Model of Beremin

Summary

One first of all points out the bases of the models of local approach of the rupture allowing to model brittle fracture.
One describes how, with the model of Beremin, the probability of rupture of a structure is calculated starting from the knowledge of the mechanical fields requesting it. While placing oneself in the case general of a nonmonotonous way of thermomechanical loading and by supposing that certain parameters of the models do not depend on the temperature, one establishes the general expression of the cumulated probabilities of rupture. The model of Beremin also makes it possible to include Ltook into account of a correction of plastic deformation.
Lastly, indications concerning the implementation of the model of Beremin in Code_hasster are summarized.

Contents

1 Introduction

The integrity of the structures of the nuclear power plants for all the load patterns, normal or accidental, must be constantly assured. In particular, for the most important structures as the tank or the primary education circuit, one seeks to evaluate the mechanical resistance as of Ldesign has with respect to brittle and ductile fracture.
From the point of view of the maintenance in service, ON also seeks with to justify mechanical resistance ofS structureS in the presence of a crack when defects were detected during an inspection. This approach makes it possible to establish a calendar of repair or replacement of the components. In addition, certain components are not controllable, in which case it is necessary to carry out a demonstration of the mechanical resistance in the presence of hypothetical defects.
Within this framework, the breaking process provides the necessary tools to the analysis of the fissured components. Its objective is to characterize the damage (crack, damage) in order to model each type of rupture to be able to establish criteria of rupture allowing to judge margins of loading in normal or accidental operating conditions [1].
From a physical point of view, one consider with a metal structure requested thermomécaniquement. One is interested, in this document, only with the brittle fracture of a structure, C'be-with-to say when the material rompT brutally by cleavage.
One uses the model of Beremin which is based on the knowledge of the mechanical fields in the zones most requested to obtain a local criterion of rupture representative of the concerned physical mechanisms (instability of the microscopic cracks of cleavage).

1.1 Industrial context

From a point of view engineer, the resistance of one material to the propagation of a crack is measured using tenacity. According to the temperature and speed of deformation, certain steels (in particular ferritic steels of tank REFERENCE MARK or steel carbon-manganese for secondary piping) present characteristics, either fragile or ductile. At the low temperatures, these steels break in a fragile way by cleavage by having a decoherence sometimes intergranular, while at the highest temperatures, the ductile tear appears. The transition enters Cbe two mechanisms ESt characterized by temperature of the fragile/ductile transition. Measurements of impact strength allow to establish criteria, such as the temperature of transition, to define the field of application of material [2].
In the case of steels ferriticS tank REFERENCE MARK under the normal conditions of operating, the material is requested in the ductile field. However during its exploitation under the effect of the neutron irradiation the tank goes " vto ieillir "and is likely to weaken. Moreover of the very exceptional accidental conditions suchS that the thermal shock cold (Thermal Pressurized Shock, PTS) under pressure in the event of primary education loss of cooling agent (APRP) could cause a request of the component in the field of ductile-brittle transition. This is why it is important to determine the degree of embrittlement of material using the curve of ductile-brittle transition and to precisely know the tenacity of material in the field of transition in order to prevent all the risks of brutal rupture [3].
With regard to pipings of the secondary circuit, the steels C-mn which are used in the various reserve circuits (ASG, Emergency Power supply of the Steam generators, for example), are sensitive to ageing under deformation (static) which induces a shift of their ductile-brittle transition towards the high temperatures [4]. In order to lay down the brittle fracture of these components in the presence of static ageing, several former studies were conducted making it possible to model the mechanical behavior of material by taking account of ageing under deformation [5, 6, 7].
This work already showed that the probability of rupture per cleavage can be correctly described in the brittle stage by a local approach of the rupture as suggested by Beremin.

1.2 Interest of the local approach

To justify the mechanical resistance of the components of nuclear power plants, the comprehensive approach is often used. The comprehensive approach aims at describing the conditions of loading of a fissured component leading to the rupture using one only parameter which depends on the geometry and the loading. The parameter most usually employed in the field of the rupture by cleavage (linear elastic case) is the factor of intensity of the constraints in mode I, K_I . ruin of the structure will be obtained when this parameter will reach of a breaking value, tenacity K_{Ic} . The safety analysis compares the factor of intensity of the constraints with minimal values of the tenacity of steel which are established by many tests mechanics and gathered in the shape of a curve of reference Additional RCC-M Z.G. Throughout all operation tank, it is checked that the properties of tenacity, deduced from the exploitation of the program of monitoring, are higher than those provided by the curve of reference, indexed on a temperature of conventional transition RT_{NDT} (Reference Temperature for Nil Ductility Transition) [3].

