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CONSIDERATION OF WELDING RESIDUAL STRESSES WITHIN THE FRACTURE MECHANICS ASSESSMENT OF NUCLEAR COMPONENTS – PART 1: BIBLIOGRAPHY ANALYSIS

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INTRODUCTION - CONTEXT

Welding Residual Stresses (WRS) are a consequence of inhomogeneous thermal fields during the welding process. Self-equilibrated, they are of secondary nature and thus cannot contribute to the plastic collapse. However, for a low ductility material, they can contribute to the fracture process since they contribute to the stress field at the crack tip.

If this potential effect of WRS is well known, particularly in brittle fracture, it is also well known that, for high ductility material, the WRS are removed by the overall plastic flow in the ligament and thus become inoperant. Between those two extreme situations, the inherent difficulties regarding the consideration of WRS within Fracture Mechanics Assessment (FMA) is that the domain where they become non-significant is not clearly established. This is particularly true for the brittle to ductile transition of high ductility ferritic steels where a competition between brittle and ductile fracture is observed for the highest temperature of the ductile to brittle transition.

Behind this unclear definition of the influence domain of WRS, the fracture models conventionally used in FMA are too simple to capture the real impact of WRS. Those are based on global approach parameters such as J or K_J which appear to be over-conservative when applied to real structures. The local approach criteria, much more complex to use, are better candidates for modelling fracture process with WRS, but they are limited to expertise applications and not generalisable to industrial applications.

The development of a limit defining the conditions when the WRS will impact the FMA is of strong interest since, with such limit, useless and non-physical modelling could be avoided. For that reason, EDF and FRAMATOME have initiated a cooperative R&D project for defining exclusion criteria for the WRS consideration within FMA. This project is focussed on testing and modelling, as well as literature survey and pre-codification.

The present paper deals with the part 1 of this work devoted to the analysis of the existing testing and modelling results in open literature (the applications and modelling is presented in part 2). The target of the survey is the brittle to ductile transition of ferritic steels with the objective to highlight main results and recommendations already available. This survey is developed in the first part of the paper. In a second part, the numerical interpretation of one available test series is performed in order to illustrate the capability of global and local approach models to quantify the effect of WRS on brittle fracture.

LITERATURE SURVEY

General consideration

The reason why the WRS are significant or not regarding the fracture process are well known and can be roughly described as follows:

- Within the quasi-elastic domain (lower shelf of the brittle to ductile transition of ferritic steels), all stresses are significant regarding the fracture process. WRS are impacting the fracture risk like any other type of loading.
- When plasticity becomes more and more significant before fracture (up to the upper shelf) the WRS become less and less significant since they are *erased* by this plasticity: WRS, which in practice are associated to elastic strains, are rapidly compensated by plastic strains induced by the external loading, which are significantly larger in general.

These two points are well known and recognized in the open literature. However, they do not allow a clear definition of a domain of importance of the WRS given the fact that, for ferritic steels, we move gradually from one behaviour to the other. In addition, there are intrinsic difficulties directly linked to the nature of the WRS that must be overcome to build a reference experimental database:

- WRS can operate at different scales depending on the mechanisms that created them. In the following, we are interested in self-balancing WRS at the scale of the welded joint and directly related to the welding processes.
- The definition of these WRS is complex, both in amplitude and in distribution across the thickness, these two parameters having a first order importance on the loading of a crack. Both measurement and modelling are still R&D fields today with difficulties to overcome.
  One of the direct consequences of this point is the difficulty of imposing reliable and reproducible WRS stress field, therefore, to carry out reference tests.
- WRS issue is necessarily related to deposited metal: in a welded joint, the weld metal is potentially different of the base metal, both in terms of mechanical behaviour and fracture behaviour. A precise characterization of the weld metal (often in addition to that of the base metal) is therefore required, which constitutes an additional effort that may be complex if the sampling of characterization specimens is limited by the size of the weld bead.
- Considering the two previous points, carrying out reference tests, preferably with and without WRS, is very difficult: as we will see later, some test campaigns published in the open literature are including some approximations that have significant effects on the fracture results.
- Numerical analysis of this type of multi-material configuration (base metal and deposited metal) is also a complex exercise, both in terms of mechanical behaviour and determination of fracture mechanics parameters.
- The same is true for the failure criteria which should be intrinsic to the material but which, in practice, depend on the stress field distribution, in particular through the triaxiality and the confinement of plasticity. This is particularly the case for conventional global approach, which is not very efficient on this point in the field of brittle-ductile transition.

The following literature survey relies on these various observations with the aim of showing that most of the results and recommendations already published on the effect of WRS must be analysed with care regarding their relevance. The strengths and weaknesses of each publication are thus detailed, highlighting experimental campaigns as much as possible.

For each test or calculation campaign looked at, the domain of investigation in temperature is specified considering that it is a major element regarding the risk of brittle fracture. On that point, it is important to note that a large majority of publications aim to show the detrimental effect of WRS on fracture. Few aim the reverse, i.e., the evaluation the condition where the WRS have no impact. To do this, the tests are mainly carried out in the lower shelf of the transition, and sometime very low in the brittle to ductile transition where the material behaviour is quasi-elastic. In the brittle to ductile transition, particularly close to the upper shelf, the results are much less numerous.

