure 74: Adhesive Path Differs from Root Path

Adhesive generally follows inner routes around corners.



Figure 75: Reinforcements need to be considered as Part of the Inner Panel

Reinforcements need to be considered as part of the Inner Panel, and glued accordingly.

To address the features above, the hemming is treated as a composite connection. This allows for separate paths between the hemming root and the adhesive of each region.

### Definition of element <hemming/>

XML specification of ***<connection\_1d/>*** with attribute ***label:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| label | Alphanumeric | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 123: Attributes of **<connection\_1d/>**for **<hemming/>**

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| hemming | 1 | Optional | - |
| loc\_list | 1-\* | Required | See section 8.1.2 loc\_list |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 124: Nested elements of **<connection\_1d/>**for **<hemming/>**

##### Element "loc\_list"

This is the path of the *hemming root*. It follows the same syntax as defined in section 8.1.2 Location.

Element "appdata"

This follows the same syntax as defined in section 5.2.1 User Specific Data <appdata>.

Element "femdata"

This follows the same syntax as defined in section [5.2.2 Finite Element Specific Data <femdata>](#_Finite_Element_Specific).

##### Element "hemming"

For the ***<hemming/>*** element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| folded\_width | Floating point | > 0.0 | Optional | - |
| folded\_part | Integer | - | Optional | Index of the folded sheet |

Table 125: Attributes of element **<hemming/>**

* folded\_width: This is the measure of the width of the folded metal sheet. It is different from the width of the adhesive which may optionally exist.
* folded\_part: refers to the index of the part that is folded for this kind of connection, as defined in 5.3.1.1 Element <part/>.

Its definition is similar to "base" attribute of <seamwelds/> in section 8.2.4.2 Type Specification. The usage of adhesive can be specified by the optional nested elements, <region>, below.

The three regions of the hemming can be described in the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| Region | 1-3 | Optional | - |

Table 126: Nested elements of element **<hemming/>**

##### Element "region"

For ***<region/>*** element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| label | Alphanumeric | "A", "B", or "C" | Required | - |
| fill\_percentage | Floating point | [0.0, 100.0] | Optional | - |
| top\_index | Integer | > 0 | Optional | refers to ***<part>*** index attribute |
| bottom\_index | Integer | > 0 | Optional | refers to ***<part>*** index attribute |

Table 127: Attributes of element **<region/>**

This element defines adhesion properties of region A, B, or C.

* label : this is an identifier of the hemming region, according to Figure 72 "The Three Regions of a Hemming". Only values "A", "B" and "C" are meaningful.
* fill\_percentage: target hem fill for this region.
* top\_index: the index (see section 5.3.1.1) where the region’s adhesive connects to.
* bottom\_index: the index (see section 5.3.1.1) where the region’s adhesive connects to.

Existence of top\_index and bottom\_index is meaningful only if adhesive element is specified, especially when the hemming involves more than 2 flange partners.

The order of top\_index and bottom\_index is not important. However, if they are not specified, the corresponding adhesive is free to select any of the hemming’s flange partners. The adhesive will guess which are the relevant partners, using its position.

The adhesive of hemming regions "A" and "C" can be described in the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| connection\_1d  connection\_2d | 1 | Optional | Exactly one of these elements. It must either contain an <adhesive\_line/> or an <adhesive\_face/>. |

Table 128: Nested elements of element **<region/>**

The usage of adhesives in the <region/> is described in sections 8.3 Adhesive Lines and 9.2 Adhesive Faces.

***Note***: Region "B" is not expected to contain an adhesive line or face. The definition is left open for future extensions.

**Example A (**main type as ***<hemming/>*):**

<connected\_to>

<part index="1" label="PART\_7000400"/> <!-- outer hood panel -->

<assy index="23">

<part label="PART\_5000300"/> <!-- inner hood panel -->

<part label="PART\_5000800"/> <!-- reinforcement -->

</assy>

</connected\_to>

<connection\_1d label="HMG\_100574">

<loc\_list> <!-- hemming root's path -->

<loc v="1"> 2169.300 -489.495 1773.936 </loc>

<loc v="2"> 2165.593 -480.000 1790.221 </loc>

<loc v="3"> 2165.593 480.000 1790.221 </loc>

<loc v="4"> 2169.302 489.495 1773.937 </loc>

</loc\_list>

<appdata>

...