The comprehensive approach is well validated and accepted by the Authority of Safety, but it remains simple and conservative. It can thus be too much envelope in certain typical cases such as for example in the case “of effect small defect”, “ ofeffect of triaxiality “, “ofeffect of hot preloading”, or in the case of loading nonproportional. This is why in support of the files of justification of the mechanical resistance, utili canR a local approach finer who allows to establish a link between the tenacity of a material and the constraint with local rupture for a material macroscopically homogeneous.

One additional reason to use the method of the local approach standard Beremin is explained by the values of tenacity which present a strong dispersion in the field of the ductile-brittle transition. By introducing a statistical model, this approach allowsto explain and to quantify dispersion inherent in these tests, via the knowledge of local metallurgical parameters [2].

2 Brittle fracture

2.1 Mechanisms

Brittle fracture is a mode of brutal rupture. It is generally associated with the phenomenon of cleavage. Cleavage is the complete decoherence of a crystal according to one of Sbe crystallographic plans. The theoretical local constraint necessary to this separation of the crystal lattice K_{Ic} is very high, and expresses themselves according to the inter-reticular distance and of the energy of surface:

$$\sigma_c=\sqrt{\frac{E\gamma_s}{d_{hkl}}} \qquad (1)$$

where E is the module Young, γ_s is the energy which corresponds to the creation of new surfaces and d_{hkl} is the inter-reticular distance.

However, the theoretical constraint of separation of the atomic plans never is reached overall, but it can locally become it thanks to structures playing a part of amplifiers of constraints. In the case of steels, in fact the many defects play this part, that they are dueS with plasticity at a peak of crack (dislocations) or with the composition of steel (inclusions, cracks) [8].

The rupture of steels by cleavage generally distinguishes three successive phases: (1) germination, (2) propagation and (3) the crossing of the microstructural barriers (joined grains, joints of the bainitic packages). Germination corresponds to the development of one microscopic crack inside healthy metal; it is generally allowed that this stage requires a rather weak preliminary plastic deformation, which generates a stacking of dislocations and a singularity of the constraints, and the attack of an ultimate stress of rupture σ_c (critical point). The phenomenon of germination of a microscopic crack can be explained by the various mechanisms of plasticity (Zener-Stroh, Cottrell, Smith, stirring) indexed in [9].

Once the stage of germination passed, a crack can be propagated under a decreasing normal constraint on condition that satisfying an energy criterion with type Griffith [10]:

$$\sigma_c=\sqrt{\frac{EW}{r}} \qquad (2)$$

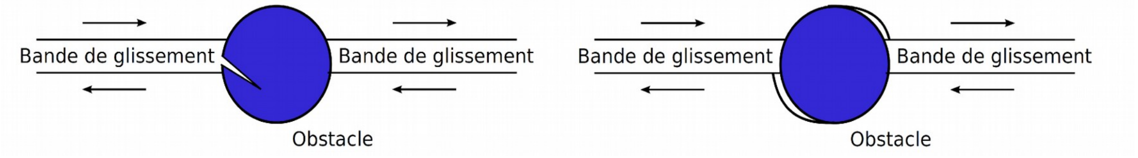
with W who represents the energy of rupture, and r the ray of a circular crack of form.

One obtains a propagation of the cracks of unstable cleavage, high speed which can sometimes to be braked by a mechanism of relieving by slip of dislocations (émoussement of cleavage by emission of dislocations) [11].

To be able to be propagated in a polycrystal without being stopped by émoussement, the crack must cross certain microstructural barriers (interphase, grain boundaries…) to lead to the ruin of structure. At the microscopic level the microstructural entity which controls the rupture is not single and strongly depends on the type of material.

The three stages all contribute to the description of brittle fracture. However, according to the temperature of tests and of the geometry of the test-tube (notched or fissured), one of these stages is dominating and controls the release of brittle fracture. By conséquenT, within the framework of a taking into account of the mechanisms of cleavage in a model of rupture, only one of these three stages is used to define a criterion of rupture [12].