To quantify the position of the test temperatures in the brittle to ductile transition temperature range of the investigated materials, we propose here a comparison with the indexing temperature allowing to define an envelope toughness curve based on the codified low alloy steel toughness curve (from the appendix ZG of the RCC-M [1]). This temperature is defined by:

$$RT_{NDT\text{-}eq} = T_0 + 40°C \sim RT_{T0} + 20°C \quad (1)$$

T_0 is here the index of the Master Curve (MC) as defined by [2] and RT_{T0} the indexing of the curve of ASME toughness offered in code case N630. The choice of this indexation is that, in presence of few test data, it is preferable to recalibrate an average MC. On the contrary, in a FMA context, it is easier to compare with a value of RT_{NDT}, the index T_0 used in MC being generally not available within French data. For that purpose, the formula proposed here is very useful because it makes it possible to link the tests to the FMA approach (RT_{T0} and $RT_{NDT\text{-}eq}$ being indexes equivalent to RT_{NDT} for defining the minimum envelop toughness curve).

Large scale testing

<u>Test campaign performed by Wu [3]:</u>

Wu [3] has performed tests on plates of large dimensions with a welded joint in their vertical symmetry plane (30 mm thick plates, represented on fig. 1) or horizontal symmetry plane (100 mm thick plates). The base metal is a fine grain ferritic steel (denomination OX 522D) with a yield stress σ_y = 406 MPa at room temperature. The weld joint is an X joint as shown in fig. 1b, its yield stress being of the order of 430-460MPa.

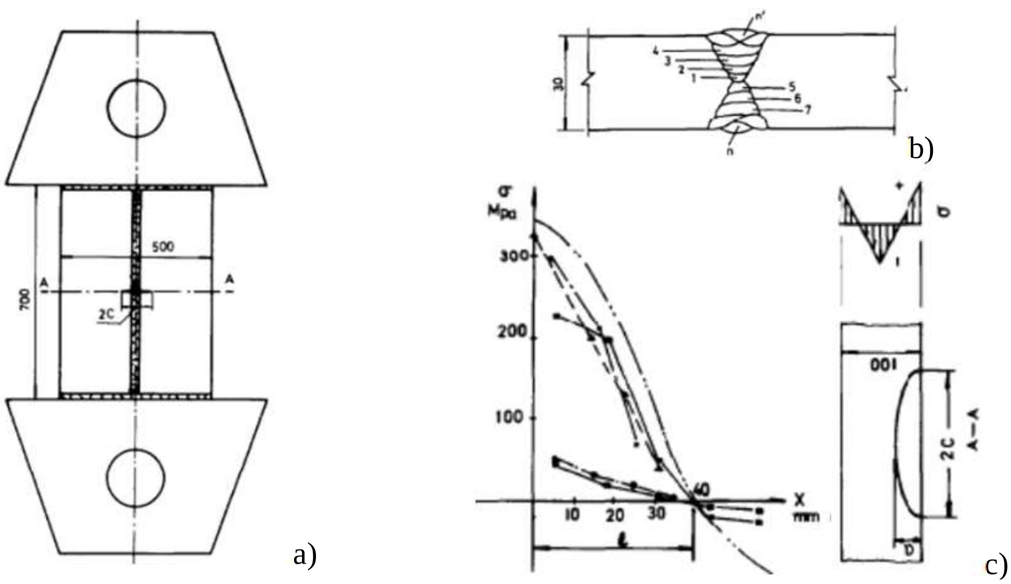


Figure 1. Test on large scale plates [3]
a) tensile device, b) weld joint description, c) welding residual stress distribution

The tests are carried out after welding (with WRS) and after Post Weld Heat Treatment (PWHT), the WRS being assumed to be largely relaxed following this PWHT. Test temperature is close to -120°C. At this temperature and after PWHT, the average toughness measured on CT specimens and PWHT plates is respectively 90 MPa√m for the 30 mm thick welded joint, and 114 MPa√m for the 100 mm thick one. This tells us that the tests temperature is close to T_0, thus close to $RT_{NDT\text{-}eq}$ - 40°C.

These relatively old tests are affected by the difficulty of precisely defining the WRS field and the difficulty of taking it into account in the calculation of the Stress Intensity Factor (SIF) K or the J parameter. Despite this point, tests results are showing a significant decrease of the apparent toughness in comparing, for the tests with WRS, the toughness determined considering the WRS to the toughness without WRS. Adding the contribution of the WRS makes it possible to obtain good consistency between the two test conditions, thus showing that the global approach is appropriate in this configuration at low temperature. However, as explained further, the direct comparison of the two material states is questionable since the PWHT modifies the brittle to ductile transition temperature.

R6 validation tests [4]:

Similar tests results have been published more recently by Ainsworth *et al.* [4]. We focus here on tests on large plates also included in the 'validation cases' of the R6 rule. This test series was carried out on low alloy A533B steel plates with a thickness of 70 mm. The initial plate of large dimensions is cut then rewelded by an X joint, therefore a similar welded joint than the previous campaign, leading to a self-balancing stress field across the wall. Once the welded joint has been made, plates (for tests with surface defects in the middle of welded joint – see fig. 2a) and bending specimen (SENB specimen for toughness characterization) are used. Half of the specimens are stress relieved while the other half is tested as welded.

