Memorandum

idm@F4E Ref:	F4E_D_ 2KGUF6 v.1.0	**Date**	2020-03-17

Subject:	**SCD-IC Material Library for ANSYS**

From:	**Miguel Gonzalez**
Department:	A&C / Engineering Unit / ITER Department
Contact	miguel.gonzalez@f4e.europa.eu

To:	**Everybody interested**

In order to keep F4E Analysis and Codes capabilities up-to-date with the latest, state-of-the-art method and pre-processing tools, a practical tool called "SDC-IC_Mat_Lib.mac" has been developed.

The tool is an ANSYS APDL based script able to generate material properties characteristics, in SI units, for all the different materials (irradiated and unirradiated) contained in [1].

This has been developed in order to centralize the SDC-IC material properties in a single routine and help to tackle an inherent step in any analysis process as it is the material properties definition.

To conclude, the tool has been verified and recorded in this document.

What "SDC-IC_Mat_Lib.mac" does

Capabilities of SDC-IC_Mat_Lib are the following ones:

- Definition of properties for the material model according [1].
- Definition of other properties according [1].

Definition of properties for the material model:

The properties for the material model are included in the material model that ANSYS use to describe the behavior of the material. These are:

- ALPX- Mean average or secant coefficient of thermal expansion
- CTEX- Instantaneous coefficient of thermal expansion
- EX- Young Modulus
- PRXY- Poisson's ratio
- DENS- Mass density
- KXX- Conductivity
- C- Specific heat
- MELAS- Stress-strain elastic curves. Nonlinear structural, multilinear elastic.
- BISO- Isotropic hardening plasticity. Bilinear stress-strain curves.
- MISO- Isotropic hardening plasticity. Multilinear stress-strain curves.
- BKIN- Kinematic hardening plasticity. Bilinear stress-strain curves.
- KINH- Kinematic hardening plasticity. Multilinear stress-strain curves.

Definition of other properties:

The so called "other" properties are properties not included in the material model but which may be used for post-processing tasks. These are:

- SY_MIN - Minimum yield strength
- SY_AV - Average yield strength
- SU_MIN - Minimum tensile strength
- SU_AV - Average tensile strength
- SY_IRR_MIN - Minimum yield strength. Material irradiated
- SY_IRR_AV - Average yield strength. Material irradiated
- SU_IRR_MIN - Minimum tensile strength. Material irradiated
- SU_IRR_AV - Average tensile strength. Material irradiated
- ETOT_MIN - Minimum total elongation
- ETOT_AV - Average total elongation
- EUNIF_MIN - Minimum uniform elongation
- EUNIF_AV - Average uniform elongation
- ETOT_IRR_MIN - Minimum total elongation. Material irradiated
- ETOT_IRR_AV - Average total elongation. Material irradiated
- EUNIF_IRR_MIN - Minimum uniform elongation. Material irradiated
- EUNIF_IRR_AV - Average uniform elongation. Material irradiated
- STRAIN_RUPT_MIN - Minimum true strain at rupture
- STRAIN_RUPT_AV - Average true strain at rupture
- SM - Allowable stress intensity
- SMB - Design stress intensity for bolt materials
- SE_IRR - Allowable stress for the primary plus secondary membrane stress intensity dependent on temperature and neutron fluence. A value of 9.99E+020 indicates that there is no limit for that Dose and Temperature.
- FATIGUE_STRAIN - Fatigue curves for unirradiated material. Number of cycles - Strain amplitude (Strain/2).
- FATIGUE_STRESS - Fatigue curves for unirradiated material. Number of cycles - Stress amplitude (Stress/2).
- K_CYCL - Coefficient for cyclic stress - strain curves
- m - Coefficient for cyclic stress - strain curves

- K_v - Coefficient for cyclic stress - strain curves
- K_e - Coefficient for cyclic stress - strain curves

How to use SDC-IC Mat Lib

The SDC-IC_Mat_Lib tool operates through an ANSYS APDL code based macro. To be launched the user has to allocate the macro "SDC-IC_Mat_Lib.mac" in the corresponding ANSYS working folder.

