Methodological guide on the approaches in breaking process

Summary:

This note constitutes a methodological guide for the use of the breaking process with *Code_Aster*. It brings a total sight on the existing approaches in breaking process or project in *Code_Aster* and a shunting constitutes towards the dedicated notes and documentations.

Contents

1 Glossary

Initials

- **FEELS** : Individual Edge Notched Tension: tensile specimen with a side notch
- **SENB** : Individual Edge Notched Bending: bend-test specimen 3 points with a side notch
- **CT** : test-tube Compact Tension for the measurement of tenacity and the tear strength ductile
- **AE** : notched axisymmetric test-tube
- **LCF:** cycle of a preloading hot standard Loading Cooling Fractures
- **LUCF:** cycle of a preloading hot standard Loading Unloading Cooling Fractures
- **DSR** : defect under coating
- **GDR** : defect in the coating

Definitions

- Starting/Propagation of a crack:
  According to the reference or the discipline, there can be litigation on these definitions. For example, in fatigue, the word starting is more commonly employed to indicate the appearance of the crack in a healthy material. Whereas in breaking process, one evaluates the starting of an existing crack. In fatigue, one implies the propagation under cyclic loading. Whereas in breaking process, one employs the word propagation to indicate a tear under monotonous loading. In order to remove any ambiguity, one employs in this document the word **starting** to indicate the aspect stability of an existing crack; will it be propagated or not? The word is also employed **propagation** to indicate the evolution of the face of crack under monotonous loading:
  - if quick change - propagation unstable: cleavage
  - if progressive evolution - stable propagation: ductile tear

- K_I , K_{II} **and** K_{III} **, stress intensity factors** modes I , II and III , respectively, valid in linear thermoelastic mechanics, providing the characteristics of the stress fields to the accesses of the bottom of crack
- G **, rate of refund of energy** , due to Griffith, valid in or not linear linear elasticity. A link (formulas of Irwin) exists between the factors K_I , K_{II} , K_{III} and G in linear elasticity. For example, in plane deformation: $G=\frac{1-\nu^2}{E}\left(K_I^2+K_{II}^2\right)+\frac{1+\nu}{E}K_{III}^2$
- G_{ENL} , rate of refund of energy in post treatment of a nonlinear thermoelastic calculation
- J **, integral of contour**, due to Rice, equivalent to G in plane linear elasticity, the rate of refund of energy of a structure containing characterizes a crack at the time of the projection of this one. This integral is independent of contour when the material is elastic
- **tenacity** of a material is its aptitude to resist the propagation of a crack, it is defined by the stress intensity factor K_{IC} or when plasticity is confined at a peak of crack by the integral of Rice-Cherepanov (J_{IC}). G_{IC} is the rate of refund of critical energy. K_{IC} and G_{IC} the criteria of resistance of material to the propagation of cracks characterize
- In plane elasticity, there exists an equivalence between the criteria of propagation:
- $G<G_{IC}\,;K<K_{IC}\,;J<J_{IC}$ **The crack is stable**
- $G\geq G\,;K\geq K_{IC}\,;J\geq J_{IC}$ **The crack is unstable**
- K_{IC} or J_{IC} are obtained on standardized test-tubes.
- **Brittle fracture** : J_{IC} is tenacity with starting
- **Ductile tear** : The energy of starting and propagation of a fatigue crack in quasi static conditions are necessary to know the tear strength of steels.

  - $J_{0,2}$: energy of starting for a value of $\Delta a=0{,}2\,mm$
  - $\frac{dJ}{da}$: resistance to the propagation

- **impact strength** corresponds to conditions of rupture in dynamic conditions (deflection tests per shock). There exists little of data of tear strength of materials in power station whereas there exists a very important database on the values of impact strength. For certain materials, correlations were installation between impact strength and the tear strength

- **Essai Charpy** : test measuring impact strength, energy necessary to the breaking by shock of a standardized notched sample (KCV or KCU according to the shape of the notch)

- **Curve master degree** : Main curve of the tenacity (proposed by Wallin), which describes at the same time the evolution of tenacity according to the temperature and the dispersion of tenacity at a given temperature. This dispersion is characterized by a law of distribution of Weibull.
- **Factor of margin** : relationship between tenacity material K_{IC} and the factor of intensity of the constraints corrected plastically K_{CP} in a given point of the face of crack. $FM=\frac{K_{IC}}{K_{CP}}$
  - $FM\geq 1$: mechanical resistance tank is justified
  - $FM<1$: mechanical resistance tank is not not justified by this method
- **Factor of intensity of the constraints corrected plastically** : depends on factors intensities of the constraints rubber band $K_{elas}(t)$ and plastic $K_{plas}(t)$ evolving in time t . One a:
  - $\mathrm{K}_{\mathrm{CP}}(\mathrm{t})=\mathrm{K}_{\mathrm{elas}}(\mathrm{t})+\chi\Delta\mathrm{K}_{\max}(\mathrm{t})$
  - where $\Delta K_{max}(t)=max\left\{0,max\left[\begin{array}{c}0<u\leq t, u\in phases\,croissantes\\ i.e.\,u\,tel\,que\,\frac{dK_{elas}}{ds}(u)>0\\ \chi(K_{plas}(u)-K_{elas}(u))\end{array}\right]\right\}$
  - and $\chi=\left\{\begin{array}{lll}1 & si\,max(K_{plas})\geq max(K_{elas}) & :cas\,DSR\\ -1 & sinon & :cas\,DDR\end{array}\right\}$
- **Factor of margin lawful** : it is defines as:
  - $FM_{ASN}=\left\{\begin{array}{lll}FM & si\,max(K_{plas})\geq max(K_{elas}) & :cas\,DSR\\ \frac{K_{IC}}{K_{elas}} & sinon & :cas\,DDR\end{array}\right\}$

2 Introduction

This methodological guide constitutes a help to facilitate the apprehension of a study of harmfulness of generic or exceptional defects highlighted on the metal structures. The purpose of this document is mainly to inform the engineer in breaking process about the approaches available in *Code_Aster* to solve a given problem. This document refers to the documents of the U2 type in the documentation base of *Code_Aster* ; IL does not point out the formulations detailed in the reference documents R, nor the means of using these features sufficiently clarified in the documents of use U4 or U2 but delimits the perimeter of application of each approach.

Thus, one proposes to point out the various approaches available and to briefly define their field of application. The field of validity of these approaches can be dependent, that is to say with the definition of the model (brittle fracture, ductile rupture,…), that is to say with the degree of maturity of the approach on its implementation industrial (heaviness of calculations, developments still necessary, parameters materials nonavailable…).

However, we cannot describe all the types of study possible or carried out in breaking process. The user will make the choice of the approach according to the requirements and conditions of his study. References to some notes of study of which the goal was to validate these approaches or to apply them to industrial cases are also given.

The approaches on starting and stability are dominant in this document to the detriment of those which treat the tear. The methods of propagation under monotonous loading to simulate the ductile tear remain to be been developed in Code_Aster.