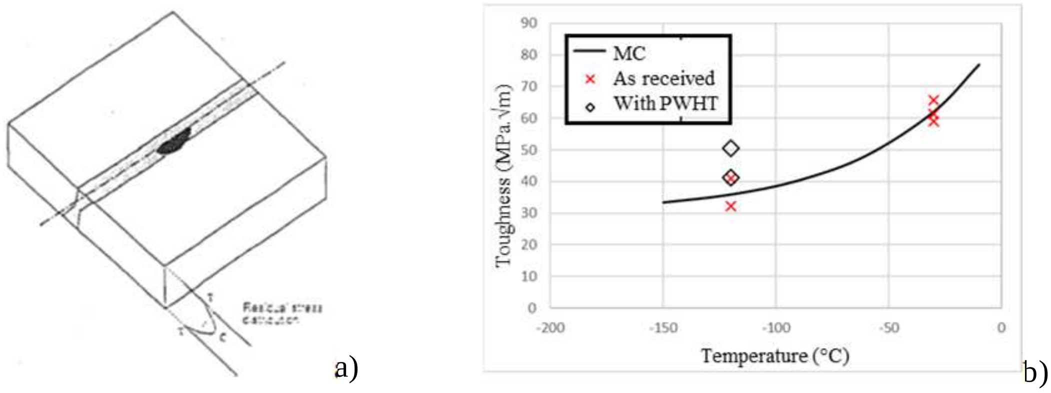


Figure 2. Test on large scale A533B steel plates [4]: a) mock-up description, b) available toughness data

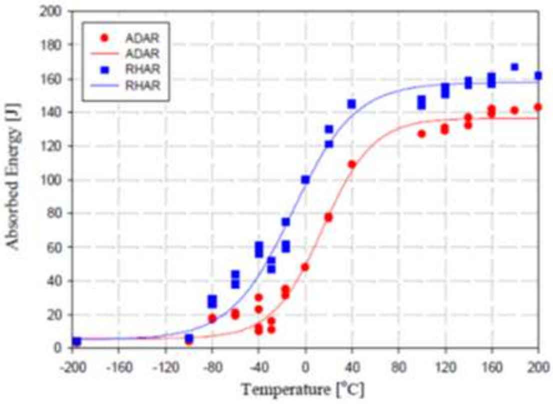


Figure 3. Softening of the material due to PWHT observed by V.J. Farron [5]

For that test series, the WRS are measured before and after PWHT through a cutting technic on a dedicated block. Additionally, tensile properties of materials are determined for the two material states and the two test temperatures. The following points emerge from this characterization:

- The effect of the PWHT on the yield stress of the two materials is quite small. A small undermatch (lower yield stress of the welded joint) of the order of 10% at -120°C, and of the order 18% at -30°C is observed. At both temperatures, there is a reduction of around 60 MPa (a drop of 10% approximately) of the ultimate stress after PWHT.
- At -120°C, the toughness measured on SENB specimens is about 10% higher after PWHT (average over 2 or 3 trials) to that measured before PWHT. At -30°C, the fracture mode changes with the material state, with a fracture in the brittle domain before PWHT specimen and a quasi-ductile fracture after PWHT (respectively K_{JC} = 62 MPa.√m compared to 320 MPa.√m).
  For explaining this large difference, one could imagine an effect of WRS for SENB tests, but since these were tested with a depth ratio of a/W = 0.5, this track can be ruled out because machining a half thickness defect significantly relaxes the WRS.

Based on all these results, we can reasonably consider that the PWHT has a significant impact on the fracture behaviour of the welded joint, with a softening of the material and an increase of the brittle to ductile transition temperature. This softening was observed by V.J Farron in her PhD [5], showing a temperature shift of the brittle to ductile transition, measured on Charpy specimens, around 30 to 40°C (see figure 3). With such a shift, the direct comparison of as welded and PWHT states is biased especially at the higher temperature of the transition.

Looking to the test temperatures and based on SENB test (see fig. 2b), we can estimate:

- A T_0 of the order of -10°C for the as welded state (5 SENB tests are available). The tests on plate for this as welded state are therefore carried out respectively at $RT_{NDT\text{-}eq}$ - 150°C and $RT_{NDT\text{-}eq}$ - 60°C, thus relatively low in the transition in both cases.
- A T_0 of the order of -40°C in the stress relieved state (but only based on the 2 tests available at -120°C). With this estimation, the plate tests for this PWHT state are therefore carried out respectively at $RT_{NDT\text{-}eq}$ - 120°C and $RT_{NDT\text{-}eq}$ - 30°C, which remains relatively low in the transition.

However, these estimates remain rather rough given the small number of available results. Nevertheless, they are compatible with the shift showed in Farron's thesis [5]. They show that all the tests are made significantly below or very far from the $RT_{NDT\text{-}eq}$ reference temperature.
For plate tests, a crude comparison of failure loads is offered in [4] between the two material states, without PWHT (therefore with WRS) and after PWHT (without WRS). This gives:

- A reduction in the failure load approximately 1.7 times less than with WRS compared to without WRS state at -120°C.
- An equivalent failure load for the two material states at -30°C, with in both cases a ductile propagation of the order of 4-5 mm).

