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| **Report IDM reference No.** | EFDA\_D\_2N3M6L | **Version: see IDM** |

Draft Report

on Deliverable

MAT-1.3.3-T003-D002 - Summary overview report on DDC Development

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|  | | **Deliverable-ID**[[1]](#footnote-1) | *MAT-1.3.3-T003-D002* |
| **Work Package** | *WPMAT* | **Date** | *31st Oct. 2016* |
| **Project Leader** | *Michael Rieth* | | |
|  | | | |
| **TS Title** | Summary overview report on DDC Development | | |
| **TS Ref. No.** | *MAT-1.3.3-T003* | **TS IDM-link** | 2N3M6L |
| **Task Owner** | *Manminder Kalsey* | | |
| **RU(s)** | *CCFE* | | |

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| **Executive Summary** |
| *This report provides a summary of the DDC development in 2016.*  *The DDC structure is now created and available for review. This report attempts to plan the review activities.*  *In addition, a number of recommendations have been made for future activities.* |

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| **Comments** (shortcomings, deviations, etc.) |
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**Abbreviations**

|  |  |
| --- | --- |
| *DIV* | *Divertor work package* |
| *BB* | *Breeder Blanket work package* |
| *IND* | *Industry* |
| *CCFE* | *Culham Centre for Fusion Energy, Great Britain (formerly UKAEA)* |
| *DME* | *Damage Mechanism Expert* |
| *EDDI* | *Engineering Data and Design Integration* |
| *RIM* | *Reliability and Integrity Management* |
| *DDC* | *DEMO Design Criteria* |

# Short Introduction and Objectives of Work

The high level goal of WBS1.3 is to develop structural design criteria for Plasma Facing Components. The target for 2016 is to release the first issue of the DDC (DEMO Design Criteria WBS1.3.3). This target is supported by two streams supporting tasks:

WBS1.3.1 – Priority Gaps

WBS1.3.2 – Enhancing Content and Usability

Although the DDC will take a number of years to fully develop, a target of delivering the first issue DDC by the end of 2016 has been identified with the intention that this provides guidance to design projects on the most appropriate design rules to be applied in the near-term and placeholders indicating which developments are currently planned in future design criteria development activities.

At the start of 2016, the following objectives were identified as an indicative approach to developing the DDC.

* Address received draft DDC comments.
* Test the usability of the proposed elastoplastic rules using ANSYS.
* Assess the possibility of making the DDC both ANSYS and ABAQUS compatible.
* Complete the DDC and release issue 1.
* Include case studies of both Blanket and Divertor components.

This report provides a summary of the progress of these activities in 2016 along with highlighting any additional activities that may have been carried out.

# Description of Work

## Address received draft DDC comments

The comments received for the draft DDC issued at the end of 2015 were reviewed and addressed. These have been incorporated into the DDC v1.0, to be released at the end of 2016. Details of the 2016 DDC developments can be found in section 2.4.

## Test the usability of the DDC

In the first Quarter of 2016, the EDDI team organised a workshop to disseminate developments from the EDDI project to relevant members of the DEMO project. This workshop included a number of items from the DDC project, specifically:

* DDC importance and history, work to date, current outcomes, next steps and anticipated timeline
* Overview of Ratcheting rule development, example of implementation, impact of assessments and steps to incorporate into DDC.
* Ratcheting rule worked example with interactive support and Q&A session.
* Overview of Creep Fatigue assessment tool development, example of implementation, impact of assessments.
* Creep Fatigue Tool, worked example with interactive support and Q&A session.

Following this workshop, a number of DIV and BB team members have been attempting to use both the new Ratcheting design rule and the Creep Fatigue assessment tool. This is a vital aspect of the development process, ensuring that any issues are identified and rectified along with identifying potential areas of further development. The following is a summary of the views of the users for both the Ratcheting rule (2.2.1) and the Creep Fatigue Tool (2.2.2).

### DDC Ratcheting Rule usability and recommendations

The DDC Ratcheting Rule has been trialled by a number of the DIV team members (Mike Fursdon, Jeong Ha and Muyuan Li).