The macro can be called as an usual ANSYS macro with the command *USE, Name, ARG1, ARG2, ARG3, ARG4,

Examples of use

1. The three lines below produce the same output:

*USE, SDC-IC_Mat_Lib.mac,'304L Stainless Steel',,'EX','C','ALPX','PRXY','KXX','DENS','MISO'

*USE, SDC-IC_Mat_Lib.mac,,101,'EX', 'ALPX','PRXY','KXX','DENS','MISO'

*USE, SDC-IC_Mat_Lib.mac,'304L Stainless Steel',101,'EX','ALPX','PRXY','KXX','DENS','MISO'

2. Defining material model properties and other properties:

*USE, SDC-IC_Mat_Lib.mac,,107,'ALPX','PRXY','KXX','DENS','BISO','SY_MIN_107','SU_MIN_107'

The list of steps for the use of the macro it's explained below.

1. Select MAT_NAME or MAT_NUMB corresponding to the desired material. Both variables are specified below in Figure 1. Only one of the two variables is needed, the other can be left blank.

   MAT_NAME input variable has to be a string parameter. MAT_NUMB input variable has to be a scalar parameter. The numbers of the material are fixed and this can't be changed.

   Only one material can be defined for each execution of the macro.

2. Select the desired properties to be defined in material model.

   The name of the properties is specified above in the section "Definition of properties for the material model ".

   General information about the properties can be found in the section below under the title "Properties for the material model" and "Other properties".

```
MAT_NUMB   -          MAT_NAME                    -          MAT_TAG

  101      -       304L Stainless Steel           -       MAT_SS304
  102      -       316L Stainless Steel           -       MAT_SS316
  103      -       316L (N-IG) Stainless Steel    -       MAT_SS316_NIG
  104      -       GRADE 660 Stainless Steel      -       MAT_SS660
  105      -       XM-19 Steel                    -       MAT_XM19
  106      -       Alloy 625                      -       MAT_ALLOY625
  107      -       Ti-6Al-4V Alloy                -       MAT_TI64
  108      -       Pure Copper                    -       MAT_CU
  109      -       Copper-Chromium-Zirconium Alloy -      MAT_CUCRZR
  110      -       Dispersion-Strengthened Copper -       MAT_CUAL25=110
  111      -       Aluminium-Nickel Bronze        -       MAT_ALNIBRZ
  112      -       Alloy 718                      -       MAT_INCONEL718
  113      -       Beryllium                      -       MAT_BERYLLIUM
  114      -       Tungsten                       -       MAT_TUNGSTEN
  115      -       CFC EU Grade                   -       MAT_CFC_EU
  116      -       CFC CX-2002U Grade             -       MAT_CFC_CX
```

Figure 1: List of Materials

SDC-IC Mat Lib verification process

The macro (SDC-IC_Mat_Lib.mac) has been developed following a script based procedure which allows extracting the material properties from the original Word file for SDC-IC [1]. Then these properties are placed inside an excel file with a specific format which allows the conversion of this file into the final APDL macro using a Python script.
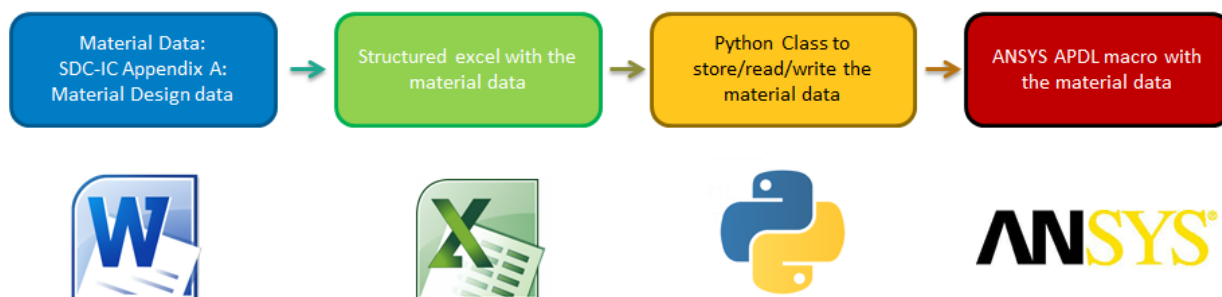

Figure 2: Procedure to generate SDC-IC_Mat_Lib.mac

This procedure aims to reduce the errors (typos, mixing values…) and to automatize as much as possible the generation of the final APDL script.