In the case of low alloy steels at very low temperature ($T<-160\,°C$) the rupture is controlled by the phase of starting, i.e the germination of the microscopic cracks. With higher temperature ($T>-160\,°C$) the rupture is controlled by the phase of propagation of the microscopic cracks started on fragile particles of second phase (carbides, sulphides of manganese, titanium nitrides) [13, 14]. The amplification of the constraints results from the incompatibilities from deformations between these particles and the matrix. This amplification of the constraints at the top of stacking of dislocations can cause: rupture of the fragile particle of second phase (figure 1 (a)) or in the case of an interface weak particle/matrix, the decoherence of the interface (figure 1 (b)).



(A) **(b)**

Figure 1: (A) starting of a microscopic crack on a fragile particle of second phase, (b) decoherence of the interface [2]

The studies on ferritic steels of tanks (16MND5) show that at the low temperatures (negative temperatures), it is well the stage of propagation of the microphone-defects (created at the time of the phase of starting) in the surrounding ferritic matrix which constitutes the critical stage to propagate cleavage [15, 16, 17]. On the other hand the origin of cleavage cannot be only allotted to one only microstructural element (a chemical species). The influence of the microstructure of steels of the tanks is complex since it can utilize many parameters of which variation induced several consequences [8]. Among these parameters one thinks in particular in keeping with grains, with the sizes of inclusionS and with distribution of sizes of defects. One can thus conclude that there exists a statistical aspect in terms of population of defects leading with brittle fracture.
For more details on the influence of the microstructure on brittle fracture in steels slightly allied of type 16MND5 one will be able to refer to work [2, 3, 4].

2.2 Statistical aspect DE brittle fracture

Cleavage is a mode of probabilistic rupture of nature because the constraint of cleavage depends on the distribution of size of the defects and the local mechanical fields depend on the local microstructure. The rupture starts on the defect for which the critical stress is reached in first. However, Ritchie, Knott and Rice [18] (model RKR) apply that the rupture intervenes only if the constraint criticizes at a peak of crack is reached at a characteristic distance which represents approximately the size of two grains. Thus the rupture by cleavage is conditioned by a characteristic distance and a critical size of defect. The model of RKR represents the first attempt to connect the breaking strength fragile, expressedE by tenacity, with a local criterion of rupture based on the mechanisms of germination [8]. This model opened up the way towards the probabilistic models.
Thereafter, work of Curry and Knott [19] showed that the distance characteristic of model RKR should not be correlated in keeping with grains but with the distribution of carbides like to their sizes. Thus for a size of grain fixed, at a temperature of test given, the tenacity of material increases when the distance inter-particle decreases. This work allowed the introduction of the concept of statistics into the models of brittle fracture [2]. However, in the two models the scale effect and dispersion of the experimental measurements associated with the brittle mode of fracture are not taken into account.
In order to describe the scale effect and the dispersion of measurements of tenacity, of the statistical models were developed as from the years 1980. Among these models, most usually used are those of Beremin [20] and of Wallin [21]. These models are based on the theory of the weakest link and one statistics of Weibull [22, 23].
The model of Beremin has a strong recognition with the international plan. The approach of Beremin profits from an important experience feedback of the fact at the same time from its maturity and amongst researchers and engineers who tested it and modified. The model makes it possible to take into account of many effects (small defect, triaxiality, hot preloading) in complex situations of loading. Many applications were considered as well on test-tubes as on structures.

3 Description DU models BeremiN

In this section, the bases of the model of Beremin are first of all pointed out. The assumptions related to the definition of the potential sites of cleavage are clarified. The mechanism considered as criticism is the propagation of a crack of cleavage in the adjacent grain, itself regarded as started by the mechanisms of plasticity. Probability of rupture of these sites which leads to the probability of rupture DE structure of deduced. The classical formulation of the model of Beremin is extended to loadings plus generals by including an alternative of plastic correction often used in this model [24].
The model of Beremin APUIE on the knowledge of the local mechanical fields requesting the structure considered. ON considers a structure subjected to a history of thermomechanical requests as from the moment $t=0$ fixed arbitrarily. One seeks at any moment to determine the probability of cumulated rupture of this structure.
By assumption, this structure is made up (at least partly) of a steel, likely to break by cleavage at low temperature, presenting a elastoviscoplastic law of behavior and of which one of the internal variables corresponds to the cumulated equivalent plastic deformation: an example of list of compatible laws is provided to the paragraph § 4.

