Operator `POST_FATIGUE`

1 Drank

Compute, in a point, the damage of fatigue of a structure subjected to a load history.

Unlike `CALC_FATIGUE`, `POST_FATIGUE` does not operate on a field but on a "signal" extracted beforehand from a computation or defines in addition.

The various methods available [R7.04.01] are:

methods based on uniaxial tests: methods of Wöhler, Manson-Whetstone sheath and Taheri
These methods have as a common point to determine a value of damage from the evolution during the characterizing time of a scalar component, for the computation of the damage, the stress state or of structural deformations. With this intention, it is necessary to extract, by a method of counting of cycles, the elementary cycles of loading undergone by structure, to determine the elementary damage associated with each cycle and to determine the total damage by a rule of linear office plurality,
method of Lemaître generalized
This method makes it possible to calculate the damage (of Lemaître or Lemaître-Sermage) from the data of the tensor of the stresses and of the cumulated plastic strain,
criteria of fatigue multiaxial
These criteria apply to uniaxial or multiaxial loadings periodic or NON-periodicals. They provide a value of criterion indicating if there is damage or not, and also values of the damage and number of cycle to the fracture.

The command produces a concept of the type `counts`.

2 Syntax

```
tabl_post_fatig = POST_FATIGUE    (

#si loading purely uniaxial (or considered as uniaxial)

    ♦/CHARGEMENT      = "UNIAXIAL",

        ♦HISTOIRE=        _F  (
                               ♦/SIGM      =  histsigm/      [function]
                                                         /   [formula]
                                  /EPSI    =  histepsi/      [function]
                                                         /   [formula]
                            ),

        ♦   COMPTAGE=/              "RAINFLOW",
                          /  "RAINFLOW_ MAX ",
                          /  "RCCM",
                          /  "NATUREL",

        ◊DELTA_OSCI=/delta            ,                       [R]
                          /0  . ,                          [DEFAULT]

        ◊COEF_MULT    = _F   ( ♦KT   =  kt   ),               [R]

        ◊            CORR_KE=' RCCM',

        ◊DOMMAGE=/                  "WOHLER",
                          /  "MANSON_COFFIN",
                          /  "TAHERI_MANSON",
                          /  "TAHERI_MIXTE",

        ◊   MATER=mater            ,

        ◊   CORR_SIGM_MOYE=/       "GOODMAN",
                             /  "GERBER"  ,

        ◊   TAHERI_NAPPE=fnappe        ,                   /[three-
dimensions function]
                                                           /[formula]
        ◊TAHERI_FONC=ffonc             ,                   /[function]
                                                           /[formula]

                          ◊CUMUL=' LINEAIRE',
```

```
#si periodic loading (for fatigue with great numbers of cycles and for periodic cycles)

    ♦/CHARGEMENT      = "MULTIAXIAL",

        ♦    TYPE_CHARGE=/          "PERIODIQUE",
                            /   "NON_PERIODIQUE",

        ♦HISTOIRE  = _F   (
                            ◊SIGM_XX    =  fxx  ,          /[function]
                                                           /[formula]
                            ◊SIGM_YY    =  fyy  ,          /[function]
                                                           /[formula]
                            ◊SIGM_ZZ    =  fzz  ,          /[function]
                                                           /[formula]
                            ◊SIGM_XY    =  fxy  ,          /[function]
                                                           /[formula]
                            ◊SIGM_XZ    =  fxz  ,          /[function]
                                                           /[formula]
                            ◊SIGM_YZ    =  fyz  ,          /[function]
                                                           /[formula]

                            ◊EPS_XX     =  fxx  ,          /[function]
                                                           /[formula]
                            ◊EPS_YY     =  fyy  ,          /[function]
                                                           /[formula]
                            ◊EPS_ZZ     =  fzz  ,          /[function]
                                                           /[formula]
                            ◊EPS_XY     =  fxy  ,          /[function]
                                                           /[formula]
                            ◊EPS_XZ     =  fxz  ,          /[function]
                                                           /[formula]
                            ◊EPS_YZ     =  fyz  ,          /[function]
                                                           /[formula]

                            ◊EPSP_XX    =  fxx  ,          /[function]
                                                           /[formula]
                            ◊EPSP_YY    =  fyy  ,          /[function]
                                                           /[formula]
                            ◊EPSP_ZZ    =  fzz  ,          /[function]
                                                           /[formula]
                            ◊EPSP_XY    =  fxy  ,          /[function]
                                                           /[formula]
                            ◊EPSP_XZ    =  fxz  ,          /[function]
                                                           /[formula]
                            ◊EPSP_YZ    =  fyz  ,          /[function]
                                                           /[formula]
                        )

        ◊MATER=mater              ,                         [to
subdue]

        ◊DOMMAGE    =     "WOHLER",
                        /  "MANSON_C",
                        /  "FORM_VIE",

            # If DOMMAGE = "FORM_VIE"
            ♦FORMULE_VIE  = for_vie,                  /  [formula]
                                                      /  [function]
```

```
          # Finsi

        ◊COEF_CORR=/corr              ,                              [R]
        ◊COEF_PREECROU        =   co_pre   ,                         [R]
                           / 1. ,                                [DEFAULT]

    # If TYPE_CHARGE = "PERIODIQUE"

        ♦CRITERE=/                  "MATAKE_MODI_AC",
                           /   "DANG_VAN_MODI_AC",
                           /   "FORMULE_CRITERE",
                           /   "CROSSLAND",
                           /   "PAPADOPOULOS",

        ◊METHODE=/                  "CERCLE_EXACT",

        # If CRITERE = "FORMULE_CRITERE"

          ♦FORMULE_GRDEQ         =for_grd   ,                        /
    [formula]
        # Finsi

    # Finsi

    # If TYPE_CHARGE = "NON_PERIODIQUE"

        ♦   CRITERE=/           "MATAKE_MODI_AV",
                           /   "DANG_VAN_MODI_AV",
                           /   "FATESOCI_MODI_AV",
                           /   "FORMULE_CRITERE",

        ♦PROJECTION=/           "UN_AXE",
                           /   "DEUX_AXES",

        ◊DELTA_OSCI=/delta            ,                        [R]
                           /0  . ,                         [DEFAULT]
        # If CRITERE = "FORMULE_CRITERE"

          ♦FORMULE_GRDEQ         =for_grd   ,                        /
    [formula]
        # Finsi

    # unspecified

  Finsi
```

```
#Finsi #si loading (damage of Lemaitre or Lemaitre-Sermage)
♦/CHARGEMENT      = "QUELCONQUE",
      ♦HISTOIRE  = _F   (
                          ♦SIGM_XX    =  fxx  ,           /[function]
                                                          /[formula]
                          ♦SIGM_YY    =  fyy  ,           /[function]
                                                          /[formula]
                          ♦SIGM_ZZ    =  fzz  ,           /[function]
                                                          /[formula]
                          ♦SIGM_XY    =  fxy  ,           /[function]
                                                          /[formula]
                          ◊SIGM_XZ    =  fxz  ,           /[function]
                                                          /[formula]
                          ◊SIGM_YZ    =  fyz,             /[function]
                                                          /[formula]
                          ♦EPSP       =  p,               /[function]
                                                          /[formula]
                          ♦TEMP       =  temp  ,          /[function]
                                                          /[formula]
                        )
      ◊DOMMAGE=          "LEMAITRE",
      ♦MATER=mater              ,
                        ◊CUMUL=' LINEAIRE',
#Finsi
      ◊INFO=/1                  ,                          [DEFAULT]
                          /2  ,
      ◊TITER=titer                                         [l_Kn]
                                    )
```

3 Operands

3.1 Operand CHARGEMENT

This key word makes it possible to the user to specify the type of treated loading. The loading can be "UNIAXIAL", "MULTIAXIAL" or "QUELCONQUE". To each loading corresponds its (or its) method (S) of evaluating of the damage by fatigue.