3 Short outline on the breaking process

Any metal part subjected to requests mechanical, thermal, hydraulic or chemical is exposed to cracking. The defect or the crack comes from the manufacturing (welding) or a process of damage of material during operation (tiredness, creep, stress corrosion,…). As soon as the cracks become of sufficiently large size so that the volume which surrounds them satisfies the assumptions with continuity with mechanics with the continuous mediums, the mechanical study must be carried out in the field of the breaking process. The studies must then estimate the degree of harmfulness of these cracks: is they inoffensive and will thus their presence be tolerated for a more or less long time without risks, or on the contrary are they harmful, which requires to repair or replace the component?

3.1 Starting/Propagation

On certain types of components, mechanisms of degradation like creep, stress corrosion or tiredness are at the origin of the creation of cracks which can then cause the brutal rupture.

The breaking process makes it possible to predict harmfulness **of an existing crack** : the kinetics of propagation of defects and their critical sizes. If the phase of propagation is very fast, the final rupture is known as brutal or unstable, in the contrary case, the rupture is stable what characterizes for example the ductile tear. The propagation can lead to a total rupture or a stop of the crack.

3.2 Brittle fracture (cleavage)/ductile Rupture (tear)

The temperature and the speed of deformation of a material are two parameters which characterize its state: fragile or ductile. Certain metallic materials are fragile below a temperature known as temperature of fragile/ductile transition (cf appears schematic Figure 3.2-a), and in particular ferritic steels (low alloy steels and steels carbon-manganese).

The structures are generally calculated so that the nominal constraint undergone does not exceed the elastic limit of material, which puts them safe from unrecoverable deformations. Rupture of a fragile type can then occur on a crack preexistent or created by tiredness, at low temperature and/or high speeds of deformation.

Ductile rupture (tear)

A material is ductile when it becomes deformed plastically before breaking, plasticity is generalized. This plastic deformation can lead to the appearance of a crack which becomes critical when it is propagated. After starting, the growth of the crack is in general slow and stable (according to the characteristics of the loading applied). The ductile rupture relates to materials as copper, lead, the mild steels with room temperature, the austenitic stainless steels. The mechanism of rupture comprises three phases: the generation of microscopic vacuums around preferential sites, growth and the coalescence of the cavities leading to the rupture. The rough surface is in this case of aspect chechmate and rough.

Brittle fracture (cleavage)

Brittle fracture occurs without notable plasticization locally. After starting, the propagation of the crack is fast (the tests reveal speeds of a few hundreds of m/s) and generally unstable (with stop or brutal rupture of the part according to the case). It characterizes fragile materials like glass, the ceramics and the steels irradiated or at low temperature. Impact strength characterizes the capacity of material to store energy when it becomes deformed in an elastic way. The fragile material is fractured under the effect of a weak energy. The more important energy required is to deform it, the more the material is tough. The impact tests are carried out on test-tubes of the type Charpy and the toughness tests are generally carried out on test-tubes of the type CT . In the case of a fragile material - contrary to ductile material - plasticity remains confined in bottom of crack, this kind of phenomenon is known under the term of “cleavage”: the propagation of crack is done by separation of atomic plans and the rough surface consists of plans of brilliant aspect. To a fragile material a low tenacity corresponds. Tenacity with starting K_{1c} is not an intrinsic data with material, it depends on the geometry and the rate of the triaxiality.

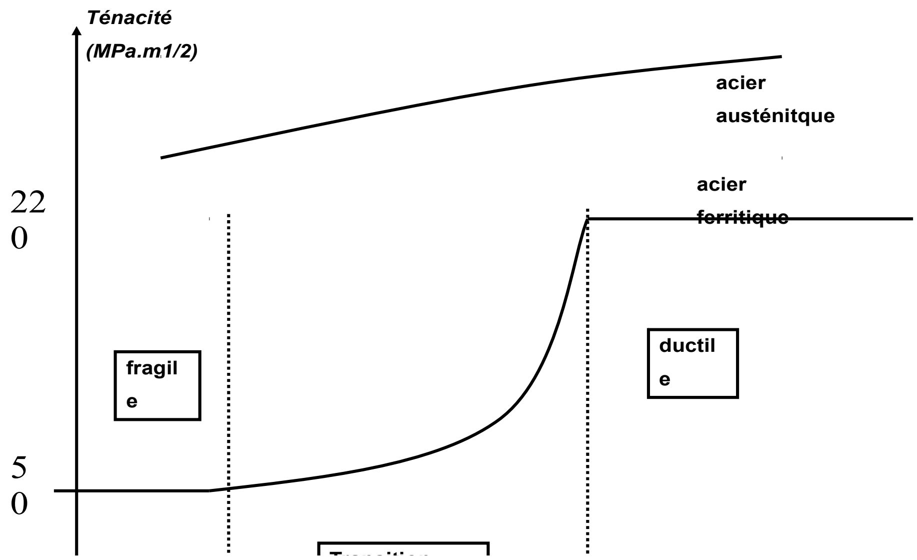


Figure 3.2-a . Curve of fragile transition – ductile

4 Summary or minis user guide of the approaches

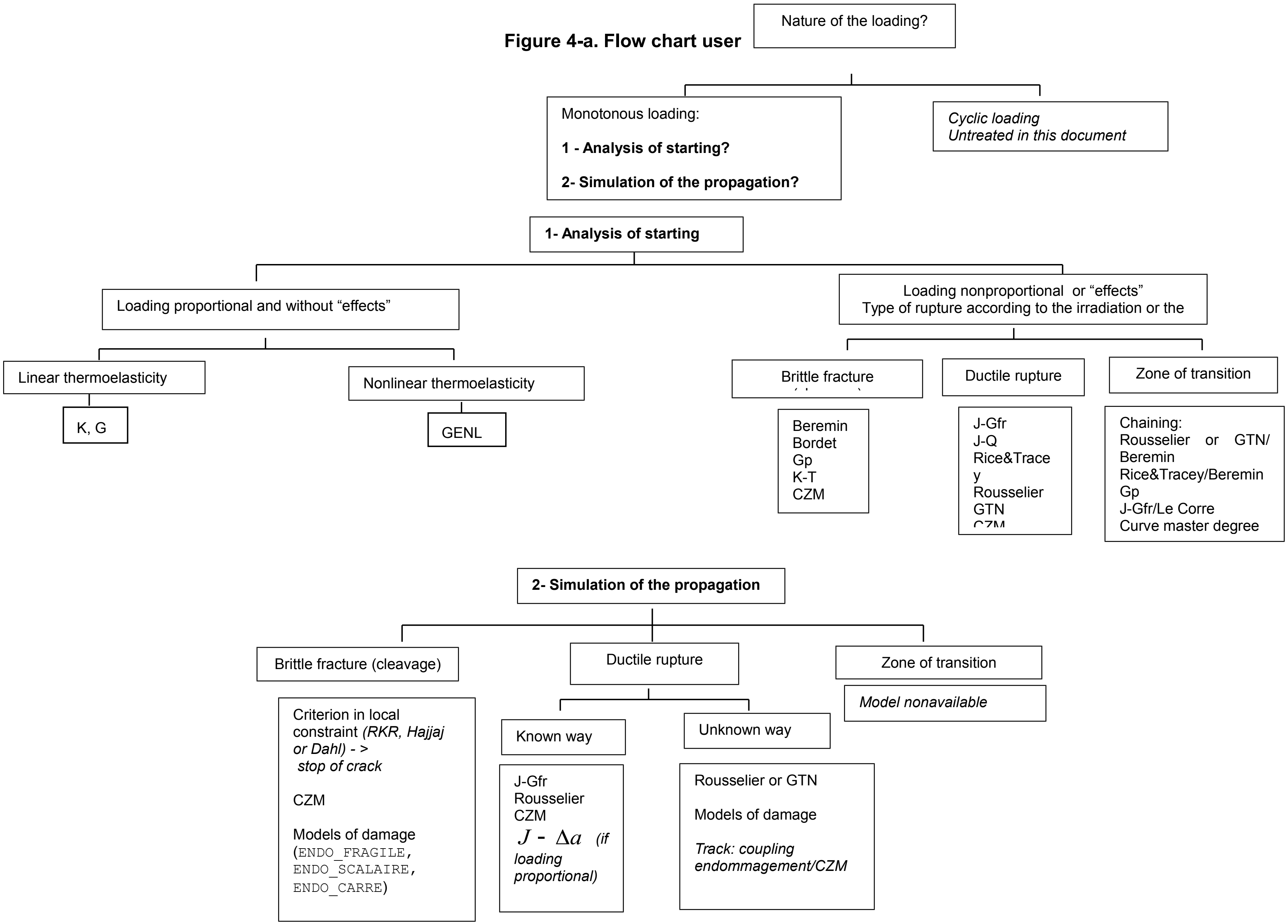
The table and the flow chart following aim at giving in a fast way an indication to the user on the field of application of a given approach. In other words, would it be valid to represent starting in brittle or ductile fracture? Would it be valid to simulate the propagation in brittle fracture or ductile?