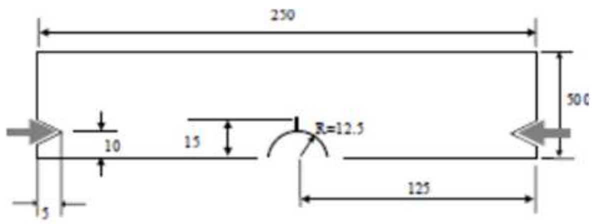
Qualitatively, these tests clearly show that, very low in the transition, there is a significant effect of WRS (the difference in toughness between the two states of the material at -120°C is only 20%), and as soon as the plasticity and ductile fracture appear, there is no longer any effect. This change in the fracture mode, despite the low-test temperature ($RT_{NDT\text{-}eq}$ - 30°C), could be explained by the low constraint testing configuration and the weld joint under-match. This should be investigated through a numerical interpretation which is not available here.

Small specimen testing

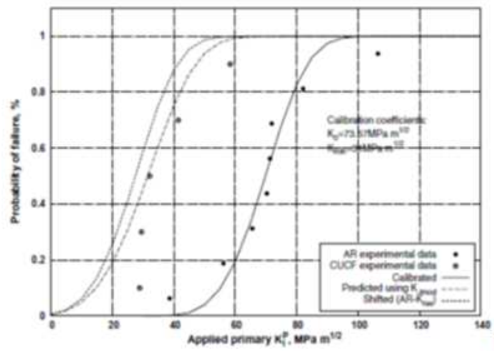
Tests performed by Mirzaee Sisan *et al.* [6]:

Mizaee Sisan *et al.* have performed tests on small specimen of A533B ferritic steel where Residual Stresses (RS) are introduced by an initial mechanical loading. The technique used for that purpose consists of pre-

loading, by bending at ambient temperature, bars containing a groove (see fig. 4a). Pre-compression, as applied, leads to a plastic zone at the bottom of the groove and, once the load is released, to tensile RS. A crack is then introduced by machining then propagated by fatigue in this RS field.
Once the specimens are pre-cracked, the fracture tests are carried out at -150°C (3 Points Bending tests – 3PB). Two material states are again compared: with and without RS. From each series of tests, the analysis deduces a probability of failure as a function of the applied SIF only including the contribution of bending load (fig. 4b).



a)



b)

Figure 4. Tests on pre strained bars [5] a) Specimen description, b) Tests results and interpretations

Based on tests performed on specimen without RS, T_0 is estimated at -130°C. Tests being performed at -150°C, it results in a test temperature of $RT_{NDT\text{-}eq}$ = -60°C, thus low in the brittle to ductile transition.
The numerical interpretation of those tests, illustrated by fig. 4b show a significant effect of the RS, which is not surprising given the low-test temperature. They also illustrate the fact that, for that low-test temperature where the material behaviour is quasi-elastic, the global approach criterion gives correct results.

However, this conclusion could be discussed because the pre-straining of the material is not without consequences on the material. Here the process used to introduce RS is directly imposed to the zone where the crack is introduced. This pre-straining is likely to harden the material and thus shift its brittle to ductile transition to the left.

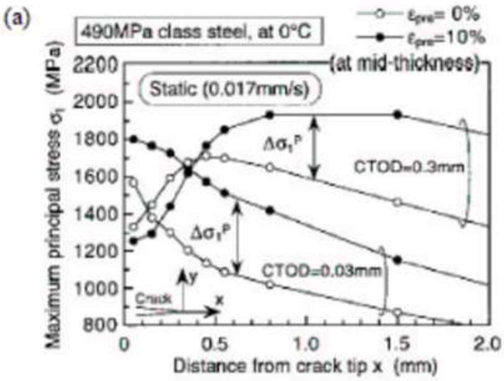


Figure 5. Effect of pre-straining on stress distribution (from [8])

The paper proposed by Cosham *et al* [7] deals with this question by proposing an experimental study completed by a numerical analysis and a literature survey. Two points are identified as potentially affecting the fracture probability: work hardening and pre-damage of the material. However, it is clearly announced that material hardening dominates.

Regarding our problem of brittle to ductile transition, the strain hardening mechanism is simple to understand and quantify: the material being hardened, the stresses at the crack tip are reaching a higher level for a given external load and therefore increase the risk of cleavage. This point is illustrated in Fig. 5 taken from [8]. This aspect is critical in the brittle-ductile transition because it is precisely this level of stress, relatively low compared to the critical cleavage stress, which leads to the competition between brittle fracture and ductile fracture.

<u>Tests performed by Hurlston *et al* [9]:</u>

Hurlston, Sharples and Sherry offer the same type of test-small specimen with RS introduced by local hardening. The material is again the A533B low alloy steel.

The specimens are bending specimens, but this time the RS are introduced by lateral punching (see fig. 6a). This compression is carried out at ambient temperature up to an average lateral strain of 1%. Being performed outside the ligament, this pre-straining does not affect the crack tip of the specimen, but partly the global behaviour of the specimen.