Note: When the loading is muti-axial, it is enough to give the history of the loading over one period or a block of the neck-cycles. If the loading is unspecified, it is necessary to provide the group of the history of the loading.

3.2 Operands specific to the computation of the type UNIAXIAL

3.2.1 Operand HISTOIRE

the load history can be the evolution of a value of stress or of uniaxial strain in the course of time,

Note:

That does not mean that the loading cannot be multiaxial, but only that for the computation of the damage, the loading is characterized by the evolution of a scalar component, in the course of time (Von-Put signed, invariant of a signed nature 2,…). It is the evolution of this scalar component which the user must provide to command POST_FATIGUE .

3.2.1.1 Operand SIGM

◊SIGM = histsigm,

Name of the function or the formula describing the history of the loading in stresses in a point. It is a function or a formula of the parameter INST, which gives the evolution during the time of a scalar component characterizing the stress state of structure.

This operand is compulsory for the computation of the damage by a method of WOHLER.

3.2.1.2 Operand EPSI

◊EPSI = histepsi,

Name of the function or the formula describing the history of the loading in strains in a point. It is a function or a formula of the parameter INST, which gives the evolution during the time of a scalar component characterizing the strain state of structure.

This operand is compulsory for the computation of the damage by the methods of MANSON_COFFIN or TAHERI_MANSON or TAHERI_MIXTE .

3.2.2 Operand COMPTAGE

♦COMPTAGE =

to be able to calculate the damage undergone by a structure, it is necessary beforehand to extract the elementary cycles from the load history. For that of many methods are available. In *Code_Aster*, three methods were programmed.

/ "RAINFLOW",

Method of counting of the extents in cascade or method of RAINFLOW (recommendation AFNOR A03-406 of November 1993) for the extraction of the elementary cycles of the load history [R7.04.01].

/ "RAINFLOW_MAX",

This method is similar to that of Rainflow excludes the fact that the elementary cycle whose amplitude is maximum is placed at the beginning of the load history to take into account effects of the overloads.

/ `“RCCM”,`

Method of the RCC-M [R7.04.01].

/ `“NATUREL”,`

Method known as natural which consists in generating the cycles in the order of their application [R7.04.01].

In the special case where the load history is constant (for example, average loading applied), Code_Aster null will count the whole load history like a cycle of amplitude.

3.2.3 Operand `DELTA_OSCI`

`◊DELTA_OSCI = delta,`

Filtering of the history of the loading. In all the cases, if the function remains constant or decreasing on more than two consecutive points one removes the intermediate points to keep only the two extreme points. Then, one removes load history the points for which the variation of the value of the stress is lower than the value `delta`. By default `delta` is equal to zero, which amounts keeping all the oscillations of the loading, even those of low amplitude.

It is noted that if key word `COEF_MULT` and `DELTA_OSCI` are all present, Code_Aster will initially apply `COEF_MULT` and then `DELTA_OSCI.`

Example: Let us consider the following load history:

N° point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Loading	4.	7.	2.	10.	9.6.9.8		5.	9.	3.	4.	2.	2.4.2.2		12.	5.
N° point	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
Time	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	
Loading	11.	1.	4.	3.	10.	6.	8.	12.	4.	8.	1.	9.	4.	6.	

The extraction of the peaks of this load history, with a value of $delta\ \ 0,9$ conduit to destroy all the oscillations of amplitude lower than 0,9. What leads to the following load history:

N° point	1	2	3	4	7	8	9	10	11	14	15	16	17	18	19
Time	0.	1.	2.	3.	6.	7.	8.	9.	10.	13.	14.	15.	16.	17.	18.
Loading	4.	7.	2.	10.	5.	9.	3.	4.	2.	12.	5.	11.	1.	4.	3.
N° point	20	21	23	24	25	26	27	28	29						
Time	19.	20.	22.	23.	24.	25.	26.	27.	28.						
Loading	10.	6.	12.	4.	8.	1.	9.	4.	6.						

One removed:

- item 5 because $\Delta\sigma=|\sigma(5)-\sigma(4)|<0,9$,
- item 6 because $\Delta\sigma=|\sigma(6)-\sigma(4)|<0,9$,
- item 12 because $\Delta\sigma=|\sigma(12)-\sigma(11)|<0,9$,
- the item 13 carformule $\Delta\sigma=|\sigma(13)-\sigma(11)|<0,9$.

In the same way the item 22 is removed because the load history is increasing between items 21,22 and 23 and thus one keep only the extreme points.

3.2.4 Key word COEF_MULT

◊COEF_MULT = _F

This key word factor gathers the coefficients of performance of the load history. For time, only one multiplying coefficient of the load history is available: the coefficient of stress concentration KT.

Values of the coefficient of stress concentration are available in the RCC_M.

3.2.4.1 Operand KT

◊KT = kt

kt is the coefficient of stress concentration which depends on the geometry of the part, the geometry of a possible default and type of loading. This coefficient is used to apply to the "filtered" load history a homothety of kt ratio.

It is noted that if key word COEF_MULT and DELTA_OSCI are all present, Code_Aster will initially apply COEF_MULT and then DELTA_OSCI.

3.2.5 Operand CORR_KE

◊ CORR_KE = "RCCM",

This operand makes it possible to take account of a coefficient of concentration elastoplastic, K_e which is defined by the RCC-M as being the relationship between the amplitude of real strain and the amplitude of strain determined by an elastic analysis.

$$\begin{cases} K_e=1 & \text{si} & & Ds < 3S_m \\ K_e=1+(1-n)\left(\dfrac{\Delta\sigma}{3.S_m}-1\right)/(n(m-1)) & \text{si} & 3S_m < & Ds < 3mS_m \\ K_e=1/n & \text{si} & 3mS_m < & Ds \end{cases}$$

where S_m is the acceptable maximum stress and n and m two constants depending on the material.

The values S_m, n and m are provided in operator DEFI_MATERIAU [U4.43.01] under the key word factor TIRES and the operands SM_KE_RCCM, N_KE_RCCM and M_KE_RCCM.

3.2.6 Operand DOMMAGE

To compute: the damage undergone by a structure in a point, various methods are available [R7.04.01]. Methods based on uniaxial tests: method of Wöhler, method of Manson-Whetstone sheath, methods of Taheri. These methods have as a common point to determine a value of damage from the evolution during the time of **a scalar component** characterizing the stress state or of structural deformation.

That does not mean that the stress state cannot be multiaxial, but only that for the computation of the damage one chose a uniaxial component characterizing the stress state or of strain (forced Von-Put signed, invariant of a nature 2 signed of the tensor of the strains,…).

The methods of Manson-Whetstone sheath and Taheri use the strains generated by the loading.

The method of Wöhler uses the stresses generated by the loading.

◊`DOMMAGE = "WOHLER",`

For a history of stresses associated with a uniaxial loading, the number of cycles to the fracture is given using the curve of Wöhler of the material $\left(N_{rupt}=\mathrm{WOHLER}\left(\frac{\Delta\sigma}{2}\right)\right)$.

The curve of Wöhler of the material must be introduced into operator `DEFI_MATERIAU` [U4.43.01] under one of the three possible mathematical forms [R7.04.01]:

- point by point discretized function (key word factor `TIRES`, operand `WOHLER`),
- analytical form of Basquin (key word factor `TIRES`, operands `A_BASQUIN` and `BETA_BASQUIN`),
- form "zones current" (key word factor `TIRES`, operands `E_REFE`, `A0`, `A1`, `A2`, `A3` and `SL` and key word factor `ELAS` operand `E`).