This table allows a short reading of the document, helping to put the questions which will switch the reader according to the conditions of his study towards the approaches described in the document. These approaches exist or are in the process of development in *Code_Aster*. By preoccupation with a legibility, the table and the flow chart contain the minimum of information, does not evoke the characteristics of the studies, the maturity of the approaches, the advantages and the disadvantages of the approaches. For more details, it is necessary to refer to the text, the tables, the references like to relative documentations in *Code_Aster*.

Type of approach		in *Code_Aster*	Phenomenon represented				
			Starting fragile	Ductile starting	Fragile propagation known way	Ductile propagation known way	Ductile propagation unknown way
classic	G	Yes	Yes	Not	Not	Not	Not
	G_{ENL}	Yes	Yes	Not	Not	Not	Not
2 parameters	$K-T$	Not	Yes	Not	Not	Not	Not
	$J-Q$	Not	Not	Yes	Not	Not	Not
energetics or total	Gp	Yes	Yes	Not	Not	Not	Not
	Gtp	Yes	Not	Yes	Not	Yes	Not
	$J-G\ fr$	Not	Not	Yes	Not	Yes	Not
local	Rousselier GTN	Yes	Not	Yes	Not	Yes	Yes
	Beremin Bordet	Yes	Yes	Not	Not	Not	Not
	constraint criticizes (RKR, Hajjaj and Dahl)	Yes	Yes	Not	Yes and stop	Not	Not
	fragile damage (ENDO_FRAGILE, ENDO_SCALAIRE)	Yes	Yes	Not	Yes	Not	Not
alternative	CZM		Yes	Yes	Yes	Yes	Yes

Table 4-1 . Which approach for which scope of application?

Figure 4-a. Flow chart user



5 Panorama of the approaches in breaking process

The comprehensive approach is known for a long time, but it is with field of limited validity. The local approach is with more extended validity, but it is not with the range that informed mechanics. The local approaches make it possible to apprehend and understand all the more complex phenomena as they can reduce the degree of conservatism of the codified approaches based on the comprehensive approaches.

The theory of brittle fracture rests on criteria of rupture "comprehensive approach" established in a macroscopic way and it does not pose the problems of behavior because the material is often considered elastoplastic with confined plasticity. The purely macroscopic approach of brittle fracture is not valid any more when the material is strongly plasticized, because it is not possible any more to represent the crack like a surface of discontinuity of displacements and constraints. Dissipation is concentrated in bottom of crack and it is difficult to separate plastic dissipation from the dissipation of rupture. In ductile rupture, a "local approach" based on a mechanical approach is often necessary.

When an approach becomes generic and applicable in a rather broad range of situations, it becomes also complex.

5.1 Classical approach

The linear elastic breaking process rests on the stress intensity factor which characterizes the deformation and stress fields in the vicinity of a crack. In plasticity, the classical breaking process has rigorous bases only by analogy with nonlinear elastic behaviors (in the case of loadings nonproportional and isotropy), for which the integral of contour J or the rate of refund of energy is the fundamental parameter.

In or not linear linear elasticity (cf § 7.1 and § 7.2), three parameters can calculated beings:

- J, the integral of Rice: integral of contour – the experimental calculation of J is obtained by the surface under the curved force-opening of the test-tubes (CT or $SENB$ in general). This parameter is not available in *Code_Aster*.
- G, the rate of refund of energy: integral of field adapted to calculation by finite elements (cf [55], [56]),
- K, coefficients of intensity of constraint corresponding to the 3 modes, associated with the singular fields in bottom of crack. The latter have a direction only in linear elasticity (cf [58], [60]).

In elastoplasticity, this parameter is strictly valid only when elastoplasticity can be comparable to nonlinear elasticity, i.e. **for a radial monotonous loading**.

L' classical approach presents several limitations when it is applied apart from its field of validity ("effect small defect", "effect of triaxiality", "effect of hot preloading",…) or in the case of loading nonproportional, which led to developments of the global or energy new approaches or the local approaches. It proves that in certain typical cases J_{1C} or K_{1C} can depend on the geometry and are not intrinsic with material.

Effect small defect:

It proves that the tenacity, which is supposed to be intrinsic with material, seems to depend on the size of the defect, or more exactly of the report of the size of the defect on the size of the ligament (in fact, it is the rate of triaxiality affecting the vicinity of the defect which is responsible for this effect). Tenacity in the case of a small defect is higher than that of a great defect.

Effect of geometry:

The geometry of the medium 'test-tube or structure' influences the nature of the rupture, in particular in zone of transition. At a given temperature, for the same material and with equivalent loading, a test-tube CT breaks into fragile whereas a fissured pipe breaks into ductile. For test-tubes AE notched homothetic, the dispersion and the median value of the diametrical deformation with rupture decrease when the diameter of the test-tube increases. More a/w is weak, more the value connect J_{1C} is high.

Effect "mismatch":

In the presence of two materials, the classical approach is valid when plasticity remains confined in a homogeneous zone. When the field of plasticization covers two materials, the classical approach is not valid any more.

Effect of triaxiality "constraint effect":

To be able to use the classical approach in elastoplasticity, it should be supposed that the loading is proportional what is often far from being the case for the real structures. The loading and the geometry influence the type of stress field in bottom of crack in a structure. The field of the constraints in bottom of crack can become complex compared to the usual conditions of loading proportional adopted on a test-tube.