</appdata>

**<hemming folded\_width="5" folded\_part="1">**

**<region label="A" fill\_percentage="50">**

<connection\_1d label="100574 region A adhesive">

<**adhesive\_line** base="1" width="4" thickness="1" material="CAD\_test\_Mat"/>

<loc\_list> <!-- adhesive’s path -->

...

</loc\_list>

<appdata> <!-- adhesive's appdata -->

...

</appdata>

</connection\_1d>

</region>

**<region label="B" fill\_percentage="100"/>**

**<region label="C" top\_index="23" bottom\_index="1" fill\_percentage="100">**

<connection\_2d label="100574 region C adhesive">

<**adhesive\_face** thickness="1" material="CAD\_test\_Mat"/>

<loc\_list> <!-- adhesive face's nodes -->

...

</loc\_list>

<face\_list> <!-- adhesive's facets -->

...

</face\_list>

<appdata> <!-- adhesive's appdata -->

...

</appdata>

</connection\_2d>

</region>

</hemming>

</connection\_1d>

## Sequence Connections

A sequence connection represents a set of 0d connections collectively described, using the definition of a connection line. The connections are uniformly distributed along the line, at a given density. This type of modeling allows for easy optimization of the number of connections along a line.

The distribution of connections is described by spacing and margin. Spacing is a mandatory dimension.



Figure 76: Sequence without margin

An optional margin value allows space to be left from each side.



Figure 77: Sequence with margin and spacing

The default value for margin is 0.

However, there are cases where the spacing and margin do not add up to exactly the length of the line. In this case, either the margin or the spacing may be relaxed:



Figure 78: Margin relaxation



Figure 79: Spacing relaxation

To decide which case is required, one has to give **priority** either to spacing or to margin.

* When priority is given to spacing, the margin can be slightly stretched to a greater value, so that the maximum number of connections can fit using the given spacing.
  + If 2 x margin is greater than the line length, one connection is placed at the middle of the line.
* When priority is given to margin, spacing can be slightly squeezed or stretched (such that Δspacing is minimal).

A <loc\_list> is necessary for this type of connection.

Example A (with minimum definition for *<sequence\_connection\_0d/>*):

<connection\_1d label="SPOT\_LINE\_11000">

**<sequence\_connection\_0d spacing="30.0">**

**<spotweld/>**

**</sequence\_connection\_0d>**

<loc\_list>

...

</loc\_list>

<appdata>

...

</appdata>

</connection\_1d>

Example B (full definition for *<sequence\_connection\_0d/>*):

<connection\_1d label="DROP\_LINE\_33000">

**<sequence\_connection\_0d spacing="30.0" margin="1.0" priority="spacing">**

**<gumdrop diameter="4.0" mass="10." material="CAD\_Material"/>**

**</sequence\_connection\_0d>**

<loc\_list>

...

</loc\_list>

<appdata>

...

</appdata>

</connection\_1d>

To define the type of 0d-connection elements that this connection line describes, any of the connection\_0d types can be nested in the **<sequence\_connection\_0d>** element.

Example C (definition of a *<sequence\_connection\_0d/>* of <spotweld/>):

<connection\_1d label="SPOT\_LINE\_11000">

**<sequence\_connection\_0d spacing="30.0" margin="1.0" priority="spacing">**

**<spotweld diameter="6"/>**

**</sequence\_connection\_0d>**

<loc\_list>

...

</loc\_list>

<appdata>

...

</appdata>

</connection\_1d>

XML specification of ***<connection\_1d/>*** in case of <sequence\_connection\_0d/>***:***

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| sequence\_connection\_0d | 1 | Optional | - |
| loc\_list | 1-\* | Required | See section 8.1.2 loc\_list |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 129: Nested elements of **<connection\_1d/>** for **<sequence\_connection\_0d/>**

The XML definition of a *<sequence\_connection\_0d/>* may contain any of the following 0d connection types:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| spotweld | 1 | Optional | - |
| gumdrop | 1 | Optional | - |

Table 130: Nested elements of **<sequence\_connection\_0d/>**

***Remark***: nesting 0d elements with directions (such as rivet, screws, robscans) would be impossible with this definition. Note: Only *one* of the nested elements (spotweld, or gumdrop) must exist. If all are missing, then this will default to spotweld.