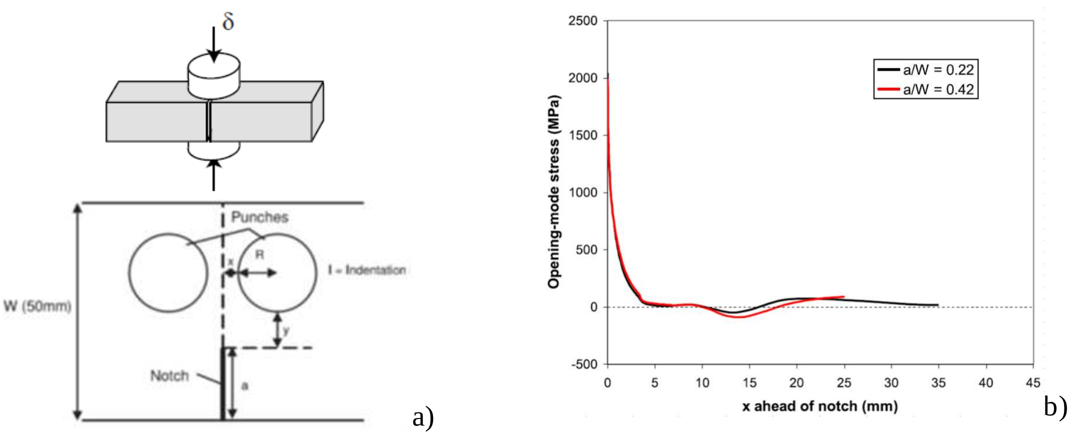


Figure 6. Tests on punched bars [6] a) Punching system, b) Residual Stress distribution after punching

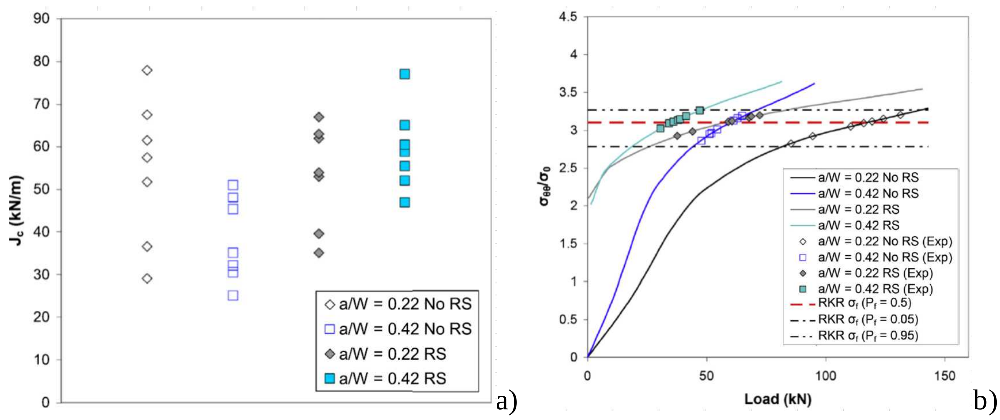


Figure 7. Punched bar tests interpretation [9] a) J at fracture, b) Opening stress at fracture (r = 0.2 mm)

The tests are performed with and without punching, for two different initial crack sizes (a/W ~ 0.2 and a/W ~ 0.4, 7 tests per series). RS distribution was determined through FE modelling (see fig. 6b).

The test series performed without RS and with a deep crack allows us to evaluate a T_0 value of -130°C. Therefore, the tests temperature is equivalent to RT_{NDT-eq} - 50°C. This temperature remains relatively low in the brittle to ductile material transition.

Figure 7a shows the distributions of the J parameter at fracture for the different test configurations. J is here a value determined through FEM and including the contribution of the RS. This representation shows the following results:

- For the shallow crack (a/W = 0.22), the average values are of the same order of magnitude with and without RS. On the other hand, the dispersion seems reduced in the presence of RS.
- The situation is opposite for the deep crack (a/W = 0.42), the average value being higher with RS with a similar dispersion.
- In both cases, for the average apparent toughness and even more if we are interested in the lowest values, the global approach seems relatively penalizing. For the deep cracks, the minimum toughness observed (lowest K_J of the series at fracture) is of the order of 2 times higher in the presence of RS than without RS.

Those results are discussed more in detail in next section.

The RKR model was also applied with an opening stress calculated at 0.2 mm from the crack tip (fig. 7b). This local model, although very simple, seems better to predict fracture, with all the points gathered in the same dispersion band. This is not perfect since, with RS and for the deep crack, this model shows a lower value at fracture significantly higher than the one observed on the other configurations.

Effect of the WRS on the stress triaxiality

One of the consequences of WRS on the fracture risk, in addition to the presence of additional stresses, is the modification of stress constraint at the crack tip. The WRS stress field is generally three-dimensional, leading to a stronger constraint and therefore to a higher risk of fracture.

Panontin and Hill ([10] and [11]) have worked extensively on this question of triaxiality through FEM based on the RKR fracture model. Lee *et al* [12] investigated this question through a test campaign. Those tests were performed on A533B steel plates of 70 mm thick which underwent a specific heat treatment in order to increase its brittle to ductile transition temperature. CT specimens with a thickness of 25 mm are then taken from the plate.