Effect of hot preloading:

Effect of hot preloading or "WPS: Pre-Stressing Warm", following a rise in temperature, the material passes from the fragile field to the ductile field, and a mechanical loading is then applied (hot preloading). After cooling of the test-tube and dimensional check of tenacity, one finds a value of tenacity higher than that of material tested without preloading. Hot preloading has a beneficial effect induced by émoussement of the crack and the appearance of residual stresses.

Effect of loading nonproportional:

Several situations induce a loading nonproportional in point of crack what makes the approach classical nonvalid:

- problem of discharge following a thermal shock, although in certain cases the correction Beta can be applied to suppose that behaviour after discharge is elastic (cf [72]),
- problem of nonmonotonous loading or not proportional, following a propagation, with a thermal transient, the presence of residual stresses or a mixed mode.

If the loading is unspecified, one can use a local approach (Beremin (cf. [57]) or Bordet (cf [59]) or an energy approach (cf [62]) in the event of cleavage, or Rousselier and GTN for the tear (cf [64], [65] and [83]) who do not need the assumption of loading proportional.

5.2 Approach with 2 parameters

This approach is developed to answer the dependence of tenacity with the triaxiality. It rests on the extension of the expression of the fields in bottom of crack with terms of a higher nature. More complex than the classical approach, it enriches it by the introduction by a second parameter which takes account of triaxiality, of the stability and the zone of plasticity. It loses its validity when the loading is not proportional any more: load followed by a discharge, propagation of cracks, residual stresses, mixed mode… or when the material viscous or is subjected to a thermal transient. This approach very requires the installation of one a large number of tests to build the locus of the rupture (cf § 7.12). The comprehensive approach with two parameters is not developed in *Code_Aster* (cf [48]).

5.3 Energy approach

Within an elastic or elastic framework nonlinear, energy approach led to the calculation of the parameter G , rate of refund of energy. In the case of a confined plasticity, it caused the development of the approach Gp (cf [62], [70]) who is an energy approach avoiding the paradox of Rice by the use of a notch (cf §7.3).

In a case of a ductile material or in extended plasticity, it is declined with the calculation of the parameter Gtp (cf. [36]) who from now on is reabsorbed in Code_Aster.

This approach was applied within the framework of European project VOCALIST to the case effect small defect and within the framework of the European project SPALLS on the case hot preloading WPS.

It is possible to employ this approach in the cases of loadings nonproportional.

5.4 Local approach of the rupture

The description of the rupture passes by a local modeling of the damage. The rupture is characterized by an intrinsic variable with material. It allows the definition of a local criterion of the rupture based on considerations materials and geometrical the level of the bottom of crack.

In brittle fracture:

In this case, it is enough to analyze the harmfulness of the defect to starting. The models are in general criteria in postprocessing of a calculation.

For brittle fracture or cleavage, the model more used is the model of Beremin (cf [8], [57], [66] [84]), based on the theory of the weakest link, with a constraint of Weibull and a statistical law of distribution of microphone-defects (cf § 7.4). This model also makes it possible to give an account of the scale effect, i.e. the variation of the risk of rupture with respect to the size of the test-tube. The users of the Beremin approach recommend the use of a crack or more recently of a notch, with a size of mesh of $50\,\mu m$ as that was a long time allowed. Indeed, the notch has a morphology more adapted than the crack to collect the fields in elastoplasticity. The advantage of the Beremin approach is that it is largely tested. The taking into account of the triaxiality is intrinsic with the method. Local approach of Bordet (cf § 7.5), introduced recently into *Code_Aster* (cf. [59], [67], [81]) is an extension of Beremin. It allows in more one treatment improved in the case of hot preloading thanks to the taking into account of active plasticity. Whereas active plasticity is taken into account in modified Beremin, the model of Bordet allows besides taking into account the effect of plasticity on the microphone-defects at the origin of cleavage.

In ductile rupture:
The models for the ductile tear raise several difficulties. The determination of the parameters materials is not standardized and is carried out on a case-by-case basis. The approaches suggested in the literature are classified in 3 families:

- **Uncoupled models** : the damage of material does not affect its total behavior. The rupture of the structure occurs when the damage reached a breaking value which is supposed to be intrinsic with material. These models are used to analyze the crack initiation.
- **Coupled models** : based on elastoplastic potentials endommageables or micromechanical approaches. The behavior of material and the damage are dependent. The rupture of the structure is described implicitly by the softening of the total answer of the structure.
- **Semi-coupled models** : intermediate models with the two preceding families. The total behavior is not affected by the damage but there is a local coupling of the damage with the behavior. The rupture of the structure takes place when local softening is reached.

Models uncoupled from Rice & Tracey (cf [59] and § 7.11), or coupled of Gurson [83] of Rousselier (cf [64] and § 7.9) are intended for the ductile rupture. The limitations relative to these approaches come from the difficulty of identification of the parameters and the transferability test-tube-structure.

5.5 Alternative approach - CZM

It is an approach largely developed in the literature which is total on the minimization of energy and local by the fine description of the residual forces in bottom of crack. It makes it possible to predict in a robust way the kinetics of propagation (cf [77], [49]). The ambition of these models of cracking is to represent the evolution of surfaces of damage and or rupture of a solid in 2D or healthy 3D or partially fissured subjected to a broad range of requests (mixed, cyclic mode with amplitude unspecified, thermal,…). The characterization of the parameters materials, in particular the constraint criticizes, is a paramount stage for the good use of these elements. It is an approach which makes it possible to predict starting and the propagation according to a way known a priori (cf. 7.8). However, the size of the crack to starting is not precise because it is dependent on the size of the cohesive element in the grid. It is less influential on the result expected in the analysis of the propagation.

Table 5.5-1 . Documentations in Code_Aster

Methods		Documents R	Documents U	U2 documents
Classical approach	G	R7.02.01	U4.82.03	U2.05.01
	K	R7.02.05 R7.02.08	U4.82.05	U2.05.01
	G_{ENL}	R7.02.03	U4.82.03	U2.05.01
2 parameters	$K-T/J-Q$	Approach nonavailable in Code_Aster		
Energy approach	Gp	R7.02.16	U4.82.31	U2.05.08
	$J-Gfr$	Approach nonavailable in Code_Aster		
Local approach	Rousselier GTN	R5.03.06 R5.03.29	U4.51.11 U4.51.11	Nonavailable
	Beremin	R7.02.04	U4.81.22 and U4.81.31	U2.05.08
	Bordet	R7.02.06	U4.81.41	U2.05.08
	Rice&Tracey	R7.02.06	U4.81.22	Nonavailable
	Critical stress	Documentations of BEHAVIOR (U4.51.11) and of DEFI_MATERIAU (U4.43.01)		
	Models of damage (ENDO_FRAGILE, ENDO_SCALAIRE, ENDO_CARRE)	U2.05.06 and U4.51.11 which switch towards the laws of damage in quasi static (brittle fracture) and techniques of regularization		
Alternative approach	CZM	R7.02.11	U3.13.14	U2.05.07

Table 5.5-2 . Which type of parameter or approach for a given field?