On top of this measurement to avoid errors, a verification of the material properties curves generated by this script has been performed. The material properties curves obtained in ANSYS, once this script is run, have been visually compared with the ones reported in [1].
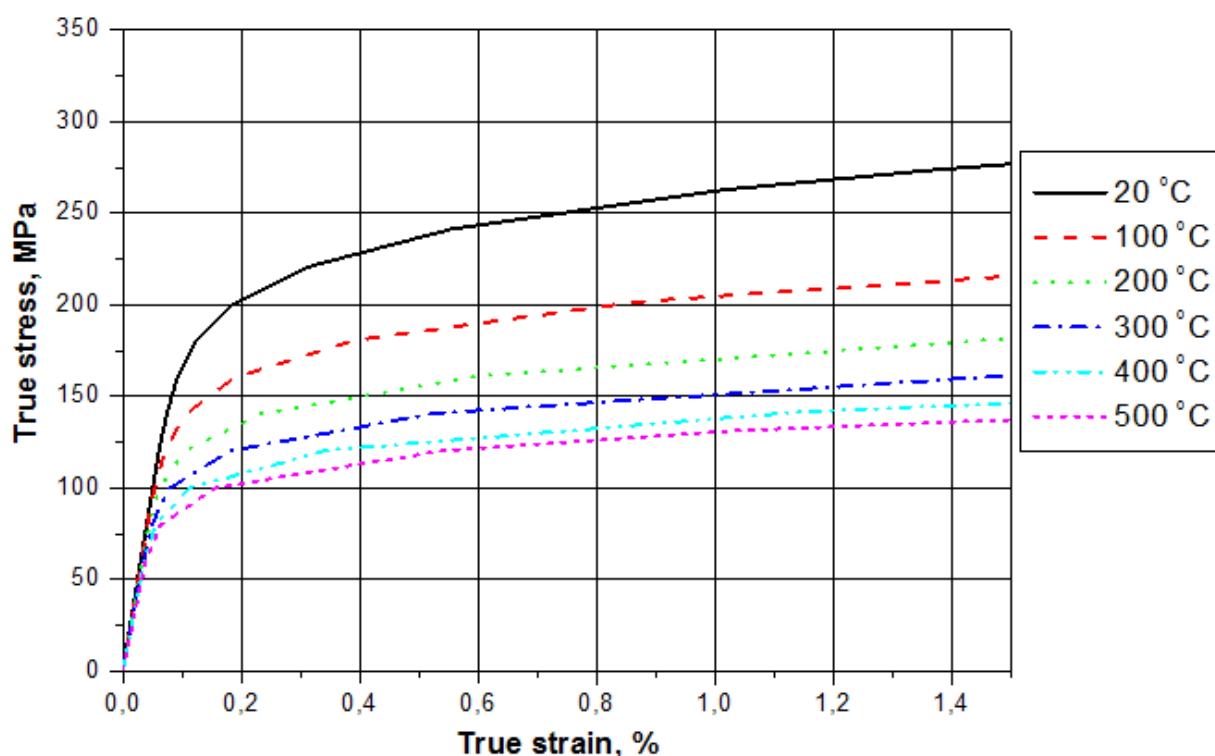

Figure 3: A.S03.3.1-1: Minimum true Stress-Strain Curves for SS 316L(N)-IG Steel – **Source: [1]**
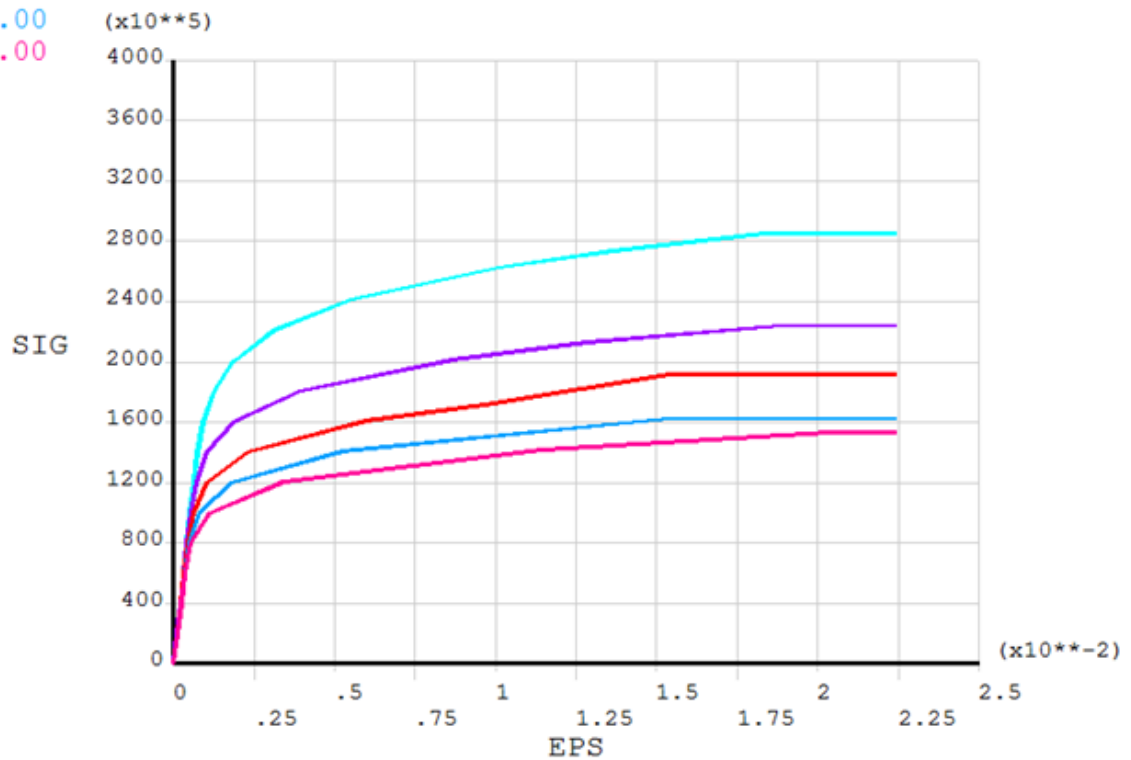
Figure 4: Minimum true Stress-Strain Curves for SS 316L(N)-IG Steel – **Source: APDL**