Notice on the curves of fatigue:

For the small amplitudes of stresses, the difficulty of the prolongation of the curve of fatigue can arise: for example, for the curves of fatigue of the RCC-M beyond 10^6 cycles, the corresponding stress, $180\,MPa$ is regarded as limit of endurance, i.e. very forced lower than $180\,MPa$ must produce a factor of null use or an infinite number of cycles acceptable. The method adopted here corresponds to this notion of limit of endurance: if the amplitude of stress is lower than the first X-coordinate of the curve of fatigue, then one takes a factor of null use i.e. an infinite number of cycles acceptable.

◊`DOMMAGE = "MANSON_COFFIN",`

For a uniaxial load history of type strains, the number of cycles to the fracture is given using the curve of Manson-Whetstone sheath of the material $\left(N_{rupt}=\mathrm{MANSON\_COFFIN}\left(\frac{\Delta\varepsilon}{2}\right)\right)$.

The curve of Manson-Whetstone sheath of the material must be introduced into operator `DEFI_MATERIAU` [U4.43.01] (key word factor `TIRES`, operand `MANSON_COFFIN`).

◊`DOMMAGE = "TAHERI_MANSON",`

This méthode de calcul of the damage applies only to loadings in strains.

Are n elementary cycles (extracts by a method of counting) of half-amplitude $\frac{\Delta\varepsilon_1}{2},\cdots,\frac{\Delta\varepsilon_n}{2}$.

The value of the elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of the material.

The computation elementary damage of the following cycles is carried out by the algorithm described below:

- If $\frac{\Delta\varepsilon_{i+1}}{2}\geqslant\frac{\Delta\varepsilon_i}{2}$

  the computation of the elementary damage of the cycle $(i+1)$ is determined by interpolation on the curve of Manson-Whetstone sheath of the material,

- If $\frac{\Delta\varepsilon_{i+1}}{2}<\frac{\Delta\varepsilon_i}{2}$

  one determines:

$$\frac{\Delta\sigma_{i+1}}{2}=\text{Fnappe}\left(\frac{\Delta\varepsilon_{i+1}}{2},\underset{j<i}{\text{Max}}\left(\frac{\Delta\varepsilon_j}{2}\right)\right)$$

$$\frac{\Delta\varepsilon^*_{i+1}}{2}=\text{Ffonc}\left(\frac{\Delta\sigma_{i+1}}{2}\right)$$

where:

`Fnappe` is a three-dimensions function introduced under the operand `TAHERI_NAPPE`,

`Ffonc` is a function introduced under operand `TAHERI_FONC`.

The value of the damage of the cycle $(i+1)$ is obtained by interpolation of $\frac{\Delta\varepsilon^*_{i+1}}{2}$ on the curve of Manson-Whetstone sheath of the material.

$N_{rupt_{i+1}}$ the number of cycles to the fracture of the cycleformule $(i+1)$

$$N_{rupt_{i+1}}=\text{MANSON\_COFFIN}\left(\frac{\Delta\varepsilon^*_{i+1}}{2}\right)$$

and Dom_{i+1} is the damage of the cycle $(i+1)=\frac{1}{N_{rupt_{i+1}}}$.

The curve of Manson-Whetstone sheath of the material must be introduced into operator `DEFI_MATERIAU` [U4.43.01] (key word factor `TIRES`, operand `MANSON_COFFIN`).

◊DOMMAGE = "TAHERI_MIXTE",

This méthode de calcul of the damage applies only to loadings in strains.

Are n elementary cycles (extracts by a method of counting) of half-amplitude $\frac{\Delta\varepsilon_1}{2},\cdots,\frac{\Delta\varepsilon_n}{2}$.

The value of the elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of the material.

The computation elementary damage of the following cycles is carried out by the algorithm described Ci - below:

- If $\frac{\Delta\varepsilon_{i+1}}{2}\geqslant\frac{\Delta\varepsilon_i}{2}$

  the computation of the elementary damage of the cycle $(i+1)$ is determined by interpolation on the curve of Manson-Whetstone sheath.

- If $\frac{\Delta\varepsilon_{i+1}}{2}<\frac{\Delta\varepsilon_i}{2}$

  one determines:

$$\frac{\Delta\sigma_{i+1}}{2}=\text{Fnappe}\left(\frac{\Delta\varepsilon_{i+1}}{2},\underset{j<i}{\text{Max}}\left(\frac{\Delta\varepsilon_j}{2}\right)\right)$$

  where `Fnappe` is a three-dimensions function introduced under the operand of `TAHERI_NAPPE`.

The value of the damage of the cycle $(i+1)$ is obtained by interpolation of $\frac{\Delta\sigma_{i+1}}{2}$ on the curve of Wöhler of the material.

$N_{rupt_{i+1}}$ is the number of cycles to the fracture of the cycleformule $(i+1)$

$$N_{rupt_{i+1}}=\text{WOHLER}\left(\frac{\Delta\sigma_{i+1}}{2}\right)$$

and Dom_{i+1} is the damage of the cycle $(i+1)=\frac{1}{N_{rupt_{i+1}}}$.

This method requires the data of the curve of Wöhler and the curve of Manson - Whetstone sheath of the material which must be introduced into operator DEFI_MATERIAU [U4.43.01] (key word factor TIRES).

3.2.7 Operand MATER

♦MATER = to subdue,

Makes it possible to specify the name of the MATER material created by DEFI_MATERIAU [U4.43.01].

The MATER material must contain the values of all the data materials necessary to computation of the damage.

3.2.8 Operand CORR_SIGM_MOYE

```
◊ CORR_SIGM_MOYE =      "GOODMAN",
                     /  "GERBER"  ,
```

This operand is used only in the case of the computation of the damage by the method of WOHLER.

If the part is not subjected to pure or symmetric alternate stresses, it is - with - to say if the average constraint of the cycle is not null, one can balance the curve of Wöhler to compute: the number of effective cycles to the fracture using the diagram of Haigh [R7.04.01].

From a cycle (S_{alt},σ_m) identified in the signal, one calculates the value of the corrected alternate stress S'_{alt}.

If one uses the line of Goodman

$$S'_{alt}=\frac{S_{alt}}{1-\frac{\sigma_m}{S_u}}$$

If one uses the parabola To stack

$$S'_{alt}=\frac{S_{alt}}{1-\left(\frac{\sigma_m}{S_u}\right)^2}$$

when the material breaks the value of the limit S_u must be introduced into operator DEFI_MATERIAU [U4.43.01] (key word factor RCCM, opérande SU).

3.2.9 Operand TAHERI_NAPPE

◊ TAHERI_NAPPE = fnappe,

This operand makes it possible to specify the name of a three-dimensions function.

$\text{Fnappe}=\left(\frac{\Delta\varepsilon}{2},\varepsilon_{max}\right)$ with the computation of the damage by methods TAHERI_MANSON and TAHERI_MIXTE.

The three-dimensions function must have as parameters X and $EPSI$. The parameter X corresponds to the maximum strain reached during a possible pre-hardening.

The three-dimensions function introduced under operand TAHERI_NAPPE is the cyclic curve of hardening with pre-hardening of the material.

The cyclic curve of hardening without pre-hardening, given under key word TAHERI_FONC, must be obligatorily one of the curves defining the three-dimensions function. This curve must be given for $X=0$.

3.2.10 Operand **TAHERI_FONC**

◊TAHERI_FONC = ffonc,

This operand makes it possible to specify the name of a function $\text{Ffonc}=\left(\frac{\Delta\sigma}{2}\right)$ necessary to the computation of the damage by method TAHERI_MANSON .