Approach	linear elasticity	nonlinear elasticity	confined plasticity	wide plasticity	limitations
classic or energetics	K , G	G_{ENL}	G_{ENL} if radial monotonous loading if not 'effect' or Gp	Gtp	restricted field of validity identification of the critical parameters conservatism
2 parameters	$K-T$	$J-Q$	$J-Q$ if radial monotonous loading if not 'effect'	$J-Q$ if radial monotonous loading if not 'effect'	identification of the critical parameters conservatism
local			Beremin, - Bordet Critical stress ENDO_FRAGILE ENDO_SCALAIRE ENDO_CARRE	Rice and Tracey, Rousselier	implementation heavy identification of the parameters
CZM	Prediction identical to the classical approach if σ_c is sufficiently large (for the propagation)		Prediction very sensitive to the ratio $\frac{\sigma_c}{\sigma_y}$	Model very much used in the literature – under development in Code_Aster	identification of the parameters

For each type of approach indexed in the §5, one gives these documentary references in Code_Aster in Table 5.5-1 and one recapitulates his field of validity and his limitations in Table 5.5-2 .

6 Approach for a study in breaking process

A document important to consult before starting a study in breaking process with Code_Aster is the U2.05.01 documentation quoted in [76].

6.1 Grid

6.1.1 Crack or notch

The grid constitutes a significant portion of the study and especially in breaking process when the defect should be netted very precisely. In all the cases, a precise calculation of the mechanical fields at a peak of the crack/notch is paramount. With this intention, it is largely recommended to net finely in bottom of crack or to use quadratic elements with elements of Barsoum at a peak of crack if calculation is elastic, and to employ under-integrated elements or incompressible elements if calculation is elastoplastic. It is known that a radiant grid in bottom of crack led to a quality of the solution in term of rate of refund of energy higher than that obtained with other types of grids and than lower costs in term of performance in computing times.

The grids of cracks are largely used in the tools trades when it is necessary to use the classical approaches of calculations of G , rate of refund of energy. The cracks are definitely easier to model than the notches on grids in 3D.
When one is interested in a total result got on a test-tube CT or AE , the defect can be represented by a crack or a notch. On the other hand, to precisely know the mechanical fields around the point of the defect, it is recommended to net a notch. Indeed, the notch makes it possible to smooth the singular mechanical fields in bottom of crack and to reduce the zone in which the constraints are kicked up a rumpus.

The grid of a notch in 3D is tiresome. Like calculations with Gp grids of notches with chips require, on which this method rests, of Gibi scripts were developed for this purpose. The definition of the definite block fissured with Gibi, it there has about twenty years, is inherent in the presence of a torus around the bottom of crack with a radiant grid.

Under development:
- A procedure of insertion of crack with radiant grid in a healthy structure with Salomé.
- A procedure of insertion of crack with free grid with the Zcracks tool.
- A library of grids of test-tubes fissured in 3D is envisaged in Salomé-Meca. Parametric grid of a test-tube CT in 3D is available right now (in overload) in the form of plug-in.

6.1.2 XFEM

This method makes it possible to avoid netting the crack. It is based on the definition and the enrichment of the model by level-sets (cf [78]). The implementation of a calculation with XFEM is recalled in the document [76]. The criteria and method of refinement for calculations as well as a synthesis of the developments and applications are the object of the references [53] and [54]. This method is operational at the present time on elastic structures. The extension of the validation of its field to plasticity is in the process of development.

6.2 To evaluate the risk of starting: The crack T will it be propagated?

6.2.1 In thermoelasticity

In **linear thermoelasticity**, the classical comprehensive approaches are applicable:
- Calculation of the rate of refund of energy G (cf [68], [55]),
- Calculation of the stress intensity factors K (cf [58], [69]),
- Comparison of the stress intensity factor with the tenacity or the rate of refund of energy with critical energy,

In **nonlinear thermoelasticity**, the classical comprehensive approaches are applicable only in the case of a loading radial and proportional. They are based on the calculation of the rate of refund of energy G_{ENL} in postprocessing of a nonlinear thermoelastic calculation (cf [68], [56]),

In **brittle fracture**, calculation of G_{ENL} in comparison with G_c or calculation of K_G from G_{ENL} and comparison with the tenacity of material K_{1C} . Estimate of the probability of the rupture via the “Curve Master degree” (cf [24]),

In **ductile rupture**, G_{ENL} is compared to $J_{0,2}$ to study the risk of starting of the tear,

These approaches are applicable in a well defined field of validity (nonlinear elasticity thus loading proportional, and when the crack is sufficiently large), outwards of which we observe effects :

- loading nonproportional following:
  - a discharge,
  - a propagation,

    - a thermal transient,
    - a presence of residual stresses,
    - a “constraint effect” or effect of triaxiality
- Mismatch effect (2 materials)
- Effect “small defect”
- Effect of hot preloading or “WPS”

6.2.2 In elastoplasticity - fracture brittle

For a medium where plasticity remains confined, the medium remaining elastic in its globality, the comprehensive approaches and local of the breaking process or energy make it possible to apply the criteria of the breaking process. However, according to the parameters materials which one lays out, time that one can grant for the realization of the study, the availability of an adequate grid or the capacity to do it are arguments which militate for an approach or another (cf. Table 6.2.2-1) :

- Energy approach Gp (cf [70]): The advantage of the approach Gp is that it is deterministic and approaches the classical approach of the engineer J. A relation between the two parameters Gpc, the value criticizes Gp and the ray of the notch could be established, which facilitates setting in data of the parameters. The taking into account of the triaxiality is direct with this approach. Let us note that there remain points to be improved in the approach Gp to make it still more accessible to the engineer:
    - Although energy approach Gp the comprehensive approach of share its base approaches on energy principles, it in the case of depends on the ray of the notch the loadings nonproportional/nonmonotonous and thus thickness of the zone in chips.
    - The grid of the chips is not easily realizable, and is obligatory in 3D. It is moreover necessary to control techniques of refinement of grid to avoid the stretching of the meshs in causing bottom of notch of the stress concentrations.
    - It is supposed that the approach Gp is valid for all the loadings nonproportional. The calculations carried out under these conditions cannot be validated without accompanying them by broad trial runs.
- Local approach of Beremin: This approach has the advantage of being largely used. However, it is a probabilistic approach thus the results are difficult to interpret and it is not recommended in the top of the zone of transition. The parameters materials must be finely identified in dependence at the temperature.
- Local approach of Bordet: This approach requires a large number of nonobvious parameters to identify. The macro one `POST_BORDET` is developed in Code_Aster.
- Approach based on the constraint criticizes (Hajjaj [9], Ritchie, Knott, Rice, [15], Dahl [12]): Approach developed for the treatment of the stop of cracks in viscoplasticity. The criterion of rupture is a comparison between the maximum principal constraint and the critical stress. This approach allows to simulate the projection of the crack by cancellation of the rigidity of the elements in bottom of crack, when the criterion is reached.
- Approach with cohesive elements (cf [61], [69]). This approach was compared with the classical approach in the note quoted in [20], is not often used in brittle fracture for lack of parameters materials. However, the identification of these parameters (2 only) can be done by confrontation with other models or the experimental results. It is an approach which makes it possible to predict cleavage on a known way.
- Approach with 2 parameters $K-T$ into fragile and $J-Q$ into ductile which makes it possible to take into account of the effect of the triaxiality in a qualitative way (cf [48], [28]). These approaches are not developed yet in *Code_Aster*.
- Laws of damage in quasi static can be used in brittle fracture (cf [80]). However, they are rather used for the simulation of the cracking of the géomatériaux one, which does not prevent them use for simulation of the damage of metallic materials with the parameters adequate materials and of regularization.