Recommendations and warnings
- Testing only done visually and in part of the material properties.
- I encourage to perform a in-depth review of the material properties assigned to the

Further developments
- Update according last SDC-IC version

Reference

1. SDC-IC In-vessel Components, Appendix A, Materials Design Limit Data, ITER_D_222RLN v3.2

Internal ⬤⬤🟢

Appendix 1. List of properties available for each material

101 - 304L Stainless Steel

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_101, SY_AV_101, SU_MIN_101, SM_101, FATIGUE_STRAIN_101, K_101, m_101, K_e_101, K_v_101

102 - 316L Stainless Steel

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_PIP_FORG_102, SY_AV_PIP_FORG_102, SY_MIN_FLAT_102, SY_AV_FLAT_102, SU_MIN_PIP_102, SU_MIN_FLAT_102, SM_102, FATIGUE_STRAIN_102, K_102, m_102, K_e_102, K_v_102

103 - 316L (N-IG) Stainless Steel

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_103, SY_AV_103, SU_MIN_103, SU_AV_103, EUNIF_MIN_103, EUNIF_IRR_MIN_103, EUNIF_AV_103, EUNIF_IRR_AV_103, ETOT_AV_103, ETOT_IRR_AV_103, STRAIN_RUPT_AV_103, SM_103, SE_IRR_103, FATIGUE_STRAIN_103, K_103, m_103, K_e_103, K_v_103

104 - GRADE 660 Stainless Steel

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_104, SY_AV_104, SU_MIN_104, SU_AV_104, ETOT_AV_104, STRAIN_RUPT_AV_104, SM_STRUCTURAL_104, SMB_NONLEAKTIGHT_JOINTS_104, SMB_LEAKTIGHT_JOINTS_104, FATIGUE_STRESS_104

105 - XM-19 Steel

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_105, SU_MIN_105, SM_105, SMB_NONLEAKTIGHT_JOINTS_105, SMB_LEAKTIGHT_JOINTS_105, FATIGUE_STRESS_105

106 - Alloy 625

Material model properties: ALPX, EX, PRXY, DENS, KXX, C

Other properties: SY_MIN_106, SU_MIN_106, SM_106

107 - Ti-6AI-4V Alloy

Material model properties: ALPX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_107, SY_AV_107, SU_MIN_107, SU_AV_107, EUNIF_MIN_107, ETOT_MIN_107, STRAIN_RUPT_AV_107, SM_107, SE_107

108 - Pure Copper

Material model properties: ALPX, EX, PRXY, DENS, KXX, C, MELAS_TUBE, MELAS_PLATE, MELAS_ROD ,BISO_TUBE, BISO_PLATE, BISO_ROD, MISO_TUBE, MISO_PLATE, MISO_ROD, BKIN_TUBE, BKIN_PLATE, BKIN_ROD, KINH_TUBE, KINH_PLATE, KINH_ROD

Other properties: SY_MIN_PLATE_108, SY_MIN_TUBE_108, SY_MIN_ROD_108, SU_MIN_108, EUNIF_AV_108, ETOT_AV_108, STRAIN_RUPT_AV_108, SM_PLATE_108, SM_TUBE_108, SM_ROD_108, FATIGUE_STRAIN_108