For those CT specimens, either the geometry is standard (fig. 9a) or modified to introduce a pre-loading by compression (fig. 9b), pre-loading which creates tensile RS at the crack tip. In a second step, these specimens are either tested as they are, or welded to extensions to produce a tensile loading (configuration which modifies the constraint conditions). There are therefore 4 test configurations: standard CT (CT), pre-stressed CT (P-CT), the tensile specimens (SENT) and pre-hardened tensile specimen (P-SENT).

All the tests are interpreted by finite element calculation (pre-compression phase included). From those FEM, the author deduces the values of J at fracture (including the contribution of the RS). All the results are grouped together in Fig. 9 which shows:

- For the standard CT specimen (fig. 9a), the average toughness is around 100 MPa.√m, which means that the test temperature is close to T_0 and therefore RT_{NDT-eq} - 40°C.
- For P-CT specimen, the K_J distribution with RS shows a steeper slope characteristic of the effect of pre-hardening. The K_J deducted from the load, therefore without considering the RS, gives a left-shifted distribution. It can therefore be seen that a simple superposition of the K corresponding to the mechanical contribution to that of the RS distribution gives a relatively good distribution compared to the one of CT specimen.
- For the SENT specimen (fig. 9b) the results are different: the distributions seem translated and no longer modified in shape (P-SENT distribution integrating the contribution of RS). In the presence of RS, the apparent toughness seems significantly reduced compared to the one without RS. On the other hand, it is important to observe that, without RS, the distribution corresponding to SENT specimen

appears translated in comparison to the CT specimen. This results from a loss of constraint. In the presence of RS, the distribution returns to the distributions of CT specimens.

At the end, when looking to the lowest probabilities of fracture, the three '*confined*' configurations (CT, P-CT and P-SENT) give very close values (~75 MPa.√m). Thereby, the possible reduction of the apparent toughness due to a higher constraint in the presence of RS only applies for the low constraint configurations. The demonstration, as carried out in France, is therefore not to be corrected since it does not consider the loss of constraint.
Moreover, it is important to remember that here the RS were introduced by pre-loading. The effect of the work hardening might be not negligible since it is applied directly at the tip notch. Its influence on fracture process is mixed with the one of the RS and impossible to separate.

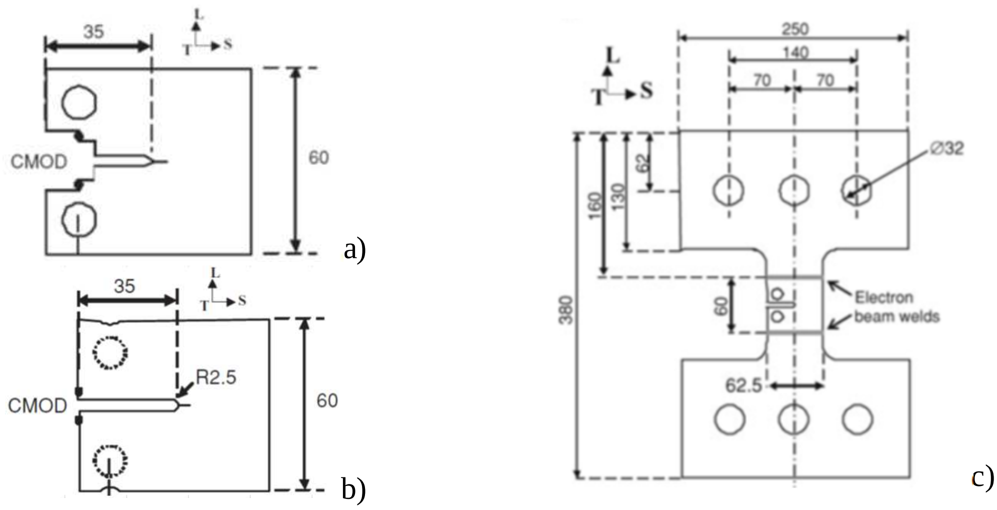


Figure 8. Test set-up on pre-strain specimen (from [12])
a) Standard CT specimen, b) Specimen for pre-straining c) Mock-up for tensile loading

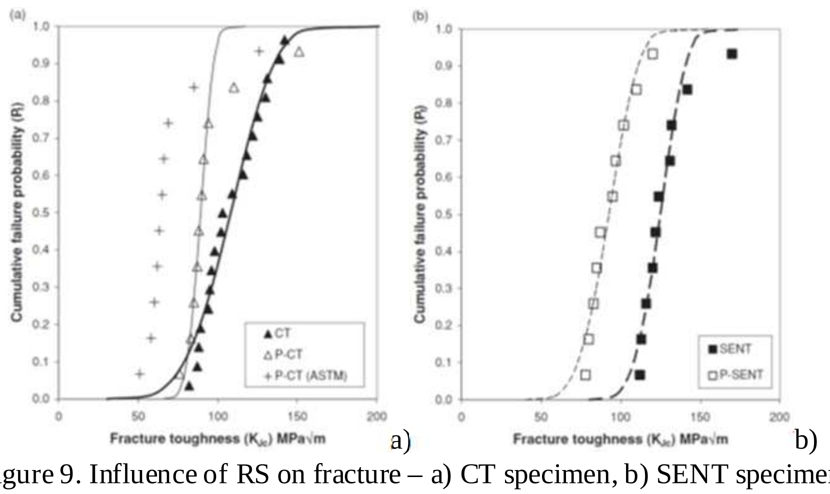


Figure 9. Influence of RS on fracture – a) CT specimen, b) SENT specimen

Intermediate synthesis

The literature survey proposed here shows that major part of available results is focused on the illustration and the quantification of the WRS on brittle fracture. Therefore, it mainly focusing on relatively low temperatures. Logically, at these temperatures, the effect is pronounced. Higher in the transition (from $RT_{NDT\text{-}eq}$ up to $RT_{NDT\text{-}eq}$ + 40°C), no data has been found.