3.1 Bases

3.1.1 Assumptions general

The model considers a representative ground volume Ω material and rests on several fundamental assumptions recapitulated in [25]:

1. It is supposed that L'starting of microscopic cracks on the sites of damage can be done only when **plasticity is active** (the rate of cumulated plastic deformation $\dot{p}(u)$ at the moment u must be positiF $\dot{p}(u)>0$) and their number does not increase any more during the history of the requests.

Foot-note:

> *Let us stress that this condition of active plasticity who will be that considered subsequently document is different from the classically adopted condition ($p>0$). ItS two conditions are equivalent in the case of a monotonous way of loading.*
> *Pour of the ways of loading plus generals, this condition of active plasticity $\dot{p}>0$ conduit on the other hand with much better results [26].*

2. It is noted that only **the maximum principal constraint** σ_I intervenes in the propagation of the defect, the defects then being regarded as directed perpendicular to the principal direction.

3. The propagation of microscopic cracks is controlled by one **criterion of type Griffith** .

4. The rupture will be initiated from **the most important defects** in terms of size, only the knowledge of the distribution of the latter is necessary.

5. The structure solicited can be regarded as the juxtaposition DE several elements of volume V_0 perfectly **independent** from the point of view rupture. V_0 must be smallest possible to check statistical, but rather large independence so that the probability of finding a defect of sufficient size there is reasonable in practice (V_0 includes some grains).

6. **The theory of the weakest link** is used according to which rupture of one of ground volumes δV spiritE rupture of the whole of the structure.

7. One applies a form of distribution of the defects g for the positive constraints $g(\sigma)=\alpha'\sigma^{m-1}$ and $g(\sigma)=0 \text{ si } \sigma<0$. For each one of these sites, one notes $g(\sigma)d\sigma$ the probability of having a constraint criticizes cleavage understood in $[\sigma;\sigma+d\sigma]$. Probability that one of the sites of damage has a constraint of cleavage lower than a pressure applied σ_{Ic} is thus:

$$\int_0^{\sigma_{Ic}} g(u)\,du \tag{3}$$

3.2 Probability of cumulated rupture of the structure

One supposes here to know the probability of cumulated rupture (function of distribution) of each site of damage of volume V_0 , NexceptE $p_r(\text{site})$ and regarded as identical for all the sites. The probability of survival is worth, it, $1-p_r(\text{site})$. One can then write the probability of cumulated rupture of a volume elementary δV whose characteristic dimension is lower than the macroscopic fluctuations of the mechanical fields ($\delta V > V_0$) and whose stress field is supposed to be homogeneous:

$$1-p_r(\delta V)=\prod_{\text{site}\in\delta V}(1-p_r(\text{site})) \tag{4}$$

That is to say:

$$p_r(\delta V)=1-\left(1-p_r(\text{site})\right)^{\frac{\delta V}{V_0}} \tag{5}$$

Probability of survival of the structure (volume Ω) at the end of the loading is equal to the product of the probabilities of survival of each ground volume δV (statistical independence). Probability of survival of the structure rise then with:

$$1-P_r=\prod_{\delta V\in\Omega}(1-p_r(\delta V))=\prod_{\delta V\in\Omega}(1-p_r(\text{site}))^{\frac{\delta V}{V_0}}=\prod_{\delta V\in\Omega}\exp\left(\ln\left(1-p_r(\text{site})\right)\frac{\delta V}{V_0}\right) \tag{6}$$

Knowing that $p_r(\text{site})$ remain small in front of the unit, the preceding expression can be simplified to give finally:

$$P_r\approx 1-\prod_{\delta V\in\Omega}\exp(-p_r(\text{site})\frac{\delta V}{V_0})=1-\exp\left(-\int_\Omega p_r(\text{site})\frac{\delta V}{V_0}\right) \tag{7}$$

That is to say:

$$P_r=1-\exp\left(-x\right) \text{ with } x=\int_\Omega p_r(\text{site})\frac{\delta V}{V_0} \tag{8}$$

3.3 Probability of rupture cumulated ofS sites

L here is consideredE case of **way of radial loading and not necessarily monotonous**, evolution fields mechanicsS in each element δV is characterized in any point by a history of maximum principal constraint $\sigma_I(u)_{0\le u\le t}$.

3.3.1 Case where the critical stress of cleavage is independent on the temperature

LE loading being radial, the direction of maximum principal constraint is supposed to be constant. Only times are considered passed u for which plasticity is active ($\dot{p}(u)>0$), since the rupture is not possible that at these moments there (assumption 1). One notes $\{u<t, \dot{p}(u)>0\}$ the whole of these moments for the element δV considered.