109 - Copper-Chromium-Zirconium Alloy

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C, MELAS_B, MELAS_C , BISO_B, BISO_C, MISO_B, MISO_C, BKIN_B, BKIN_C, KINH_B, KINH_C

Other properties: SY_MIN_A_109, SY_IRR_MIN_A_109, SY_MIN_B_109, SY_AV_B_109, SY_IRR_MIN_B_109, SY_MIN_C_109, SU_MIN_A_109, SU_IRR_MIN_A_109, SU_MIN_B_109, SU_AV_B_109, SU_IRR_MIN_B_109, SU_IRR_AV_B_109, SU_MIN_C_109, SU_IRR_MIN_C_109, STRAIN_RUPT_A_AV_109, STRAIN_RUPT_B_AV_109, STRAIN_RUPT_C_AV_109, SM_A_109, SM_IRR_A_109, SE_IRR_A_109, SM_B_109, SM_IRR_B_109, SE_IRR_B_109, SM_C_109, FATIGUE_STRAIN_109, K_e_109, K_v_109

110 - Dispersion-Strengthened Copper

Material model properties: ALPX, CTEX, EX, PRXY, DENS, KXX, C

Other properties: SY_MIN_110, SY_IRR_MIN_110, SY_AV_110, SY_IRR_AV_110, SU_MIN_110, SU_IRR_MIN_110, SU_AV_110, SU_IRR_AV_110, EUNIF_AV_110, EUNIF_IRR_MIN_110, STRAIN_RUPT_AV_110, SM_110, SM_IRR_110, FATIGUE_STRAIN_110

111 - Aluminium-Nickel Bronze

Material model properties: ALPX, EX, PRXY, DENS, KXX, C, MELAS_BAR, MELAS_PLATE, MELAS_FORG ,BISO_BAR, BISO_PLATE, BISO_FORG, MISO_BAR, MISO_PLATE, MISO_FORG, BKIN_BAR, BKIN_PLATE, BKIN_FORG, KINH_BAR, KINH_PLATE, KINH_FORG

Other properties: SY_MIN_BAR_111, SY_MIN_PLATE_111, SY_MIN_FORG_111, SU_MIN_111, EUNIF_MIN_111, EUNIF_AV_111, EUNIF_IRR_MIN_111, ETOT_MIN_111, ETOT_AV_111, ETOT_IRR_MIN_111, STRAIN_RUPT_MIN_111, SM_BAR_111, SM_PLATE_111, SM_FORG_111, FATIGUE_STRAIN_111

112 - Alloy 718

Material model properties: ALPX, EX, PRXY, DENS, KXX, C, MELAS, BISO, MISO, BKIN, KINH

Other properties: SY_MIN_112, SY_AV_112, SU_MIN_BOLT_112, SU_MIN_PLATE_112, SU_AV_112, EUNIF_AV_112, ETOT_AV_112, STRAIN_RUPT_AV_112, SM_PLATE_STRUCTURAL_112, SM_BAR_FORG_STRUCTURAL_112, SMB_BAR_NONLEAKTIGHT_JOINTS_112, SMB_BAR_LEAKTIGHT_JOINTS_112, SM_IRR_PLATE_STRUCTURAL_112, SMB_IRR_BAR_NONLEAKTIGHT_JOINTS_112, SMB_IRR_BAR_LEAKTIGHT_JOINTS_112, FATIGUE_STRESS_112

113 - Beryllium

Material model properties: ALPX, EX, PRXY, DENS, KXX, C

Other properties: SY_AV_113, SU_AV_113, EUNIF_AV_113, ETOT_AV_113

Internal ◖○○●

114 - Tungsten

Material model properties: ALPX, EX, PRXY, DENS, KXX, C

Other properties: SY_STRESSRELIEVED_AV_114, SY_RECRISTALIZED_AV_114, SU_STRESSRELIEVED_AV_114, SU_RECRISTALIZED_AV_114, EUNIF_AV_114, ETOT_STRESSRELIEVED_AV_114, ETOT_ANNEALED_AV_114, STRAIN_RUPT_AV_114

115 - CFC EU Grade

Material model properties: ALPX, ALPY, ALPZ, PRXZ, PRXY, PRYZ, DENS, KXX, KYY, KZZ, C

116 - CFC CX-2002U Grade

Material model properties: DENS, KXX, KYY, KZZ, C

Internal ⦿○●