XML specification of ***<sequence\_connection\_0d/>*** :

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| spacing | Floating point | ≥ 0.0 | Optional | - |
| margin | Floating point | ≥ 0.0 | Optional | Default value is 0.0 |
| priority | Selection | {"spacing", "margin"} | Optional | Default value is "spacing" |

Table 131: Attributes of element *<sequence\_connection\_0d/>*

# 2D connections

## Generic Definitions

### Identification

Each face connection is optionally identified by its *label*. The XML definition at ***<connection\_2d/>*** level contains the following attributes:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| label | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 132: Attributes of **<connection\_2d/>**

***Attribute "label"***

The label defines the human readable identification of the connection.

**Example (**typical definition**):**

<connection\_list>

**<connection\_2d label="ADH\_PATCH">**

<loc\_list>

...

</loc\_list>

<face\_list>

...

</face\_list>

<adhesive\_face>

...

</adhesive\_face>

**</connection\_2d>**

</connection\_list>

### Connection Face

The definition of the connection face is described using tessellations. Each tessellation is a set of facets. The facets refer to 3 or 4 points, also described in the same level. Faces of any curvature can be represented by adding more points to the tessellations to obtain the needed accuracy.

The facets do not have any sense of order. The facets refer to the points via an index to the corresponding points, to avoid data duplication. The index is valid only within one certain <connecton\_2d/>. Hence, it can start with e. g. 1 every time again.

***Element "loc\_list"***

The list of locations for the definition of the connection face is stored in the element ***<loc\_list>***. This element contains nested elements ***<loc/>*** defining the location of a point of the connection line in space. These locations have to be uniquely identifiable so that the facets can refer to them.

No additional attributes are associated to the element ***<loc\_list>***.

The <loc\_list> element has the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| loc | 3-\* | Required | - |

Table 133: Nested elements of **<loc\_list>**

***Element "loc"***

Each location specified by the element ***<loc/>*** contains three values specifying the x, y and z coordinates of the location.

The attributes associated to the element <loc/> are:

| ***Attributes*** | ***Type*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| v | Integer | Required | Unique within the parent element <connection\_2d/> |

Table 134: Attributes of element **<loc/>**

The attribute ***v*** is used to ensure unique identification. The index values must be unique within the <connection\_2d/> element.

**Example:**

<loc\_list>

**<loc v="1"> 2581.21 -708.408 31.6532 </loc>**

**<loc v="2"> 2581.42 -708.357 35.2816 </loc>**

**<loc v="3"> 2581.05 -708.302 39.0643 </loc>**

</loc\_list>

***Element "face\_list"***

The list of facets for the definition of the connection face is stored in the element ***<face\_list>***. This element contains nested elements ***face*** defining tessellated facets of the connection face in space. These facets are in no particular order.

No additional attributes are associated to the element ***<face\_list>***.

The face\_list element has the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| face | 1-\* | Required | - |

Table 135: Nested elements of element *<face\_list>*

***Element "face"***

Each location specified by the element <***face/>*** contains *four* values specifying each vertex of the facet, using the <loc> identifier, v.

| ***Attribute (****Vertex)* | ***Type*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| **v**1 | Integer | Required | Must correspond to an **v** in a loc from loc\_list |
| **v**2 | Integer | Required | Must correspond to an **v** in a loc from loc\_list |
| **v**3 | Integer | Required | Must correspond to an **v** in a loc from loc\_list |
| **v**4 | Integer | Optional | Must correspond to an **v** in a loc from loc\_list |

Table 136: Attributes of element **<face/>**

* To represent a quadrangular facet, four distinct vertex indices must be supplied.
* To represent a triangular facet, three distinct vertex indices must be supplied.