According to the assumption (2), only **the maximum principal constraint** σ_I intervenes in the propagation of the defect. So that LE volume δV that is to say **broken** at the moment t , it is necessary that:

$$\sigma_{Ic}\le\max_{\{u<t,\,\dot{p}(u)>0\}}\sigma_I(u) \tag{9}$$

Taking into account the assumption (7), Lprobability of rupture has of this volume δV can thus écriRe:

$$p_r(\text{site}) = \int_0^{\max\limits_{[u<t,\,\dot{p}(u)>0]} \sigma_I(u)} g(\sigma)\, d\sigma = \left(\frac{\max\limits_{[u<t,\,\dot{p}(u)>0]} \sigma_I(u)}{\sigma_u} \right)^m \qquad (10)$$

While defining $\sigma_u = \left(\frac{m}{\alpha'}\right)^{\frac{1}{m}}$ like the constraint of cleavage (i.e. the constraint for which the probability of cumulated rupture of the potential sites of cleavage is worth 1) , L probability of rupture of the structure has can be written from (8) like:

$$P_r = 1 - \exp\left(-\left(\frac{\sigma_W}{\sigma_u} \right)^m \right) \qquad (11)$$

with σ_W being the constraint of Weibull [23] at the moment t defined by:

$$\sigma_W(t) = \left[\int_\Omega \sigma_I^m \frac{\delta V}{V_0} \right]^{\frac{1}{m}} \text{ with } \sigma_I = \max_{[u<t,\,\dot{p}(u)>0]} \sigma_I(u) \qquad (12)$$

In this expression, the module of Weibull m , an idea of the dispersion of the size of defects likely gives to start brittle fracture. σ_u represent an average breaking stress of a sample of volume V_0 .

In case, where, with any moment, evolution of the mechanical fields in each element δV is supposedE **radial and monotonous increasing ($\dot{p}>0$),** the preceding expression of the constraint of Weibull is reduced to:

$$\sigma_W = \left[\int_\Omega \sigma_I^m \frac{\delta V}{V_0} \right]^{\frac{1}{m}} \qquad (13)$$

3.3.2 Case where the critical stress of cleavage is dependent on the temperature

Until present one considered the parameters of model of cleavage independent of the temperature. The application of the local approach to real transients of study (for example, simulations of the tests of hot preloading on steel 16MND5 with the model of Beremin) requires the modification of the initial formulation to be able to take into account ways of loading comprising of the mechanical and thermal discharges [24, 26, 27] and also to be able to take account of the dependence of the constraint of cleavage of the temperature.

For that, one supposes that evolution of the mechanical fields in each element δV is radial and nonmonotonous. This evolution is characterized by a history of maximum principal constraint $\sigma_I(u)_{0\le u\le t}$ like by a history of temperature $\theta(u)_{0\le u\le t}$.

For any moment u , we suppose that in the vicinity of each site of damage, the normal constraint “microscopic” checks:

$$\sigma_{I(micro)}(u) = f\, \sigma_I(u) \qquad (14)$$

f being a parameter of localization depending only on the average temperature $\theta(u)$ in δV . So that the site of damage **did not break**, it is necessary thus that:

$$\sigma_{Ic} \ge \sigma_{I(micro)}(u) \text{ such as } \dot{p}(u)>0 \qquad (15)$$

Shears:

$$\sigma_{Ic} \ge f\, \sigma_I(u) \text{ such as } \dot{p}(u)>0 \qquad (16)$$

DE left that the probability of rupture cumulated a site (10) rise with:

$$p_r(\text{site}) = \left[\max_{[u<t,\,\dot{p}(u)>0]} \left\{ \frac{\sigma_I(u)\,.\,f(\theta(u))}{\sigma_u} \right\} \right]^m \qquad (17)$$

OU still:

$$p_r(\text{site})=\left[\max_{[u<t,\,\dot{p}(u)>0]}\left\{\frac{\sigma_I(u)}{\sigma_u(\theta(u))}\right\}\right]^m \tag{18}$$

Withvec $\sigma_u(\theta)$ a function of the temperature such as:

$$\sigma_u(\theta)=\frac{\sigma_u}{f(\theta)} \tag{19}$$

L'introduction of the parameter of localization f conduit thus with a dependence connects constraint of cleavage. In a general way, probability of cumulated rupture of the structureexpress from (8) by:

$$P_r=1-\exp\left(-\int_{\Omega}\left[\max_{[u<t,\,\dot{p}(u)>0]}\left\{\frac{\sigma_I(u)}{\sigma_u(\theta(u))}\right\}\right]^m\frac{\delta \mathrm{V}}{V_0}\right) \tag{20}$$