The parameter of this function must be SIGM.

This function is the cyclic curve of hardening of the material.

3.2.11 Operand **CUMUL**

◊CUMUL = "LINEAIRE",

the methods of WOHLER, MANSON_COFFIN and TAHERI calculate a value of damage for each elementary cycle extracted the uniaxial loading introduced by the user.

Operand CUMUL makes it possible to require the computation of the total damage undergone by structure in a point.

The only rule available is the rule To mine, which consists in adding all the elementary damages $D=\sum_i D_i$.

3.3 Operands specific to the computation of the MULTIAXIAL type

3.3.1 Operand **TYPE_CHARGE**

This operand makes it possible to specify the type of loading applied to structure:

- PERIODIQUE, the loading are periodic;
- NON_PERIODIQUE, the loading are not periodical.

3.3.2 Operand **HISTOIRE**

This key word gathers all the phase of definition of the load history. The load history can be the evolution of the stress tensor, total deflection and plastic strain in the course of time.

It is noted that at least a type of the loading (forced, total deflection, plastic strain) must be provided. For a type of the tensor, it is necessary to provide you S the very six components.

In this operator, elastic strain = total deflection - plastic strain. For the criterion which requires the elastic strain, the request of the total deflection is compulsory . If the plastic strain is not informed, one will take zero value.

3.3.2.1 Operands **SIGM_XX/SIGM_YY/SIGM_ZZ/SIGM_XY/SIGM_XZ/SIGM_YZ**

Names of the functions or the formulas describing the history of each component of the tensor of the stresses in the course of time. Each function or formula depends on the parameter INST. All the functions or formulas must be defined for same times.

3.3.2.2 Operands EPS_XX/ EPS_YY/ EPS_ZZ/ EPS_XY/ EPS_XZ/ EPS_YZ

Names of the functions or the formulas describing the history of each component of the tensor of the total deflections in the course of time. Each function or formula depends on the parameter INST. All the functions or formulas must be defined for same times.

3.3.2.3 Operands EPSP_XX/ EPSP_YY/ EPSP_ZZ/ EPSP_XY/ EPSP_XZ/ EPSP_YZ

Names of the functions or the formulas describing the history of each component of the tensor of the total deflections in the course of time. Each function or formula depends on the parameter INST. All the functions or formulas must be defined for same times.

3.3.3 Operand CHAM_MATER

```
◊CHAM_MATER    = cham_mater
```

Makes it possible to specify the name of the field of the material cham_mater created by AFFE_MATERIAU [U4.43.03].

The MATER material defined with the command DEFI_MATERIAU and which is used for the assignment of the material to the mesh with command AFFE_MATERIAU must contain the definition of the curve of Wöhler as well as information necessary to the implementation of the criterion, to see the key keys factors TIRES and CISA_PLAN_CRIT of the command DEFI_MATERIAU [U4.43.01].

Key word CHAM_MATER is not compulsory when one uses a formula for the damage.

3.3.4 Operand COEF_PREECROU

```
◊COEF_PREECROU    =/coef_pre       ,
                    /1.0   ,
```

This coefficient is used to take into account the effect of a possible pre-hardening.

3.3.5 Operand COEF_CORR

```
◊COEF_CORR      =  corr,
```

the criteria of Crossland and Dang Van-Papadopoulos makes it possible for periodic loadings to calculate a value R_{crit} which indicates if there is damage or not for the number of cycles associated with the limits with endurances τ_0 and d_0.

These criteria do not give a value of the damage, which can however be interesting.

With this intention, one proposes to use the value of the criterion and the curve of Wöhler of the material, by defining an equivalent stress:

$$\sigma^* = \left(R_{crit} + b\right) \times \mathrm{corr}$$

Most curves of Wöhler are obtained with tests of alternate pure traction and compression. However the criterion of Dang-Van-Papadopoulos is a criterion in shears. Consequently, it is necessary "to correct" the equivalent stress σ^* before applying it to a curve of Wöhler obtained with tests of traction and compression; it is the role of operand COEF_CORR .

The value of the damage is obtained by applying σ^* to the curve of Wöhler of the material.

So that there is coherence between the criterion and the curve of Wöhler, it is necessary that:

$$\begin{cases} \sigma^* \le \tau_0 & \text{pas de dommage} \\ \sigma^* > \tau_0 & \text{dommage} \end{cases}$$

for a curve of Wöhler defined in shears and that:

$$\begin{cases} \sigma^* \le d_0 & \text{pas de dommage} \\ \sigma^* > d_0 & \text{dommage} \end{cases}$$

for a curve of Wöhler defined in traction and compression.

The user can thus specify a value `corr`, by taking account of the type of curve of Wöhler it has. The value taken by default for `COEF_CORR` is $\frac{d_0}{\tau_0}$, in coherence with curves of Wöhler in tension - compression.

Note:

If $R_{crit} < 0$, if the prolongation on the left of the curve of Wöhler is linear (in `DEFI_FONCTION (… PROL_GAUCHE = "LINEAIRE"…))`, the user will obtain a damage different from zero. To obtain a null damage when $R_{crit} < 0$, it is necessary that the prolongation on the left is equal to `"EXCLU"` or `"CONSTANT"` .

3.3.6 Operand CRITERE

```
♦CRITERE   =   /"MATAKE_MODI_AC",
               /"DANG_VAN_MODI_AC",
               /"MATAKE_MODI_AV",
               /"DANG_VAN_MODI_AV",
               /"FATESOCI_MODI_AV",
               /"FORMULE_CRITERE",
               /"CROSSLAND",
               /"PAPADOPOULOS",
```

the user introduces the values of each component of the tensor of the stresses into various instantsformule $(t_0, \ldots, t_N)$, and it is supposed that $[t_{0,} t_N]$ is one period of the loading.

The loadings can be stresses, total deflections, plastic strains or combinations of these parameters.

The following table lists criteria of starting available for two types of loadings.

TYPE_CHARGE = "PERIODIQUE"	TYPE_CHARGE = "NON_PERIODIQUE"
"MATAKE_MODI_AC" "DANG_VAN_MODI_AC" "FORMULE_CRITERE" "CROSSLAND" "PAPADOPOULOS"	"MATAKE_MODI_AV", "DANG_VAN_MODI_AV" "FATESOCI_MODI_AV" "FORMULE_CRITERE"

For the loading with constant amplitude, operand `CRITERE` makes it possible to specify the criterion which the half-amplitude will have to satisfy with maximum shears. For the loading with variable amplitude, operand `CRITERE` makes it possible to specify the criterion which will have to satisfy the maximum damage.

The criteria of starting in Code_Aster can be called by a name for the well established criteria. It is also possible for the user to build a criterion of starting by itself like a formula of predefined quantities.

Notation:

$\mathbf{n}^*$	:	norm with the plane in which the amplitude of shears is maximum;
$\Delta\tau(\mathbf{n})$	:	amplitude of shears in stress in a plane of norm $\mathbf{n}$;
$\Delta\gamma(\mathbf{n})$	:	amplitude of shears in strain in a plane of norm $\mathbf{n}$;
$N_{max}(\mathbf{n})$	:	normal maximum stress as regards norm $\mathbf{n}$;
τ_0	:	limit of endurance in alternate pure shears;
d_0	:	limit of endurance in alternate pure traction and compression;
P	:	hydrostatic pressure;
c_p	:	coefficient being used to take into account a possible pre-hardening;
σ_y	:	elastic limit.