However, in the context of new tests development, some very important results are highlighted in this experimental data survey:

- There is no easy way to introduce a controlled and reproducible WRS field into a specimen or a structure. Two approaches are possible depending on the objectives:
  - The choice to work on a welded joint. This approach is the most realistic one but requires a substantial experimental effort. If such a choice is made and if tests are performed on different material states, it is necessary to be able to quantify the impact of the PWHT on the toughness.
  - The choice to introduce the CRs by an initial pre-loading inducing plastic pre-straining. This approach is simpler, especially at the stage of modelling. However, care must be taken that the crack tip is not affected by this pre-straining, because work hardening might drastically modify the toughness in the brittle to ductile transition range, even with few % of pre-straining.
- In addition to the loading induced by the presence of RS, some authors have worked on the effect of modified constraint at the crack tip. This effect is to be consider only for criterion considering this constraint effect (the J-Q approach for example). In the French regulatory approach [1], the toughness curve is defined on the basis of envelope toughness tests on CT specimen. Therefore, no correction is to be considered.
- Criteria and modelling have strongly evolved with time. However, the available results are showing that the global approach criterion is either relevant at the lower shelf, or relatively severe with respect to test results. The local approach seems more appropriate because it relies directly on the complex evolution of the stresses and strains at the tip of the crack, evolution that cannot be captured by a simple energy parameter like J or G.

COMPLEMENTARY FE MODELLING

Within tests series detailed in the literature survey, the one performed on SENB specimen by Hurlston *et al* [9] appears pertinent for complementary modelling. For this test series, RS are introduced by lateral punching far from the crack tip and thus it can be assumed that the crack tip is not affected. Many data being available, this test series can be modelled to check the relevance of finer models, like the BEREMIN one, regarding the consideration of RS. The material is the A533B low alloy steel, and the tests are performed on punched or not 3PB specimen.

For interpreting the test series, 3D modelling is performed with the following sequence and assumptions:

- A 3D model limited to a ¼ of the specimen is used. The size of mesh at the crack tip perpendicular to the crack front is 50x50 µm² to allow a post-processing by the BEREMIN model. The crack front is supposed to be straight across the specimen.
- Pre-compression is imposed at room temperature. For this first phase of modelling, the notch is 6 mm shorter than the crack which will be defined for the second phase of bending loading. The punching is obtained by imposing a displacement of approximately 0.25 mm of the external surface (fig. 10a).
- After punching, the complete crack is opened (releasing the corresponding nodes) then the bending load is imposed à -140°C (corresponding to a temperature $RT_{NDT\text{-}eq}$ - 50°C).

The fig. 10a shows the plastic strain field after punching and the load displacement curve during punching. As it is illustrated here, a good accordance is obtained between tests and modelling. The resultant plastic strain is limited at the crack tip, confirming that the effect of punching on the material toughness can be neglected.

The fig. 11 compares load-CMOD curves for the two initial crack sizes adopted in the test series: the accordance remains very good.

For the fracture interpretation (fig. 12), tests are interpreted per series, an experimental probability of failure being affected to each test by ordering them per increasing loading.

For the global approach, the interpretation is made based on the mean J along the crack front at failure (denoted J_{IC}) derived from FEM and including the contribution of the RS. On fig 12 (left graph) one can see that the points corresponding to each series are relatively grouped, in particular the lower probabilities

of failure. However, if we look more in detail, we can see that, for a/W = 0.42, the points with RS are systematically on the right of the points without RS. This illustrates that the global approach tends to overestimate the impact of RS on the fracture.
The trend is inversed for the smallest defects (a/W = 0.22): this inversion is linked to the loss of constraint in the presence of a small defect. In accordance with what has been shown in the previous literature survey, the RS have the effect of re-confining the crack tip, hence the distribution with RS is on the left of the one without RS but remains on the right of the reference one (deep crack without RS).

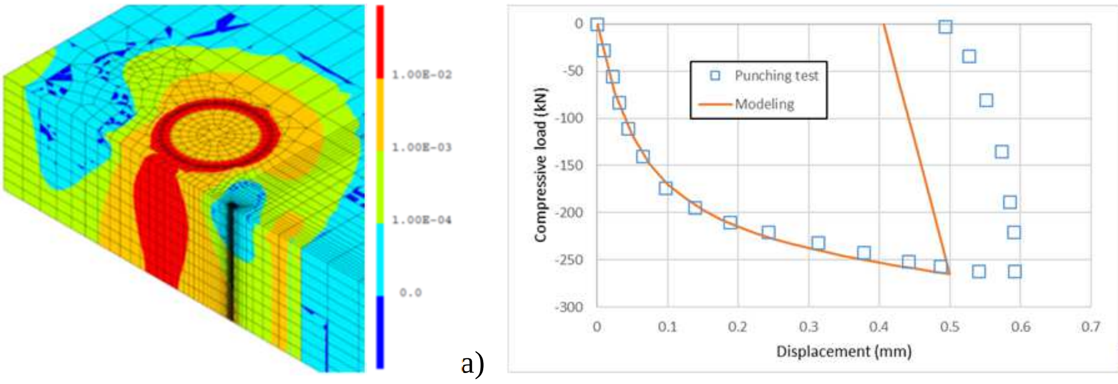


Figure 10. a) Plastic zone after punching, b) Load-displacement curve during punching