Table 6.2.2-1 . Advantages and disadvantages of the approaches in brittle fracture

Approaches		Advantages	Disadvantages/limitations
Classical approach	G / G_{ENL}	• Easy to use	• Field of validity restricted to the monotonous loading
Approach with 2 parameters	$K-T$ [1]	• Taking into account of the triaxiality • Present in the English code $R6$ • Connection of cracks in mixed mode • Recommended for short cracks	• Second parameter difficult to identify requiring an important experimental base • Nonvalid if loading nonproportional
Energy approach	Gp	• Deterministic energy approach (coherence with J) • Pas de restrictions with respect to the “effects” in certain cases • Used by engineering	• Implementation difficult • Heavy grid • Method will intra EDF
Local approach	Beremin	• Diffused with the international one	• Specific, known parameters for some standard materials • Probabilistic approach
	Bordet	• Taking into account of plasticity activates as in modified Beremin • Possibility of the taking into account of stop of propagation of the microscopic cracks	• Many parameters • Validations to be made
	Constraint criticizes (RKR, Hajjaj and Dahl)	• Good adequacy enters the digital and experimental results • Easy to implement	• Validation to continue in particular to elucidate the dependence of the constraint criticizes with the shape of the test-tube
	Models of damage (ENDO_FRAGILE, ENDO_SCALAIRE, ENDO_CARRE)	• Any type of loading • Prediction of the way of crack	• Identification of the parameters
Alternative approach	CZM	• Draft at the same time the starting and propagation of the defect • Powerful calculations • Easy to implement	• Parameters materials to be identified • Way of cracking known a priori (even disadvantage for the other methods

1 Approach nonavailable in Code_Aster

6.2.3 In elastoplasticity - rupture ductile

The models for the ductile tear raise several difficulties. The determination of the parameters materials is not standardized and is carried out on a case-by-case basis. Even notices that for brittle fracture, according to the parameters materials which one lays out, time that one can grant for the realization of the study, the availability of an adequate grid or the capacity to do it is arguments which militate for an approach or another (cf. Table 6.2.3-1):

- Energy approach Gtp : This approach is based on the calculation of total energy in post treatment of an elastoplastic calculation with the operator CALC_G (cf [68]). This approach was used some ten years ago and showed an advantage compared to the classical approach $J-\Delta a$, because of its applicability in the case of complex loadings. Its weak point lies in the definition of the criterion which includes the rupture and plasticity, which can over-estimate the bound energy on the rupture. She was confronted recently with CZM on a study of starting of crack in an elastoplastic medium (cf. 20). This approach from now on is reabsorbed in Code_Aster.

- Local approach découplée – Rice and Tracey : It is one criterion of ductile starting simple because it rests on an analytical formula according to the constraints and speeds of deformation at every moment of calculation. The advantage of this approach is that it simple and is largely used. Its employment must remain limited to preliminary analyses (cf [59])

- Coupled local approach of Rousselier: ROUSS_PR, ROUSS_VISC (cf [65]) and model of ROUSSELIER in great deformations (cf [64]) and of GTN [83] . These models present several difficulties of implementation numeric work: identification of the parameters, adaptation of grid around the crack, adaptation of the boundary conditions, not convergence of the law of behavior. Recommendations which help to overcome these difficulties (incompressible elements – great deformations – adaptation of grid to take into account the discharge) must facilitate convergence.

- Approach with 2 parameters (cf [48]): Approach $J-Q$ is promising because it will allow an application in the three fields fragile, ductile and transition and it makes it possible to represent the connection of cracks. It only remains nevertheless applicable within a framework of loading proportional. This approach is not available in *Code_Aster*.

- Cohesive models (cf [77], [61]). The taking into account of the triaxiality proved to be necessary for their good representativeness in 3D.

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Table 6.2.3-1 . Advantages and disadvantages of the approaches in ductile rupture

Approach		Advantages	Disadvantages/limitations
Approach with 2 parameters	$J-Q$ [2]	• Present in $R6$ • Recommended for short cracks • Connection of cracks in mixed mode	• Identification of the second parameter requiring an important experimental base • Nonvalid if loading nonproportional
Energy approach	Gtp	• Simple criterion • Resemble J • Valid if the loading is complex • First comparison with CZM	• Implementation heavy • The criterion of rupture integrates plasticity • Is not valid in kinematic work hardening • Is not yet valid in great deformations
Local approach	Rousselier	• Good representativeness of the results • Unspecified way of cracking	• Heaviness of calculations • Sensitivity to the grid with the parameters of regularization
	GTN		• Without Sensibility with the grid with the parameters of regularization for version NON_LOCAL
	Rice_Tracey	• Implementation simple	• Approach simplified for starting
Alternative approach	CZM	• Powerful calculations • Easy to implement	• Taking into account of the triaxiality in progress • Parameters to identify Approach to be validated • Way of cracking known a priori (even disadvantage for the other methods)

2 Approach nonavailable in Code_Aster

6.2.4 In elastoplasticity - zone of fragile/ductile transition

Certain types of thermomechanical loadings place the potential rupture in zone of the fragile/ductile transition. One makes a summary of the approaches tested or in the course of tests in this zone (cf. Table 6.2.4-1) :

- The Rousselier/Beremin chaining is implemented in the study on the passage of impact strength at tenacity (cf [30]). In this case, the ductile rupture is described by the model of damage coupled of Rousselier and the model of post treatment of brittle fracture by cleavage of Beremin. No coupling between the two phenomena of ductile and fragile rupture.
- The chaining Rousselier/Rice and Tracey and Rousselier/Beremin was implemented in a study of rupture of the lines of welded pipings of type ASG N4 (cf [33]).
- Coupling of Corre/ Gp : Gp for the prediction of the moment of starting, Corre for the prediction of cleavage. This coupling is carried out with a representation of the defect by a notch. The simulation of the ductile propagation remains to be determined, the approach Gtp pretence legitimates since based on a notch. The capacity of coupling must still be checked.
- The chaining $J-Gfr$ /Le Corre: $J-Gfr$ for the ductile propagation and Le-Corre for the prediction of the nature of starting. The Le-Corre model proposed at the ECA (cf. 7.6) use the concept of constraint threshold, coupled to a value of threshold volume. This model is based on the calculation of J , therefore can predict starting only in the case of loadings monotonous/proportional (cf [46], [81]). This model is not available in *Code_Aster*.