**Example A: (**with minimum definition for <connection\_2d/>**)**

<loc\_list>

<loc v="**1**"> 2001.557 14.435 1736.898 </loc>

<loc v="**2**"> 1994.802 14.435 1734.247 </loc>

<loc v="**3**"> 1994.790 0.0436 1734.256 </loc>

<loc v="**4**"> 2001.547 0.0545 1736.911 </loc>

<loc v="**5**"> 2008.298 14.435 1739.550 </loc>

<loc v="**6**"> 2008.336 28.784 1739.524 </loc>

</loc\_list>

<face\_list>

**<face v1="1" v2="2" v3="3" v4="4"/>** <!-- quadrangular facet -->

**<face v1="1" v2="5" v3="6"/>**  <!-- triangular facet -->

</face\_list>

### Type Specification

Each connection is identified by its type. The XML definition of 2D connections contains the following nested elements:

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- |
| adhesive\_face | 1 | Optional | - |
| stacking | 1 | Optional | See section 5.3.1.3 |

Table 137: Nested elements of **<connection\_2d/>**

***Note***: Only *one* of the type elements <adhesive\_face/> must exist in <connection\_2d/>. If none of the type elements exist, then this will default to adhesive\_face.

## Adhesive Faces

A die-cut adhesive is denoted by an element ***<adhesive\_face/>.***



Figure 80: Picture of an adhesive face

XML specification of ***<connection\_2d/>*** with attribute ***label:***

| ***Attributes*** | ***Type*** | ***Value Space*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- | --- |
| label | Alphanumeric | Alphanumeric | Optional | - |
| quality\_control | Alphanumeric | Alphanumeric | Optional | See section 6.4 Attribute **quality\_control** |

Table 138: Attributes of element **<connection\_2d/>**

| ***Nested Elements*** | ***Multiplicity*** | ***Use*** | ***Constraint / Remarks*** |
| --- | --- | --- | --- |
| adhesive\_face | 1 | Optional | - |
| loc\_list | 1 | Required | - |
| face\_list | 1 | Required | - |
| appdata | 1 | Optional | - |
| femdata | 1 | Optional | - |
| custom\_attributes\_list | 1 | Optional | See section 6.5 Custom Attributes list |

Table 139: Nested elements of element **<connection\_2d/>**

For the ***<adhesive\_face/>*** element, the following attributes can be specified:

| ***Attributes*** | ***Type*** | ***Value space*** | ***Use*** | ***Constraint*** |
| --- | --- | --- | --- | --- |
| base | Integer | > 0 | Optional | - |
| thickness | Floating point | ≥ 0.0 | Optional | - |
| material | Alphanumeric | - | Optional | - |

Table 140: Attributes of element **<adhesive\_face/>**

* base: the index of the flange partner, on which the adhesive is applied to, before the flange partners are fitted together.
* thickness: denotes the thickness of the adhesive between the sheets.
* material: is an optional label that denotes which material is to be used for the adhesive.

**Example (**main type as ***<adhesive\_face/>*):**

<connection\_2d>

**<adhesive\_face** **thickness="2.0" material="CAD\_Material"/>**

<loc\_list>

<loc v="1"> 2001.557 14.435 1736.898 </loc>

<loc v="2"> 1994.802 14.435 1734.247 </loc>

<loc v="3"> 1994.790 0.0436 1734.256 </loc>

<loc v="4"> 2001.547 0.0545 1736.911 </loc>

<loc v="5"> 2008.298 14.435 1739.550 </loc>

<loc v="6"> 2008.336 28.784 1739.524 </loc>

</loc\_list>

<face\_list>

**<face v1="1" v2="2" v3="3" v4="4"/>** <!-- quadrangular facet -->

**<face v1="1" v2="5" v3="6"/>**  <!-- triangular facet -->

</face\_list>

<appdata>

...

</appdata>

<custom\_attributes\_list>

...

</custom\_attributes\_list>

</connection\_2d>

# Future extensions

So far, only the above mentioned connection types with the corresponding parameters are described, which cover mainly the applications of CAD and CAE. However, χMCF is designed for the use in the complete development process and should be able to cover all major joint types thus two important extensions remain to be undertaken.