Criterion `MATAKE_MODI_AC`

the initial criterion of MATAKE is defined by the inequation [éq.3.12-1]:

$$\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,N_{max}(\mathbf{n}^*)\le b \qquad \textbf{3.12-1}$$

where a and b are two constant data by the user under key keys `MATAKE_A` and `MATAKE_B` of the key word factor `CISA_PLAN_CRIT` of `DEFI_MATERIAU`, they depend on the characteristic materials and are worth:

$$a=\left(\tau_0-\frac{d_0}{2}\right)/\frac{d_0}{2} \qquad b=\tau_0$$

If the user has the results of two traction tests compression, alternated and the other not, the constant ones a and b are given by:

$$a=\frac{\Delta\sigma_2-\Delta\sigma_1}{(\Delta\sigma_1-\Delta\sigma_2)-2\sigma_m},$$
$$b=\frac{\sigma_m}{(\Delta\sigma_2-\Delta\sigma_1)+2\sigma_m}\times\frac{\Delta\sigma_1}{2},$$

with $\Delta\sigma_1$ the amplitude of loading for the alternate case $(\sigma_m=0)$ and $\Delta\sigma_2$ amplitude of loading for the case where the average constraint is non-zero $(\sigma_m\neq 0)$.

We modify the initial criterion of MATAKE by introducing the definition of an equivalent stress, noted $\sigma_{eq}(\mathbf{n}^*)$:

$$\sigma_{eq}(\mathbf{n}^*)=\left(c_p\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,N_{max}(\mathbf{n}^*)\right)\frac{f}{t},$$

where f/t represents the ratio of the limits of endurance in bending and alternating torsion, and must be well informed under key word `COEF_FLEX_TORS` of the key word factor `CISA_PLAN_CRIT` of `DEFI_MATERIAU`.

Criterion `DANG_VAN_MODI_AC`

the initial criterion of DANG VAN is defined by the inequation [éq 3.12-2]:

$$\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,P\le b \qquad \textbf{3.12-2}$$

where a and b are two constant data by the user under key keys `D_VAN_A` and `D_VAN_B` of the key word factor `CISA_PLAN_CRIT` of `DEFI_MATERIAU`, they depend on the characteristic materials. If the user has two traction tests compression, alternate other not the constant ones a and b are worth:

$$a=\frac{3}{2}\times\frac{\Delta\sigma_2-\Delta\sigma_1}{(\Delta\sigma_1-\Delta\sigma_2)-2\sigma_m} \qquad b=\frac{\sigma_m}{(\Delta\sigma_2-\Delta\sigma_1)+2\sigma_m}\times\frac{\Delta\sigma_1}{2}$$

with $\Delta\sigma_1$ the amplitude of loading for the alternate case $(\sigma_m=0)$ $\Delta\sigma_2$ and the case where the average constraint is non-zero $(\sigma_m\neq 0)$.

Moreover, we define an equivalent stress within the meaning of DANG VAN, noted $\sigma_{eq}(\mathbf{n}^*)$:

$$\sigma_{eq}(\mathbf{n}^*)=\left(c_p\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,P\right)\frac{c}{t}$$

where c/t represents the ratio of the limits of endurance in alternated shears and tension, and must be well informed under key word COEF_CISA_TRAC of the key word factor CISA_PLAN_CRIT of DEFI_MATERIAU.

For more information, to consult the document [R7.04.04].

Criterion MATAKE_MODI_AV

criterion MATAKE_MODI_AV is an evolution of the criterion of MATAKE. Contrary to the two preceding criteria, this criterion selects the critical plane according to the damage calculated in each plane. It is the plane in which the damage is maximum which is retained. This criterion is adapted to the nonperiodic loadings, which induces the use of a method of counting of cycles in order to calculate the elementary damages. To count the cycles, we use method RAINFLOW.

The once known elementary damages are cumulated linearly to determine the damage.

To compute: the elementary damages we project the history of the shearing stresses on one or two axes in order to reduce this one to a unidimensional function of $\tau_p=f(t)$. After having extracted the elementary under-cycles from τ_p with method RAINFLOW we define an elementary equivalent stress for any elementary under-cycle i :

$$\sigma^i_{eq}(\mathbf{n})=\alpha\left(c_p\frac{Max\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)-Min\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)}{2}+a\,Max\left(N^i_1(\mathbf{n}),N^i_2(\mathbf{n}),0\right)\right) \quad \mathbf{3.12\text{-}3}$$

with $\mathbf{n}$ the norm of the plane running, $\tau^i_{p1}(\mathbf{n})$ and $\tau^i_{p2}(\mathbf{n})$ the values of the projected shearing stresses of the under-cycle i and $N^i_1(\mathbf{n})$ and $N^i_2(\mathbf{n})$ the normal stresses of the under-cycle i. From $\sigma^i_{eq}(\mathbf{n})$ and of a curve of fatigue we determine the number of cycles to the elementary fracture $N^i(\mathbf{n})$ and the damage corresponding $D^i(\mathbf{n})=1/N^i(\mathbf{n})$. In [éq 3.12 - 3] α is a corrective term which makes it possible to use a curve of fatigue in tension - compression. The constant ones a and α being informed under key keys MATAKE_A and COEF_FLEX_TORS of the key word factor CISA_PLAN_CRIT of DEFI_MATERIAU.

We use a linear office plurality of damage. Either k the number of elementary under-cycles, for a norm $\mathbf{n}$ built-in, the cumulated damage is equal to:

$$D(\mathbf{n})=\sum_{i=1}^{k}D^i(\mathbf{n}) \quad \mathbf{3.12\text{-}4}$$

to determine the normal vector $\mathbf{n}^*$ corresponding to the maximum cumulated damage we vary $\mathbf{n}$, the vector normalformulecorrespondant $\mathbf{n}^*$ with the maximum cumulated damage is then given by:

$$D(\mathbf{n}^*)=\underset{\mathbf{n}}{Max}(D(\mathbf{n}))$$

Criterion DANG_VAN_MODI_AV
and the approach technical implementations to compute: this criterion are identical to those used for criterion MATAKE_MODI_AV. The only difference lies in the definition of the elementary equivalent stress where the hydrostatic pressure P replaces the maximum normal stress N_{max} :

$$\sigma^i_{eq}(\mathbf{n})=\alpha\left(c_p\frac{Max\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)-Min\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)}{2}+a\,Max\left(P^i_1(\mathbf{n}),P^i_2(\mathbf{n}),0\right)\right)$$

the constant ones a and α are with being informed by the user under key keys D_VAN_A and COEF_CISA_TRAC of the key word factor CISA_PLAN_CRIT of DEFI_MATERIAU.

For more information to consult the document [R7.04.04].

Criterion FATESOCI_MODI_AV
the criterion of FATEMI and SOCIE is defined by the relation:

$$\varepsilon_{eq}(n)=\frac{\Delta\gamma(n)}{2}\left(1+k\frac{N_{max}(n)}{\sigma_y}\right)$$

where k is a constant which depends on the characteristic materials. Contrary to the other criteria, it uses the shears in strain instead of the shears in stress. Moreover, the various quantities which contribute to the criterion are multiplied and not added. The criterion of FATEMI and SOCIE is usable after an elastic design or elastoplastic. This criterion selects the critical plane according to the damage calculated in each plane. It is the plane in which the damage is maximum which is retained.

This criterion is adapted to the nonperiodic loadings, which leads us to compute: to use the method of counting of cycles RAINFLOW the elementary damages. The elementary damages are then cumulated linearly to determine the damage.