Table 6.2.4-1 . Advantages and disadvantages of the approaches in zone of transition

Approach		Comments
Energy approach	Coupling Corre/ Gp	• Validity of Gp in zone of transition is not guaranteed yet • Simulation of the nondefinite propagation
	Chaining $J-Gfr$ / Le-Corre	• Easy to implement on industrial studies • Damage and propagation uncoupled • Known way of the propagation • Validate for loadings proportional • Validity of this approach in zone of transition is not guaranteed yet
Local approach	Rousselier/chaining Beremin or Rousselier/chaining Rice&Tracey	• Model to be refined in the top of the transition for taking into account from the triaxiality • Different sizes of the elements between the two approaches

6.3 To evaluate the size of the crack: If the crack is propagated, of how much? in which direction? T will it stop?

6.3.1 Cleavage

In brittle fracture, among the approaches quoted with the § 6.2.2 :

- Approach CZM can evaluate the projection of the crack, according to a way known a priori. It was also used within the framework it project Ferments to simulate the stop of crack of a defect under coating (cf [53]).
- Approach based on the constraint criticizes (Hajjaj [9], Ritchie, Knott, Rice, [15], Dahl [12]): Approach developed for the treatment of the stop of cracks in viscoplasticity. The criterion of rupture is a comparison between the maximum principal constraint and the critical stress. This approach makes it possible to simulate the projection of the crack by cancellation of the rigidity of the elements in bottom of crack, when the criterion is reached.

Work of thesis of S. Cuvilliez (cf [52]) aim at carrying out a transition between a model from damage and the cohesive elements in the concrete. It is the only reference of model of prediction of the way of cracking per cleavage.

6.3.2 Tear

In the event of plasticity extended in ductile rupture, the evaluation of the extension risk does not return within the framework of the theory of Griffith, other approaches exist, based in most case on concepts of critical constraints and energies. In the same way, we do not have tools allowing the simulation of the ductile propagation in a zone of transition: followed ductile propagation by cleavage. Several tracks are possible but remain to be consolidated:

- Approach Gtp for the simulation of the propagation according to a way known by digging of chips. Only one application exists now (cf [36]).
- Approach $J-Gfr$ ECA, according to a known way.
- Approach CZM , according to a known way (cf [31]).
- The model of Gurson or Rousselier can predict the way of cracking. This model poses a problem of dependence to the grid or the parameters of regularization (cf [29]).

7 Cards ID of the approaches

7.1 Card ID of G/K

Type of approach	Classical approach – linear rubber band
Type of rupture	Fragile
Type of material	Rubber band
Type of phenomenon	Starting
Type of defect	Crack/notch
Type of grid	Radiating/free
Type of loading	Monotonous and proportional
Code_Aster documents	CALC_G : R7.02.01/U4.82.03 POST_K1_K2_K3 : R7.02.05/U4.82.05
Disadvantages	Field of validity restricted to the loading monotonous and proportional Not taken into account of the effects: small defect/geometry/triaxiality/preloading hot
Advantages	Easy to use
Fields of application	Used to evaluate the risk of starting per comparison to tenacity Used to calculate the rate of propagation in fatigue Used to estimate the direction of junction in mixed mode
Outlines	Profit in ergonomics/Choice of smoothing/Calculation at the edges

7.2 Card ID of GENL

Type of approach	Classical approach – rubber band nonlinear
Type of rupture	Fragile with confined plasticity
Standard material	Calculation of G in nonlinear elasticity in postprocessing of a nonlinear elastic design
Type of phenomenon	Starting
Type of defect	Crack/Notch
Type of grid	Radiating/free
Type of loading	Monotonous and proportional
Code_Aster documents	CALC_G : R 7.02.03/U4.82.03
Disadvantages	Field of validity restricted to the loading monotonous and proportional – During a calculation it is advised to use the indicators of radiality to be sure to remain in its field of validity Not taken into account of the effects: small defect/geometry/triaxiality/preloading hot
Advantages	Easy to use
Fields of application	Used to calculate the harmfulness of the defects by comparison to tenacity From G_{ENL} , possibility of estimating the probability of rupture on the Curve Master degree Can be compared with J
Outlines	Profit in ergonomics/Choice of smoothing/Calculation at the edges

7.3 Card ID of GP

Type of approach	Energetics
Type of rupture	Brittle fracture or in zone of transition (confined plasticity)
Standard material	Elastoplastic (confined plasticity) – only one parameter material Gpc critical to identify with one calculation of traction on CT
Type of phenomenon	Starting
Type of defect	Notch
Type of grid	Grid in chips in bottom of notch in 3D; free refined in 2D
Type of loading	Loading nonproportional, discharge
Code_Aster documents	`CALC_GP` : R7.02.16 / U4.82.09 which calls on `POST_ELEM`. U2.05.08
Disadvantages	Implementation hard resting on grid in chips Heaviness of the grids in 3D The use of the method is limited until now at EDF Validity to be extended in discharge and loading nonproportional Validity to be confirmed in zone of transition
Advantages	Similarity with the approach in J Used by engineering Pas de restriction with respect to the “effects” Generic approach – not of parameters materials specific to identify except Gpc the value criticizes Gp Pas de restrictions of use in the case of loading monotonous or proportional Used in several Benchmarks international
Fields of application	Fragile/ductile transition on pipe [19]/Éprouvettes [18] Compared with the experiment on studies [42], [45]
Outlines	Continuation of the validation of the approach in zone of transition

7.4 Card ID of Beremin

Type of approach	Probabilistic local approach – brittle Fracture or in zone of transition
Standard material	Elastoplasticity (confined plasticity) – parameters specific to identify: m , σ_u and V_0
Type of phenomenon	Starting
Type of defect	Notch/crack – recommendations for a notch of ray dependent on Kj with rupture
Type of grid	Radiating or regulated refined on a zone around the point of crack
Type of loading	Loadings nonproportional
Code_Aster documents	Weibull - R7.02.04 / POST_ELEM – U4.81.22 and U2.05.08 / POST_BEREMIN – U4.81.31 and U2.05.08
Disadvantages	Materials specific to identify Interpretation of a probabilistic result
Advantages	Diffused with the international one Used on industrial cases Effect of structure [33] Correlation between impact strength and tenacity [30] Used in the studies [38]
Fields of application	Test-tubes CT , Charpy – Material of Tank in the zone of transition
Outlines	SHORT-NAP CLOTH

7.5 Card ID of Bordet

Type of approach	Probabilistic approach – brittle Fracture or in zone of transition
Standard material	Elastoplasticity (confined plasticity) – a large number of parameters materials
Type of phenomenon	Starting
Type of defect	Notch/crack
Type of grid	Radiating or regulated on a zone around the point of crack
Type of loading	Loadings nonproportional
Code_Aster documents	`POST_BORDET` - R 7.02.06/U4.81.41 and U2.05.08
Disadvantages	Many parameters difficult to identify Approach not yet validated on an industrial case with EDF/R & D Very near to Beremin but with one plus a large number of parameters
Advantages	Taking into account of the history of the loading Applied in a case of hot preloading [11]
Fields of application	Idem that for Beremin
Outlines	Validation of the model

7.6 Card ID of Le-Corre

Type of approach	Local approach/brittle, ductile fracture or in zone of transition
Standard material	Elastoplasticity
Type of phenomenon	Starting – determines the nature of starting
Type of defect	Notch/crack
Type of grid	Quadratic free grids
Type of loading	Loadings proportional
Code_Aster documents	U2.05.08
Disadvantages	Is not valid if loading complexes Does not allow to predict the moment of starting Bases itself on local results in bottom of cracks which can present strong singularities
Advantages	Facilitated use of the approach which is based on an elastoplastic calculation
Fields of application	Deflection test on pipe [46]
Outlines	Taking into account of volume criticizes in more than critical stress