## Additional parameters for spot and seam welds

For prototyping and manufacturing (CAM) additional parameters and information, like the type and the manufacturer of the welding device, the current density required in case of spot welds etc., may be relevant and needed. These parameters are not included in the present document yet. Their definitions will happen in the near future by the corresponding experts.

## Other relevant and new joint types

It can be expected that increasingly new joint types will arise due to the advance of the technological development.

As mentioned before, χMCF is open for any new joint type which will come and be of relevance for the technical application.

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1. Working group 25 for joining technologies of the German Research Association of Automotive Technologies. [↑](#footnote-ref-2)
2. Up to now, only versions 1.0 and 1.1 of XML exist, where 1.1 is *not* widely used. Hence, most systems still create XML 1.0 files. (For differences see <http://www.w3.org/TR/xml11/#sec-xml11>.) [↑](#footnote-ref-3)
3. Since V2.0 introduces significant changes, root element has been renamed from "mcf" to "xmcf" in order to avoid confusion with the "old" MCF-Format. [↑](#footnote-ref-4)
4. Cf. <http://en.wikipedia.org/wiki/SI>. [↑](#footnote-ref-5)
5. MEDINA support for v3.0 is unforeseen. [↑](#footnote-ref-6)
6. Future χMCF versions may include <femdata/> at root level or <connection\_group/> elements, but this is not allowed in V 3.0 [↑](#footnote-ref-7)
7. Cite from FATXML V1.2 R2 file „02\_FATXML\_General\_Introduction\_Data\_Format\_V1.2\_R2\_170515.pdf“, p. 5: „Currently the Solver-Codes PAM-CRASH, LS-DYNA, RADIOSS, OPTISTRUCT, **MSC-**NASTRAN and PERMAS support the FATXML-Format […]. ABAQUS currently supports the FATXML-Format only with special defined comment cards […] “ [↑](#footnote-ref-8)
8. Attention: FATXML example file „SILVERADO\_FATXML\_v1.2\_20170515.fatxml“ states „<NAME>**MD**NASTRAN</NAME>“. Hence, it needs to be clarified, which of both names is valid. [↑](#footnote-ref-9)
9. To identify a property, only pid or pname shall be used, not both. Although most solvers use numbers, Abaqus uses names as identifiers. [↑](#footnote-ref-10)
10. See <http://en.wikipedia.org/wiki/Gram%E2%80%93Schmidt_process>. [↑](#footnote-ref-11)
11. See <http://en.wikipedia.org/wiki/Cross_product>. [↑](#footnote-ref-12)
12. Bolts vs Screws: <https://en.wikipedia.org/wiki/Bolt_(fastener)> [↑](#footnote-ref-13)
13. For more details, see <http://en.wikipedia.org/wiki/Screw_thread#Lead.2C_pitch.2C_and_starts>. [↑](#footnote-ref-14)
14. For details, see http://en.wikipedia.org/wiki/Clinching\_%28metalworking%29 [↑](#footnote-ref-15)
15. O.Hahn and A.Schulte, "Nutzung des festigkeitspotentials höherfesten stahlfeinbleche durch stanzniet- und clinchverbindungen", pp. 27-40, 1998 [↑](#footnote-ref-16)
16. http://www.btm-europe.de/en/tooling-system/lance-n-loc.html#how-it-works [↑](#footnote-ref-17)
17. <http://www.google.com/patents/EP1926918B1?cl=en> [↑](#footnote-ref-18)
18. curves with sharp corners (e.g. right angles) are not typically represented by a single curve in CAD systems. Using multiple <loc\_list> elements is suitable for representing such cases. [↑](#footnote-ref-19)
19. four-sheet overlap welds have been encountered, even though they are not explicitly depicted in this document. [↑](#footnote-ref-20)
20. The two most common welding positions are shown in Figure 61. The third welding position would be from underneath the base sheet, using a laser. [↑](#footnote-ref-21)
21. The three most common welding positions are shown in Figure 63. The fourth would be from underneath the base sheet, using a laser. [↑](#footnote-ref-22)
22. The attribute penetration of a *<weld\_position/>* holds for all sheets connected by this *<weld\_position/>* (e. g. important for K-Joints). [↑](#footnote-ref-23)