It is this last formulation implemented in Code_hasster who is used to simulate the tests of hot preloading and in a more general way ways of loading with discharge. While noting σ_u^o a value chosen arbitrarily, one can write:

$$P_r=1-\exp\left(-\left(\frac{\sigma_W^o}{\sigma_u^o}\right)^m\right) \tag{21}$$

The constraint of Weibull σ_w^o becomes then:

$$\sigma_W^o=\left[\int_{\Omega}(\tilde{\sigma}_I^o)^m\frac{\delta V}{V_0}\right]^{\frac{1}{m}} \text{ with } \tilde{\sigma}_I^o=\max_{[u<t,\,\dot{p}(u)>0]}\left\{\frac{\sigma_u^o\sigma_I(u)}{\sigma_u(u)}\right\} \tag{22}$$

3.4 Correction of deformation plastic

Several work on the rupture by cleavage shows the beneficial effect of the plastic deformation on the cleavage resistance. Several reasons are evoked by the authors and in particular the reduction microdéfauts in the direction perpendicular to traction connect with the strong deformations. It is also probable that a predeformation at the temperatures higher than that of cleavage can involve émoussement microphone-defects already present in material.
A correction of the greatest principal constraint σ_I who intervenes in the calculation of the constraint of Weibull was proposed in the model of Beremin. The constraint principal is corrected by a factor depend on the plastic deformation according to the principal direction ε_I^p :

$$\sigma_I^*=\sigma_I\exp\left(-\frac{\varepsilon_I^p}{k}\right) \text{ with } 2\leqslant k\leqslant 4 \tag{23}$$

The new expression of the constraint of Weibull is:

$$\sigma_W=\left[\int_{\Omega}(\sigma_I)^m\exp\left(-\frac{\varepsilon_I^p m}{k}\right)\frac{\delta V}{V_0}\right]^{\frac{1}{m}} \tag{24}$$

Probability of rupture of a site at one moment u given is written now:

$$p_r(\text{site})=\max_{[u<t,\,\dot{p}(u)>0]}\left\{\frac{\sigma_I(u)}{\sigma_u(\theta(u))}.\exp\left(-\frac{1}{2}\varepsilon_I^p(u)\right)\right\}^m \tag{25}$$

For a monotonous way of loading (constant temperature and uniform), the preceding relation leads to the classical expression [24]:

$$p_r(\text{site})=\left[\frac{\sigma_I}{\sigma_u}\right]^m\exp\left(-\frac{m}{2}\varepsilon_I^p\right) \tag{26}$$

4 Establishment in Code_ hasster

4.1 Probability calculus of rupture

Advices of use of this model are given in documentation [U2.05.08] with a recall on sensitivity of the model to the refinement of the grid at a peak of crack.

Let us consider a field Ω_c studied structure which can be the whole of the studied grid, a group of meshS or a mesh. Following an elastoplastic thermomechanical calculation, one knows the evolution of the plastic deformation and deformation, stress fields cumulated in this field. Using a criterion of damage starting from the stress field to the forefront of the crack (or notch) one seeks to determine the probability of rupture cumulated by cleavage of the structure. The use of the model is done out of post-processor using keyword `WEIBULL` order `POST_ELEM`.

Let us stress that for calculation with correction of deformation plastic (option `CORR_PLAST='YES'`), a preliminary calculation of the field of deformation of Green-Lagrange on the zone of the structure studied (via the order `CALC_CHAMP`) is necessary. In the contrary case, postprocessing stops.

Moreover, the law of behavior of material must comprise a variable interns corresponding to the cumulated equivalent plastic deformation p . They is the laws in particular (nonexhaustive list): `VMIS_ISOT_*, VMIS_ECMI_*, VMIS_*_CHAB, ROUSS_*, LEMAITRE, MONOCRYSTAL`. In the contrary case, postprocessing stops.

Corresponding digital integration in Code_hasster be carried out in two times:

- one calculates in each point of Gauss σ_I if the rate of plastic deformation cumulated in this point is strictly positive,
- by squaring on each mesh then simple summation on the field Ω_c aimed, one from of deduced the constraint from Weibull as well as the probability of associated rupture. The summation is balanced by a multiplicative coefficient which takes account of possible symmetries and the type of modeling selected (axi, 2D, 3D.). One will take care well to define this coefficient (`COEF_MULT`) in accordance with the indications given in document [U4.81.22].