In order to calculate the elementary damages we project the history of the shears in strain on one or two axes in order to reduce this one to a unidimensional function of time $\gamma_p=f(t)$. After having extracted the elementary under-cycles with method RAINFLOW we define an elementary equivalent strain for any elementary under-cycle i :

$$\varepsilon^i_{eq}(\mathbf{n})=\alpha\,c_p\left(\frac{Max\left(\gamma^i_{p1}(\mathbf{n}),\gamma^i_{p2}(\mathbf{n})\right)-Min\left(\gamma^i_{p1}(\mathbf{n}),\gamma^i_{p2}(\mathbf{n})\right)}{2}\right)\left(1+a\,Max\left(N^i_1(\mathbf{n}),N^i_2(\mathbf{n}),0\right)\right)$$

3.12-5

with $a=\frac{k}{\sigma_y}$, $\mathbf{n}$ the norm with the plane running, $\gamma^i_{p1}(\mathbf{n})$ and $\gamma^i_{p2}(\mathbf{n})$ the values of the shears in strain projected of the under-cycle i, $N^i_1(\mathbf{n})$ and $N^i_2(\mathbf{n})$ being the two values of the normal stress of the under-cycle i. From $\varepsilon^i_{eq}(\mathbf{n})$ and of a curve of Manson-Whetstone sheath we determine the number of cycles to the elementary fracture and $N^i(\mathbf{n})$ the damage corresponding $D^i(\mathbf{n})=1/N^i(\mathbf{n})$.

It will be noted that the shear strains used in the criterion of FATEMI and SOCIE are distortions γ_{ij} ($i\neq j$). If one uses the shear strains of the tensorial type ϵ_{ij} ($i\neq j$), they should be multiplied by a factor 2 because $\gamma_{ij}=2\,\epsilon_{ij}$.

In the equation [éq 3.12-5], α is a corrective term which to use a curve of Manson-Whetstone sheath obtained in traction and compression. c_p is a coefficient which makes it possible to take into account a possible pre-hardening.

The constant ones a and α must be indicated under key keys FATSOC_A and COEF_CISA_TRAC of the key word factor CISA_PLAN_CRIT of the command DEFI_MATERIAU.

It is noted that a rigorous approach is to use the curve of Manson-Whetstone sheath obtained directly in torsion (which is not always available). The use of the curve of Manson-Whetstone sheath obtained in traction and compression with the corrective term α (which is the relationship between two limits of endurance), as programmed in Code_Aster, is thus an approximation.

As we use an office plurality of linear damage, if m is the number of elementary under-cycles, then for a norm $\mathbf{n}$ built-in, the cumulated damage is equal to:

$$D(\mathbf{n})=\sum_{i=1}^{m} D^i(\mathbf{n})$$

to find the normal vector $\mathbf{n}^*$ corresponding to the maximum cumulated damage we vary $\mathbf{n}$. The normal vector $\mathbf{n}^*$ associated with the maximum cumulated damage is then given by:

$$D(\mathbf{n}^*)=\underset{\mathbf{n}}{Max}\left(D(\mathbf{n})\right)$$

Criterion FORMULE_CRITERE

This kind of criterion allows the user to build a criterion like a formula of the quantities predefined. This criterion is based on a general relation:

"Equivalent Quantity" = "Curve of life"

where the "equivalent Quantity" is a formula provided under operand FORMULE_GRDEQ (see 3.4.6) and the "Curve of life" is provided under operand COURBE_GRD_VIE (see 3.4.7) either by a function (counted or formulates, under the operand of "FORMULE_VIE", to see 3.4.8), or by a name of curve "WOHLER" or "MANSON_C" defined beforehand in DEFI_MATERIAU.

Criterion of Crossland

the criterion is written:

$$R_{crit}=\tau_a+a\,.\,P_{max}-b$$

where

$\tau_a=\dfrac{1}{2}\underset{0\le t_0\le T}{Max}\;\underset{0\le t_1\le T}{Max}\left\|\tilde{S}(t_1)-\tilde{S}(t_0)\right\|$ is the amplitude of cission

with $\tilde{S}$ deviator of the tensor of the stresses σ

$P_{max}=\underset{0\le t\le T}{Max}\left(\dfrac{1}{3}\text{ trace }\sigma\right)$ is the maximum hydrostatic pressure

$a=\dfrac{\left(\tau_0-\dfrac{d_0}{\sqrt{3}}\right)}{\dfrac{d_0}{3}}$ and $b=\tau_0$

with τ_0 the limit of endurance in alternate pure shears

and d_0 the limit of endurance in alternate pure traction and compression

Criterion of Dang Van-Papadopoulos

the criterion is written:

$$R_{crit}=k^{*}+a\,.\,P_{max}-b$$

where

$k^{*}=R$

R radius of the smallest sphere circumscribed with the way of loading within the space of stress deviators $\tilde{S}$

$$R=\underset{0\le t\le T}{Max}\sqrt{\frac{1}{2}.\left(\tilde{S}(t)-C^{*}\right):\left(\tilde{S}(t)-C^{*}\right)}$$

$C^{*}=Min\ Max\ \sqrt{\left(\tilde{S}(t)-C\right):\left(\tilde{S}(t)-C\right)}$ is the center of the hypersphère

$P_{max}=\underset{0\le t\le T}{Max}\left(\frac{1}{3}\ \text{trace}\ \sigma\right)$ is the maximum hydrostatic pressure

$$a=\frac{\left(\tau_0-\frac{d_0}{\sqrt{3}}\right)}{\frac{d_0}{3}}\quad \text{and}\quad b=\tau_0$$

with τ_0 the limit of endurance in alternate pure shears

and d_0 the limit of endurance in alternate pure traction and compression

Note:

The initial goal of these criteria Crossland and Dang Van-Papadopoulos is not to determine a value of damage, but a value of criterion R_{crit} such as:

$$\begin{cases} R_{crit}\le 0 & \text{pas de dommage}\\ R_{crit}>0 & \text{dommage possible}\end{cases}$$

One can also however determine a value of damage.

3.3.7 Operand `FORMULE_GRDEQ`

♦ `FORMULE_GRDEQ =for_grd ,` `/[formula]`

Makes it possible to provide the formula of the criterion like a function of the quantities available. The lists of quantities available for each type of loading are in the following table:

`TYPE_CHARGE = "PERIODIQUE", CRITERE = "FORMULE_CRITERE"`
quantities available: `"DTAUMA"`: half-amplitude of shears in maximum stress ($\Delta\tau(\mathbf{n*})/2$) `"PHYDRM"`: hydrostatic pressure (P) `"NORMAX"`: maximum normal stress on the critical plane ($N_{max}(\mathbf{n*})$) `"NORMOY"`: average normal stress on the critical plane ($N_{moy}(\mathbf{n*})$) `"EPNMAX"`: maximum normal strain on the critical plane ($\varepsilon_{Nmax}(\mathbf{n*})$) `"EPNMOY"`: average normal strain on the critical plane ($\varepsilon_{Nmoy}(\mathbf{n*})$) `"DEPSPE"`: half-amplitude of equivalent plastic strain ($\Delta\varepsilon_{eq}^{p}/2$) `"EPSPR1"`: half-amplitude of first principal strain (with the taking into account of the sign) `"SIGNM1"`: maximum normal stress on the level associated with ε_1