7.7 Card ID of the approach in critical stress

Type of approach	Local approach/brittle fracture, based on a comparison criterion between local constraint and critical stress
Standard material	Viscoplasticity
Type of phenomenon	Propagation and stop of crack
Type of defect	crack
Type of grid	Hexahedral grids
Type of loading	Loadings nonproportional
Code_Aster documents	Documentations of `BEHAVIOR` (U4.51.11) and of `DEFI_MATERIAU` (U4.43.01) and the case test (V6.04.226)
Disadvantages	Does not allow to predict the moment of starting Bases itself on local results in bottom of cracks which can present strong singularities
Advantages	Facilitated use of the approach which is based on an elastoplastic or viscoplastic calculation
Fields of application	Stop of crack [12]
Outlines	Independence of the constraint criticizes compared to the type of the test-tube

7.8 Card ID of the CZM

Type of approach	Alternative approach based on the cohesive elements
Standard material	Elastoplasticity (confined or extended plasticity) – several forms of laws exist according to the opening of the crack with 2 parameters materials σ_c the critical stress and G_c critical energy
Type of phenomenon	Starting and propagation on a way known a priori
Type of defect	Cohesive elements (at the top of crack or of notch) but usable also without defect for initiation
Type of grid	Specific grid with cohesive elements to represent the plan of the crack creates by `CREA_MAILLAGE` and `CREA_FISS` length of a preset line of nodes
Type of loading	Loadings nonproportional
Code_Aster documents	R7.02.11 / U2.05.07
Disadvantages	Parameters to be identified in experiments for materials of the components. Still insufficient validation
Advantages	Used to make quasi static and dynamic propagation Used to simulate a stop of crack
Fields of application	In brittle fracture on test-tube [20] In ductile rupture on test-tubes [31] Stop of crack after static or dynamic propagation
Outlines	Taking into account of the triaxiality in ductile rupture Transition between damage and crack into fragile [52] and ductile

7.9 Card ID of Rousselier

Type of approach	Coupled local approach – ductile rupture
Standard material	Elastoplasticity (wide plasticity) – or not local local damage in great deformations – parameters specific to identify: σ_1 , D_1 , f_0 and A_n
Type of phenomenon	Starting and propagation
Type of defect	Crack or preferably notch/the rupture is described by the softening of the total behavior of material
Type of grid	Incompressible quadratic elements and preferably of the incompressible elements in great deformations `_INCO_UPG` valid if law of Rousselier in nonroom
Type of loading	Loadings nonproportional
Code_Aster documents	R 5.03.06/R5.03.07
Disadvantages	Parameters to be identified in experiments on various types of test-tubes CT and AE Dependence of the law Rousselier locally in keeping with meshs Dependence of the law Rousselier in nonroom with the parameter of regularization Very heavy digital calculations in computing times
Advantages	Fine description of the ductile rupture
Fields of application	Charpy test-tubes in 3D [30] Test-tubes AE , $CT3D$ [31] Nonlocal Rousselier on test-tubes CT [29] Round – Robin, comparison with GTN
Outlines	Validation with adaptation of grid in great deformations and incompressible elements on a test-tube 2D out of ductile material

7.10 Card ID of GTN

Type of approach	Coupled local approach – ductile rupture
Standard material	Elastoplasticity and elastoviscoplasticity – or not local local damage in great deformations – parameters specific to identify: q1, q2, f0, fn, FC, δ parameters for the nonlocal regularization: C, R
Type of phenomenon	Germination, growth and coalescence
Type of defect	Crack or preferably notch/the rupture is described by the softening of the total behavior of material
Type of grid	Incompressible quadratic elements in great deformations `GRAD_INCO` valid if law in nonroom and `INCO_ UPG` if law locally
Type of loading	Loadings nonproportional
Code_Aster documents	R5.03.29
Disadvantages	Parameters to be identified in experiments on various types of test-tubes CT and AE Parameters of regularization to be identified Heavy digital calculations in computing times
Advantages	Fine description of the ductile rupture Independence of law GTN in nonroom in keeping with meshs
Fields of application	Test-tubes AE , $CT3D$ [17]
Outlines	Validation on chaining GTN-Beremin in great deformations and elements incompressible on a test-tube 2D and ductile material 3D

7.11 Card ID of Rice and Tracey

Type of approach	Probabilistic uncoupled local approach – ductile rupture
Standard material	Elastoplasticity (wide plasticity) only one parameter to be readjusted $(R/R_0)_c$
Type of phenomenon	Starting
Type of defect	Crack or notch/the rupture occurs if the damage reached an intrinsic breaking value with material – even grid recommended for Beremin: square mesh of $50\mu m$.
Type of grid	Valid grid in thermo-elastoplasticity – very fine in bottom of crack
Type of loading	Valid for the very large rates of triaxiality (>0.5)
Code_Aster documents	R7.02.06/POST_ELEM- U4.81.22- postprocessing of an elastoplastic calculation
Disadvantages	Simplified criterion
Advantages	Approach simple to use
Fields of application	Ageing under mechanical requests in a steel $C-Mn$ [7] Calculation of the effects of structures on ASG [33]
Outlines	SHORT-NAP CLOTH

7.12 Card ID of K-T/J-Q

Type of approach	Comprehensive approach with 2 parameters
Standard material	$K-T$: brittle fracture; $J-Q$: ductile rupture
Type of phenomenon	Starting
Type of defect	Crack or notch
Type of grid	Valid grid in thermoelasticity/thermoplasticity
Type of loading	Monotonous loadings and taking into account of the triaxiality
Code_Aster documents	Nonavailable
Disadvantages	Nonvalid if loading nonproportional Need for many tests to identify the second parameter
Advantages	Known with international – in the code $R6$ Comprehensive approach easy to use
Fields of application	Justified in [28]
Outlines	Appropriateness of the developments of the approaches in *Code_Aster* Application fissures short Comparison between approaches

7.13 Card ID of calculation of factor of margin

Type of approach	Classical approach – rubber band linear and elastoplastic
Type of rupture	Fragile with confined plasticity
Standard material	Calculation of G and G_{ENL} , Post-treatment factors of intensity of the constraints correspondents and comparison with tenacity K_{IC}
Type of phenomenon	Starting
Type of defect	Crack
Type of grid	Radiating/free
Type of loading	proportional
Code_Aster documents	`POST_FM` : U4.81.51
Fields of application	Used for to calculate the factors of margin FM and FM_{ASN} to justify mechanical resistance of a defect of type under coating or in the coating in a tank
Outlines	Ductile rupture and comparison with K_{JC}

8 Conclusions

After a recall of the basic concepts and an outline on the various approaches which exist in breaking process, a approach of realization of a study in breaking process is proposed, making it possible to switch the user with each stage towards the choice which is most adequate for the case treated by referring to the documents of *Code_Aster*. As one cannot be exhaustive with respect to all the characteristics and difficulties encountered at the time of a study in breaking process, one proposes a shunting towards the notes and documentations dedicated to look further into each subject. In each case, one tries to specify the limitations of the approaches or modelings. For a speed reading and specific, one adds tables which make it possible to target certain key information.

The approaches on stability and starting are dominant in this document to the detriment of those which treat tear. The methods of propagation under monotonous loading to simulate the ductile tear will be developed later on.

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