The proposed Ratcheting rule has 2 stages of assessment. The first stage assesses if the component is likely to achieve elastic shakedown (pass), or not (fail). If a component fails the first stage, than it is required that the component is assessed with a second Ratcheting design rule. This second stage assessment would determine if a component will stabilise into the low cycle fatigue regime (additional LCF assessment required) or continue to ratchet to failure. The first stage of this rule has been checked and validated and hence was released at the 2016 Q1 EDDI workshop. However the second stage aspect of this design rule was still under development during 2016, none the less, it was still presented during the workshop as future work.

Both stages of the Ratcheting Rule have been used by the aforementioned members of the DIV team. Overall it seems that the first stage of the rule is easily applicable and appears to successfully identify occasions where elastic shakedown will occur. However questions have been raised with regards to the validity of the second stage of the ratcheting rule. It has been recommended that further testing and validation of this design rule is needed before it is ready to be introduced into the DDC.

### DDC Creep Fatigue Assessment tool usability and recommendations

The DDC Creep Fatigue tool has been used by a member of the BB team (George Ellwood).

The Creep Fatigue Assessment tool has been created to allow for the automated Creep Fatigue assessment of complex 3D structures. At the time of the 2016 Q1 EDDI workshop, this tool was only applicable to the assessment of Eurofer to the ASME design code using ANSYS. Further updates of this tool have been carried out in 2016, it must be noted that these further developments have not yet been assessed.

The aforementioned member of the BB team has highlighted that the tool was easy to use and that the guidance that came with it was clear and easy to understand. However, a few areas of useful development were highlighted, these being:

* Inclusion of RCC-MRx rules.
* Include a worked example demonstrating the inner calculations the tool carries out, thus also demonstrating CODE compliance.
* The possibility of defining class lines outside of the tool.

## Assess the possibility of making the DDC both ANSYS and ABAQUS compatible

The possibility of making the DDC both ANSYS and ABAQUS compatible, is not only possible, but could be perceived as being essential as both packages are extensively used within the DEMO project.

However, ensuring that the DDC is compatible with both ANSYS and ABAQUS may require additional effort to ensure an appropriate level of validation and testing is achieved before the DDC is officially released. This additional resource may not be readily available and even if it was it may well be more effectively utilised in the development of the DDC itself.

As such it is recommended that the DDC should be primarily developed to be aligned with ANSYS. Once a design rule has been successfully validated, tested and released to work with ANSYS, it should then be developed to be ABAQUS compatible.

## Complete the DDC structure and release

### Structure

The DDC has evolved from being one document to consisting of 5 parts. This change was partially inspired by the EN13445 standard where a similar structure is adopted. However, the main driver was to make the development of the DDC more manageable, as separate parts can be developed by different people in parallel.

The DDC consist of the following parts:

Part 1: General Information: *providing required background information, including definitions, load classifications, operating conditions, damage mechanism descriptions and design assessment philosophy.* [1]

Part 2: Design Assessment: *providing required operating conditions, including definitions, load classifications, operating conditions, damage mechanism descriptions and design assessment philosophy.* [2]

Part 3: Material Data: *the required physical property data along with the associated design allowable.* [3]

Part 4: Example Calculations: *design assessment of a DEMO PFC is presented, demonstrating how an assessment should be carried out using ANSYS.* [4]

Part 5: Rule Justifications: *explanations provided for why new or modified rules are adopted in the DDC.* [5]

It must be noted that although the DDC structure has been put in place, none of the parts are complete, each containing varying degrees of information and content. However, the first issue of the DDC structure is ready to be reviewed. Following a review from key members of the DEMO community (EDDI, DIV, BB, IND), the DDC shall be updated and released. This DDC structure should then be ready to be populated by the individuals who are developing design rules, however this shall still be supported by a DDC editor to ensure a level of consistency is maintained throughout the documentation. The status of the DDC Structure review process can be seen in Table 1. More details of the design rule development status can be seen in section 2.4.3.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DDC** | **Draft v1** | **Reviewed** | **Updated** | **Released** |
| **Part 1** | Structure complete | 30th November | 31st December | 31st December |
| **Part 2** | Structure complete | 30th November | 31st December | 31st December |
| **Part 3** | Structure complete | 30th November | 31st December | 31st December |
| **Part 4** | Structure complete | 30th November | 31st December | 31st December |
| **Part 5** | Structure complete | 30th November | 31st December | 31st December |