`"DENDIS"`: density of dissipated energy (W_{cy})
`"DENDIE"`: density of energy of elastic distortions (W_e)
`"APHYDR"`: half-amplitude of the hydrostatic pressure (P_a)
`"MPHYDR"`: average hydrostatic pressure (P_m)
`"DSIGEQ"`: half-amplitude of the equivalent stress ($\Delta\sigma_{eq}/2$)
`"SIGPR1"`: half-amplitude of first principal stress (with the taking into account of the sign)
`"EPSNM1"`: maximum normal strain on the level associated with σ_1
`"INVA2S"`: half-amplitude of the second invariant of the strain $J_2(\epsilon)$
`"DSITRE"`: half-amplitude of half-forced Tresca ($(\sigma_{max}^{Tresca}-\sigma_{min}^{Tresca})/4$)
`"DEPTRE"`: half-amplitude of the half-strain Tresca ($(\epsilon_{max}^{Tresca}-\epsilon_{min}^{Tresca})/4$)
`"EPSPAC"`: plastic strain accumulated p
`"RAYSPH"`: the radius of the smallest sphere circumscribed with the way of loading within the space of deviators of the stresses R
`"AMPCIS"`: amplitude of cission τ_a

TYPE_CHARGE = "NON-PERIODIQUE", CRITERE = "FORMULE_CRITERE"

the quantities available:

`"TAUPR_1"`: projected shearing stresses of the first top of the under-cycle ($\tau_{p1}(\mathbf{n})$)
`"TAUPR_2"`: projected shearing stresses of the second top of the under-cycle ($\tau_{p2}(\mathbf{n})$)
`"SIGN_1"`: normal stress of the first top of the under-cycle ($N_1(\mathbf{n})$)
`"SIGN_2"`: normal stress of the second top of the under-cycle ($N_2(\mathbf{n})$)
`"PHYDR_1"`: hydrostatic pressure of the first top of under-cycle
`"PHYDR_2"`: hydrostatic pressure of the second top of under-cycle
`"EPSPR_1"`: shears in strain projected of the first top of the under-cycle ($\gamma_{p1}(\mathbf{n})$)
`"EPSPR_2"`: shears in strain projected of the second top of the under-cycle ($\gamma_{p2}^{i}(\mathbf{n})$)
`"SIPR1_1"`: first principal stress of the first top of the under-cycle ($\sigma_1(1)$)
`"SIPR1_2"`: first principal stress of the second top of the under-cycle ($\sigma_1(2)$)
`"EPSN1_1"`: normal strain on the level associated with $\sigma_1(1)$ with the first top with under-cycle
`"EPSN1_2"`: normal strain on the level associated with $\sigma_1(2)$ with the second top with under-cycle
`"ETPR1_1"`: first principal total deflection of the first top of the under-cycle ($\epsilon_1^{tot}(1)$)
`"ETPR1_2"`: first principal total deflection of the second top of the under-cycle ($\epsilon_1^{tot}(2)$)
`"SITN1_1"`: normal stress on the level associated with $\epsilon_1^{tot}(1)$ with the first top with under-cycle
`"SITN1_2"`: normal stress on the level associated with $\epsilon_1^{tot}(2)$ with the second top with under-cycle
`"EPPR1_1"`: first principal plastic strain of the first top of the under-cycle ($\epsilon_1^{p}(1)$)
`"EPPR1_2"`: first principal plastic strain of the second top of the under-cycle ($\epsilon_1^{p}(2)$)
`"SIPN1_1"`: normal stress on the level associated with $\epsilon_1^{p}(1)$ with the first top with under-cycle
`"SIPN1_2"`: normal stress on the level associated with $\epsilon_1^{p}(2)$ with the second top with under-cycle
`"SIGEQ_1"`: equivalent stress of the first top of the under-cycle ($\sigma_{eq}(1)$)
`"SIGEQ_2"`: equivalent stress of the second top of the under-cycle ($\sigma_{eq}(2)$)
`"ETEQ_1"`: equivalent total deflection of the first top of the under-cycle ($\epsilon_{eq}^{tot}(1)$)
`"ETEQ_2"`: equivalent total deflection of the second top of the under-cycle ($\epsilon_{eq}^{tot}(2)$)

Note:

1) For the periodic loading, the formula of criterion is used to determine the plane of maximum shears if parameter "DTAUMA" is introduced into the formula.
2) For the loading NON-periodical, after having extracted the elementary under-cycles with method RAINFLOW, we calculate an elementary equivalent quantity by the formula of criterion for any elementary under-cycle. It is noted that the under-cycle is represented by two stress states or strain, noted by the first and the second tops of the under-cycle.
3) The parameters of entries of the command FORMULA must be among those listed in the table above.
4) Statements of certain quantities are in the document [R7.04.04].
5) One stresses that the thermal strain was not taken into account, i.e., formula $\varepsilon^{tot}=\varepsilon^{e}+\varepsilon^{p}$)
The operators used in the formula must be in conformity with the syntax of Python as indicated in the note [U4.31.05]. Operand

3.3.8 DOMMAGE ♦

```
DOMMAGE    =  /    "WOHLER",/
                   "MANSON_C",/
                   "FORM_VIE" This
```

key word makes it possible to provide a curve of connecting the quantity equivalent to the number of cycles to the fracture. In
Code_Aster , the limit of endurance is fixed at 10 million cycles. If the calculated equivalent quantity is lower than the limit of endurance, the calculated damage is 0. If

DOMMAGE = "WOHLER", one will take the curve of Wohler () defined $N_f=f(SIGM)$ in AFFE_MATERIAU . If

DOMMAGE = "MANSON_C", one will take the curve of Manson-Whetstone sheath () defined $N_f=f(EPSN)$ in AFFE_MATERIAU . If

DOMMAGE = "FORM_VIE", one will provide a function defining the curve of life. Operand

3.3.8.1 FORMULE_VIE ♦

```
FORMULE_VIE   = for_vie,/[formula          ]/[
                                  function  ] Makes it possible
```

to specify the curve connecting the equivalent quantity and the life duration. If
for _vie is provided by a tabulated function, it must be in the form: (quantity
$N_f=f$ _équivalente). If
for _vie is provided by a formula, it must be in the form: .
$\text{grandeur équivalente}=f(N_f)$ In this case,
the parameter of entry for the command FORMULA must be "NBRUPT " (i.e.,). Operand N_f

3.3.9 METHODE ♦METHODE

```
= "CERCLE_EXACT" Makes it possible
```

to specify the name of the method which will be used to compute: to it half amplitude of maximum shears. The method

of the "CERCLE_EXACT " is used to determine the circle circumscribed at the points which are in planes of shears. This method rests on the process which consists in obtaining the circle which passes by three points, cf document [R7.04.04]. Operand

3.3.10 PROJECTION ♦ PROJECTION

```
= "UN_AXE          ",/"DEUX_AXES
                     ", If
```

the loading is not periodical, it is necessary to project the history of the shears on one or two axes, cf document [R7.04.04]. UN_AXE

- , the history of the shears are projected on an axis; DEUX_AXES
- , the history of the shears are projected on two axes. Operand

3.3.11 DELTA_OSCI ◊DELTA

```
_OSCI   = delta  ,/0.0
                 , Filtering
```

of the history of the loading. In all the cases, if the function remains constant or decreasing on more than two consecutive points one removes the intermediate points to keep only the two extreme points. Then, one removes load history the points for which the variation of the value of the stress is lower than the value delta . By default delta is equal to zero, which amounts keeping all the oscillations of the loading, even those of low amplitude. For more information to see documentation of the command POST_ TIRES, [U4.83.01], even operand. Operands

3.4 specific to the computation of the type QUELCONQUE the load history

can be the evolution of the stress tensor, the cumulated plastic strain and the temperature in the course of time. Operand

3.4.1 EPSP ◊EPSP

```
=   p, Name of
```

the function describing the history of the plastic strain cumulated in the course of time, only for the computation of the damage of LEMAITRE . This

function or formula depends on the parameter INST and must be defined for same times as the functions or formulas describing the history of the components tensor of the stresses. Operand