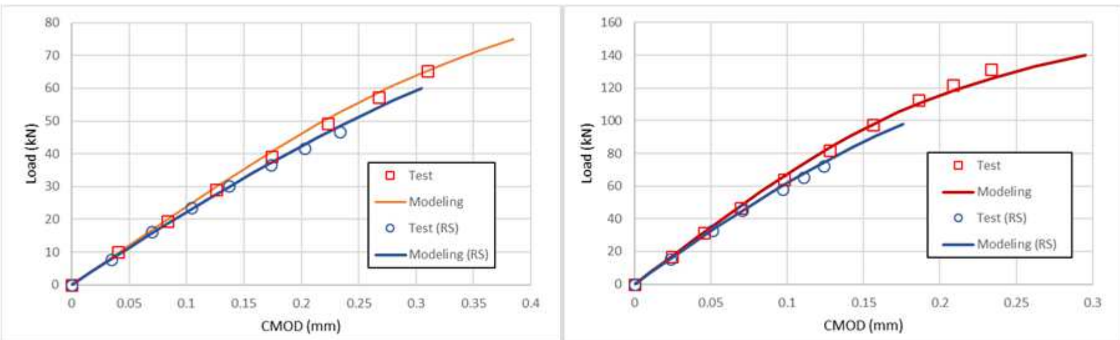


Figure 11. Comparison between tests and modelling (a/W~0.2 on left, a/W~0.4 on right)

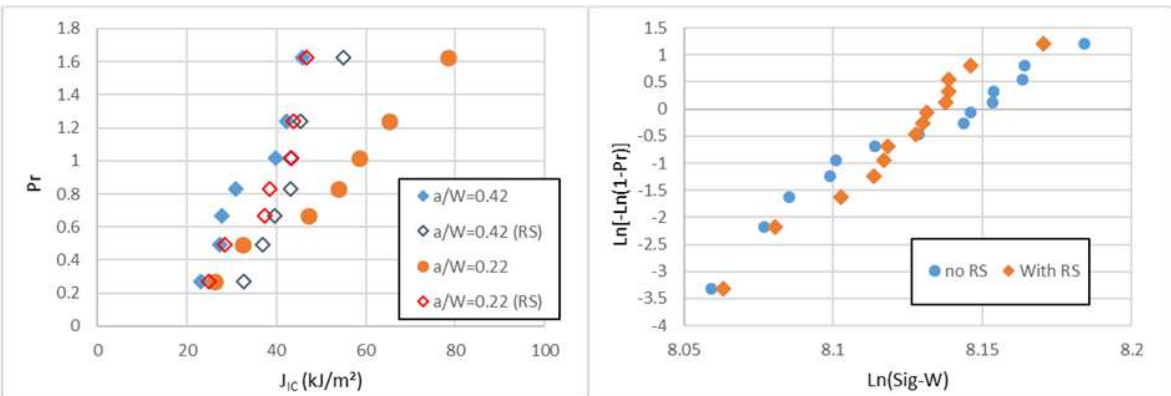


Figure 12: Application of the global (on left) and local approach criteria (on right)

Regarding the global approach, these results therefore confirm two important results:
- Relatively low in the transition, the global approach gives a correct estimate of the effect of RS on the risk of rupture. As an average value, this overestimation obtained here is around 10% on the SIF.

- The presence of RS modifies the triaxiality and the confinement of the stresses at the crack tip.

Considering that the local approach criterion is able to capture the crack size effect, the results of the two crack sizes are merged together. The local approach criterion is thus applied here for two test series: with and without RS. The results illustrated on the right graph of fig. 12 show that the two series are consistent, showing that they follow the same failure probability law, as expected. It can therefore be concluded that the local approach correctly represents the impact of RS on the risk of fracture: relying on stresses and strains determined at the crack tip and having the capability to consider the loading history effect, it is able to highlight the impact of plasticity and constraint.

CONCLUSIONS

This paper proposes a literature survey regarding available results concerning the effect of RS on the brittle fracture. Major part of available results is corresponding to relatively low temperatures where the effect of RS is pronounced. Higher in the brittle to ductile transition (pertinent temperature range for the industrial applications), no data has been found.

Nevertheless, in the context of a new test development, all those results are providing very important recommendations regarding the knowledge of RS (or WRS), the way to introduce them, effects of pre-straining or PWHT on the material.

As a complement to that literature survey, the numerical post interpretation of one of the available test series is proposed. The aim of this complement is to illustrate the intrinsic conservatism of the global approach and the relevance of local approach for quantifying the potential impact of RS on the risk of fracture.

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