Table : DDC Structure Status, (KEY: Complete, In progress)

### Damage Mechanisms

It is likely that PFC’s shall consist of 3 key elements:

* Structure
* Armour
* Joint

The DDC shall contain design rules for the damage mechanisms listed in Table 2. It must be noted that in 2016 a review of Armour and Joint assessments has been initiated. As a result, an indication of Armour and Joint relevant damage mechanisms has been provided, however this assessment was not definitive and hence is subject to change.

|  |  |  |  |
| --- | --- | --- | --- |
| **Damage Mechanisms** | **Structural Element** | **Armour Element** | **Joint Element** |
| **Monotonic Damage** |  |  |  |
| Plastic Collapse |  | Potentially relevant | n/a |
| Plastic Flow Localisation |  | Potentially relevant | n/a |
| Exhaustion of Ductility |  | Potentially relevant | n/a |
| Brittle Fracture |  |  | Potentially relevant |
| Thermal Creep |  | Potentially relevant | n/a |
| **Cyclic Damage** |  |  |  |
| Ratcheting |  | n/a | Potentially relevant |
| Fatigue |  |  |  |
| **Environmental Damage** |  |  |  |
| Swelling |  | n/a | Potentially relevant |
| Corrosion |  | n/a | Potentially relevant |
| Erosion |  |  | Potentially relevant |
| **Compound Damage** |  |  |  |
| Stress Corrosion Cracking |  | n/a | Potentially relevant |
| Creep Fatigue |  | Potentially relevant | n/a |

Table : Identified PFC damage mechanisms (KEY: Relevant, Potentially relevant), note: this table is preliminary and is subject to change.

### Rule Development Status

In the first instance the DDC shall only be providing design rules that utilise non-linear modelling techniques. As such, it is recommended that a formal non-linear design rule gap analysis is carried out in 2017.

In the absence of a formal gap analysis, the DDC has initiated the population of design rules within Part 2 (Design Assessment) of the DDC. However, it must be noted that any rules that have been placed within the DDC are merely an indication of structure the design rules need to follow. The finalisation of design rule content shall involve the Damage Mechanism Experts (DME’s) involved in developing the non-linear design rules.

All of the design rules within the DDC shall be one of the following:

* Appropriate Non-Linear design rule from existing nuclear C&S, referenced and re-written to align with the DDC design rule structure.
* Existing Non-Linear design rule from existing nuclear C&S with technical modifications, and re-written to align with the DDC design rule structure.
* New Non-Linear design rule developed by the DDC team.

The current status of the DDC design rules for the assessment of a structural element can be seen in Table 3.

|  |  |  |  |
| --- | --- | --- | --- |
| **Damage Mechanisms** | **From existing C&S, rewritten.** | **From existing C&S, with technical modifications.** | **Newly developed** |
| **Monotonic Damage** |  |  |  |
| Plastic Collapse | ASME VIII rule identified, needs load factors and review. |  |  |
| Plastic Flow Localisation |  | Drafted, Under development |  |
| Exhaustion of Ductility |  | Drafted, Under development |  |
| Brittle Fracture | Drafted, needs to be reviewed by DME |  |  |
| Thermal Creep | Drafted, needs to be reviewed by DME. |  |  |
| **Cyclic Damage** |  |  |  |
| Ratcheting |  |  | Under Development |
| Fatigue |  | Under Development,  needs to be drafted by DME | Under Development |
| **Environmental Damage** |  |  |  |
| Swelling |  |  |  |
| Corrosion |  |  |  |
| Erosion |  |  |  |
| **Compound Damage** |  |  |  |
| Stress Corrosion Cracking |  |  |  |
| Creep Fatigue |  | Under Development, needs to be drafted by DME |  |