The first stage makes it possible to introduce an alternative (keyword `SIGM_ELMOY` instead of `SIGM_ELGA`) leading to appreciably different results in the case of a fissured structure (presence of gradient): in each mesh, σ_I is given starting from the average on this mesh of the stress field (and, possibly, of the field of deformation of Green-Lagrange). It is nonworthless if the rate of plastic deformation cumulated at the moment considered is strictly positive in a point of Gauss at least.

4.2 Parameters material

The model of Beremin requires the knowledge of three parameters: two parameters characteristicS material considered in the law of Weibull, m and σ_u , as well as the ground volume of the plastic zone elementary V_0 . LE ground volume V_0 must be sufficiently large in order to respect the assumption (5) . In Lhas law of Weibull, parameters V_0 and σ_u are not independent. In fact it is the product $V_0\sigma_u^m$ who intervenes. With these three parameters, it is possible to add one threshold of plastic deformation allowing to define the plastic zone on which integration is carried out. In most case, with an aim of simplifying, one supposes that the threshold is null, which gives us a law with two parameters m and $V_0\sigma_u^m$.

The identification of these parameters is not single, but depends strongly ofS calculated stress fields. Code_hasster have an operator specific dedicated to the identification of the model starting from the experimental data: `RECA_WEIBULL` (U4.82.06). An example of use of the order is available via the case test `ssna103` (V6.01.103). The case test is carried out starting from a tensile test on a smooth cylindrical test-tube.

5 WithnearS alternativeS

Among the models buildings introducedS in Code_hasster ([R7.02.06], [U2.05.08] and [U2.05.08]) who allow to describe brittle fracture by cleavage there exists model of Bordet (see [16] and [R7.02.06]). This model represents an extension of the model of Beremin Où it is supposed that the microscopic cracks created at the time of the attack of the threshold of plasticity remain potentially active throughout the loading which is followed from there. However, in steels, the total rupture is mainly related to microscopic cracks lately created. It is thus advisable to take into account the level of plastic deformation reaches at every moment. This option is possible in the model of Beremin *via* the plastic option of correction describes in Paragraphe §3.4. The effect of plasticity on the microdéfauts is taken into account in the model of Bordet by considering that the probability of cleavage is expressed like the product of the probability of nucleation and propagation at the same moment.

Parmi the other alternative approaches there is the approach Gp, which makes it possible to define a criterion of starting of an already existing crack through the calculation of rate of elastic refund of energy. This approach is valid in elasticity linear like in non-linear elasticity.

The Gp model is a deterministic energy approach. This approach for the internal moment at EDF, it does not have the maturity of the approach of Beremin, but it has however the advantage of approaching, in its use, of the approach in J, which in fact also a candidate credible for a use in the files of engineering [29]. For more details on this approach, one will be able to refer to [R7.02.16].

6 Bibliography

1) Corre, V.: Study ductile competition tear/brittle fracture: Application to the thin mechanics of the steel C-mn tubes and their welded joints. Thesis of the Central School of Lille, 2006.

2) Andrieu, A.: Mechanisms and modeling multi-scale of the brittle trans-and intergranular fracture of steels for Pressurized water reactor, in link with thermal ageing. Doctorate of the École Nationale Supérieure of the Mines of Paris, 2013.

3) Renevey, S.: Approaches total and localE rupture in the fragile-ductile field of transition from a steel slightly allied. Thesis of ECA, Saclay, 1998.

4) Marsh, A.: Influence of static ageing on the ductile-brittle transition from the steels C-mn. Doctorate of the École Nationale Supérieure of the Mines of Paris, 2012.

5) Graff, S.: Viscoplastic behavior of zirconium alloys in the temperatures arranges 20°C-400°C: characterization and modeling of strain ageing phenomena. Doctorate of the École Nationale Supérieure of the Mines of Paris, 2006.

6) Belotteau, J.: Behavior and rupture of a steel C-mn in the presence of ageing under deformation. Doctorate of the Central School Paris, 2009.

7) Wang, H.: Mechanical behavior and rupture of the steels C-mn in the presence of dynamic ageing under deformation. Doctorate of the Central School Paris, 2011.