EPSP must be used jointly with operands SIGM_ XX,… Operand

3.4.2 TEMP ◊TEMP

```
=   temp, Name of
```

the function or the formula describing the history of the temperature in the course of time, only for the computation of the damage of LEMAITRE . It is used in this case to determine the value of the mechanical characteristics (Young modulus, Poisson's ratio E and material parameter ν) at S times of computation of the damage. This

function or formula depends on the parameter INST and must be defined for same times as the functions or formulas describing the history of the components tensor of the stresses. Operand

TEMP must be used jointly with operands EPSP, SIGM_ XX,… Methods

3.4.3 of Lemaître and Lemaître-Sermage These two

methods make it possible to calculate the damage from $D(t)$ the data of the tensor of the stresses and $\sigma(t)$ the plastic strain cumulated. They $p(t)$

thus apply to unspecified loadings and are used only in post - processing of a plastic or viscoplastic model having like p variable. The evolution

of is defined D by: where

$$\begin{cases} \dot{D}=\dfrac{1}{(1-D)^{2s}}\left(\dfrac{1}{3ES}.(1+\nu)\sigma_{eq}^{2}+\dfrac{3}{2ES}(1-2\nu).\sigma_{H}^{2}\right)^{s}\dot{p} & si\ p>p_d \\ D=0 & sinon \end{cases}$$

: Young E modulus: Poisson's ratio ν , and: S material parameters s : equivalent stress σ_{eq} of von Mises: hydrostatic pressure σ_H : cumulated p plastic strain and: threshold p_d of damage. ◊DOMMAGE

= "LEMAITRE", Allows

to calculate the damage of Lemaître or Lemaître-Sermage from $D(t)$ the data of the tensor of the stresses and $\sigma(t)$ the cumulated plastic strain. To note $p(t)$ that the damage of Lemaître is obtained by assigning the value with 1.0 the exhibitor (). Operand s $s=1$

3.5 INFO ◊INFO

=/1 , Printing

: elementary

- cycles determined by the method of counting chosen by the user, of the elementary
- damages associated with each cycle for methods WOHLER , MANSON_COFFIN and TAHERI , of the damages
- of LEMAITRE in each point of computation, of the total
- damage (if the user asked for his computation). ◊INFO

=/2 , Printing

:

- load history introduced by the user under operands SIGM and EPSI , of the peaks
- extracted the load history (introduced under operands SIGM and EPSI) , of the elementary
- cycles determined by the method of counting chosen by the user, of the elementary
- damages associated with each cycle for methods WOHLER , MANSON_COFFIN and TAHERI , of the damages
- of LEMAITRE in each point of computation, of the total
- damage (if the user asked for his computation). The printings

are made in the message file . Operand

3.6 TITER ◊TITER

=titer Title

associated with the array. Count

3.7 produced operator

POST_ FATIGUE creates an array which is different according to computations of post - processing carried out: Loading

- **uniaxial (Wöhler** methods, Manson-Whetstone sheath and Taheri). The array

  understands five parameters: NB_CYCL

  : many elementary cycles extracted by the method of counting, VALE_MIN

`: values`	of the stresses or minimal strains of each elementary cycle, VALE_MAX
`: values`	of the stresses or maximum strains of each elementary cycle, DOMMAGE
`: values`	of the damage for each elementary cycle, DOMM_
`CUMU:`	of the total damage after office plurality on all the elementary cycles.
`value`	Multiaxial

- **loading the array**

  understands all the parameters constituting the criteria used. Moreover

  , for all the criteria, it array understands: CRITERE

`: name`	of	criterion VALE_
`CRITERE: value`		of the criterion (quantity are equivalent) NBRUP
`: number`		of the cycle to the fracture (associate with a cycle or a block of the under-cycles) DOMMAGE
`: value`		of the damage of Wöhler (if requested by the user). For

  the criteria of Crossland and Dang Van-Papadopoulos: AMPLIFIER

`_CISSION: amplitude`		of cission PRES_
`HYDRO_MAX: value`		of the maximum hydrostatic pressure, RADIUS
`_SPHERE:`	the radius	of the smallest sphere circumscribed with the way of loading within the space of deviators of the stresses formulates R

- **Loading (damage** of Lemaître and Lemaître-Sermage). The array

  understands two parameters: DOMMAGE

`: value`	of the damage in each point of discretization of the loading , command

IMPR_TABLE `[U4.91` .03] makes it possible to print the produced array. Quantity

4 and components introduced into Code_Aster *the computed values*

are stored with Gauss points or the nodes according to the option selected. Quantity FACY_R (Cyclic Fatigue) was introduced into the catalog of quantities. For

the periodic loading and the criteria of the type of maximum critical plane shears DTAUM

1 first	**value** of the half amplitude max of the shears in component critical plane
VNM1X	formulates x with the critical plane related to component DTAUM 1
VNM1Y	formulates y with the critical plane related to component DTAUM 1
VNM1Z	formulates z with the critical plane related to DTAUM 1 SINMAX
normal	constraint with the critical plane corresponding to constraint DTAUM 1
SINMOY	average norm with the critical plane corresponding to DTAUM 1 EPNMAX
normal	maximum strain with the critical plane corresponding to DTAUM 1 EPNMOY
average	maximum strain with the critical plane corresponding to DTAUM 1 SIGEQ
Equivalent stress	within the meaning of the criterion selected corresponding with DTAUM 1 NBRUP
many	cycles before fracture (function of SIGEQ 1 and a curve of Wöhler) DOMMAGE
damage	associated with NBRUP 1 (ENDO 1=1/NBRUP1) VNM2X
component	formulates x with the critical plane related to DTAUM 2 VNM2Y
component	formulates y with the critical plane related to DTAUM 2 VNM2Z
component	formulates z with the critical plane related to DTAUM 2 Table

5.5-1: Components specific to multiaxial cyclic fatigue for the periodic loading For

the loading NON-periodical and the criteria of the type of critical plane of maximum damage VNM1X

component	formulates x with the critical plane related to the damage component max
VNM1Y	formulates y with the critical plane related to the damage component max
VNM1Z	formulates z with the critical plane related to the damage max DOMMAGE
damage	associated with the block with component loading
VNM2X	formulates x with the critical plane related to the damage component max
VNM2Y	formulates y with the critical plane related to the damage component max
VNM2Z	formulates z with the critical plane related to the damage max Table

5.5-2: Components specific to multiaxial cyclic fatigue for the loading NON-periodical parameter

"DOMMAGE " is for operator POST_ TIRES. Parameter ENDO1 /ENDO2 is for operator CALC_ TIRES For

the loading NON-periodical, if there exist only one critical plane of the maximum damage, VNM2X , VNM2Y , VNM2Z are identical to the VNM1X , VNM1Y, VNM1Z. If several planes exist, one emits an alarm and leaves the two foregrounds. Computation

5 examples

5.1 of the damage of Wöhler (with correction of the average constraint) One

will refer to benchmark SZLZ100 (see [V9.01.100]). Computation

5.2 of the damage of Taheri One

will refer to benchmark SZLZ108 (see [V9.01.108]). Multiaxial

5.3 computation of the criteria of fatigue One

will refer to benchmark SZLZ107 (see [V9.01.107]). Computation

5.4 of the damage of Lemaître One

will refer to benchmark SZLZ109 (see [V9.01.109]). Computation

5.5 of the damage of Lemaître-Sermage One

will refer to benchmark SZLZ109 (see [V9.01.109]). One can

find other examples in the tests: SZLZ101

([V9.01.101]): Computation of the damage/Rainflow method. SZLZ102
([V9.01.102]): Tire with various methods counting. SZLZ103
([V9.01.103]): Tire counting by Rainflow method normalizes AFNOR.