Table : Status of Structural Element design rules within the DDC (KEY: Released, Under development)

### DDC Formal Review

Now that a draft structure is in place, a formal review needs to be carried out to ensure that all interested parties are happy with the direction of the DDC development. Currently, it is recommended that the reviewers should only focus on the DDC structure and planned content. Technical details such as philosophy and design rules shall be reviewed initially by appropriate members of the EDDI team and an industrial partner.

The following table details the aspects of the DDC that need to be reviewed, and a suggestion of an appropriate person.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **DDC Aspect** | **EDDI** | **DIV** | **BB** | **IND** |
| **Philosophy** | Mike Fursdon  Jarir Aktaa |  |  | AMECFW |
| **Structure** | Mike Fursdon  Jarir Aktaa | Jeong Ha | Giacomo Aiello | AMECFW |
| **Content** | Mike Fursdon  Jarir Aktaa | Jeong Ha | Giacomo Aiello | AMECFW |
| **Design Rules** | Mike Fursdon  Jarir Aktaa |  |  |  |

Table : DDC Review participants (KEY: Completed, In progress)

### Advanced Structural Integrity Assessment techniques

The DDC is an opportunity to push the boundaries of Structural Integrity assessment techniques, particularly in areas where a potential increase in design space can be demonstrated. One area of potential improvement is the adoption of limit state assessment techniques. This is currently under investigation by AMECFW and the results of this investigation will be available in the first quarter of 2017. This study shall have an impact on the future development direction of the DDC and in particular the definition of load factors for each damage mechanism.

Another area of potential advancement is the adoption of a fully probabilistic system based code. ASME has made some progress in this area with the development of risk informed methodology (RIM – Reliability and Integrity Management). It is recommended that this is investigated further in 2017, primarily to determine if the adoption of such techniques would be advantageous to DEMO and if so, how could they be adopted by the DDC.

# Conclusion & Recommendations

The DDC now consists of a draft structure that is partially populated. This structure now needs to be reviewed to ensure that all interested parties are in agreement with the direction the DDC is going. The population of the DDC shall occur as and when design rules are developed to a state where they have been validated, tested and are ready for designers to use.

The following recommendations are made for the future development of the DDC:

* Produce a DDC strategy document with timescales that are aligned with the DEMO roadmap.
* The DME’s need to take ownership of their associated design rules within the DDC.
* The findings from the Limit State assessment should be taken forward and implemented into the DDC strategy.
* The possibility of utilising the RIM methodology should be reviewed.
* The DME’s should ensure that their damage mechanism covers the assessment of all three elements of a PFC (if relevant).
* The DME’s need to account for the complete lifecycle of a component (start of life to end of life).
* The development of all damage mechanisms (currently in progress) needs to continue as none are yet ready for release.
* The Creep Fatigue Assessment tool needs to allow to possibility to use RCC-MRx design rules, thus making it useful to the BB community.
* Engage key SDO’s and build collaborative efforts.

It must be noted, that at the time of writing, all of the activities being carried out within the DDC project had not been reviewed. As such, some additional recommendations may be raised at a later date.

# References

|  |  |
| --- | --- |
| [1] | CCFE, “DDC Part 1 General Information v1.0,” 2016. |
| [2] | CCFE, “DDC Part 5 Rule Justification v1.0,” 2016. |
| [3] | CCFE, “DDC Part 4 Example Calculaltions v1.0,” 2016. |
| [4] | CCFE, “DDC Part 3 Material Data v1.0,” 2016. |
| [5] | CCFE, “DDC Part 2 Design v1.0,” 2016. |

1. One *Deliverable Report* shall be submitted for each deliverable e.g. Study Report, Commissioning Report, Final Assessment Report, Technical Acceptance Report, Procurement Report, etc. [↑](#footnote-ref-1)