8) Mathieu, J-P.: Analysis and micromechanical modeling of the behavior and the brittle fracture of steel 16MND5: taking into account of microstructural heterogeneities. Doctorate of the ENSAM, 2007.

9) Thompson, A.W., Knott J.F. : Micromechanisms of brittle fracture. Metallurgical Transactions A, 24(3): 523-534, 1993.

10) Griffith, A.: The phenomena of rupture and flow in solids. Philosophical Transactions of the Royal Society of London, vol. 221, pp. 163-198, 1921.

11) Francois, D., Pineau, A., Zaoui, A.: Mechanical behavior of materials. Hermes, Paris, pp.139-141, 1993.

12) McMahon, C., Cohen, Mr.: Initiation of cleavage in polycrystalline iron. Recorded Metallurgica, vol. 13, No 6, pp. 591-604, 1965.

13) Bouchet, C., Tanguy, B., Besson, J., Bugat, S.: Prediction of the effects of neutron ductile irradiation one the Charpy to brittle transition curve of year A508 presses vessel steel. Computational materials science, vol. 32, No 3, p. 294-300, 2005.

14) Pineau, A., Tanguy, B.: Advances in cleavage fracture modelling in steels: Micromechanical, numerical and multiscale aspects, in Reports Physique, Academy of Science, 2010.

15) Kroon, Mr., Faleskog, J.: Micromechanics of cleavage fracture initiation in ferritic steels by carbide cracking. J. Mech. Phys. Solids, vol. 53, pp 171-196, 2005.

16) Bordet, S.R., Karstensen, A.D., Knowles, D.M., Wiesner, C.S. : “With new statistical local criterion for cleavage fracture in steel. Share I: model presentation”, Eng. Tailcoat. Mech., vol. 72, pp.435-452, 2005.

17) Odebt, G.R., Yamamoto, T., Rathburn, H. J.: Cleavage fractures and irradiation embrittlement of fusion reactor alloys: mechanisms, multiscale models, toughness measurements and implications to structural integrity assessment. J. of Nucl. Chechmate., vol. 323, pp 313-340, 2003.

18) Ritchie, R.O., Knott, J.F and Rice, J.R.: One the relationship between critical tensile stress and fracture toughness in mild steel. Newspaper of the Mechanics and Physics of Solids, 21(6): 395-410, 1973.

19) Curry, D.A. and Knott, J.F.: The relationship between fracture toughness and microstructure in the cleavage fracture of mild steel. Metal Science, 10(1): 1-6, 1976.

20) Beremin, F.: “With room criterion for cleavage fracture of has nuclear presses vessel steel”, Metall. Trans. 14A, pp 2277-2287, 1981.

21) Wallin, K., Saario, T., Torronen, K.: Statistical model for carbide induced brittle fracture in steel', Metal Science, 18.1, pp 13-16, 1984.

22) Weibull, W.: With statistical theory of the strength of materials. Proc. Roy. Swedish Int Res. Eng., 151: 1-53, 1939.

23) Weibull, W.: With statistical distribution function of wide applicability. Newspaper of Applied Mechanics, 18: 293-297, 1951.

24) Masson, R. and al.: “Definition of the local approach (into fragile) in the case of an unspecified way of loading”, EDF HT-26/00/021 Notes.

25) Tanguy, B.: Modeling of the Charpy test by the local approach of the rupture. Application to the case of steel 16MND5 in the field of transition. Doctorate of École des Mines of Paris, 2001.

26) Lefevre, W., Masson, R., Barber, R.: “Digital simulations using the model improved of Beremin of tests of preloading hot carried out with steel 18MND5”. Note EDF HT-26/00/028.

27) Lefevre, W., Barber, G., Masson, R., Rousselier, G.: With modified Beremin model to simulate the warm pre-stress effect,” Nuclear Engineering and Design, vol. 216, No 1-3, pp. 27 – 42.2002.

28) Tanguy, B., Bouchet, C., Bordet, S.R., Besson, J., Pineau, A.: “Toward has better understanding of the cleavage in RPV steels: Room mechanical conditions and of evaluation has nucleation enriched Weibull model and of the Beremin model over has broad temperature arranges”, 9 HT European Mechanics of Materials Conference, Room approach to fracture, pp 129-134, Moret on Far, 2006.

29) Wadier, Y., Link between the approaches total and local in elastoplastic breaking process. Technical note H-T64-2007-00213-FR, EDF R & D, 2007.