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SAFETY MARGIN AGAINST RATCHETTING IN AND BELOW THE CREEP RANGE

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Recently, a practical rule to estimate progressive distorsion has been proposed by Mr. COUSSERAN and co workers. This rule is based on the concept of an "effective primary stress" P_{eff}. By definition, distorsion caused by the simultaneous application of a primary stress P and a cyclic secondary stress (range ΔQ) is equal to the distorsion which would be caused by the application of an effective primary stress during the same time. An efficiency diagram allows the computation of P_{eff} value when the values of P and ΔQ are known.

As far as design is concern, the main point is the choice of allowable values of the effective primary stress intensity. At first, it seems obvious that the same requirements must be applied to primary stress (monotonic loading) and to effective primary stress (cyclic loading). Such a point of view seems rational, but it must be kept in mind that engineering rules are mainly based on experience and not only on rational considerations. Therefore a review of the current practice is necessary in order to choice margin against progressive distorsion. As a matter of fact two different reviews must be done, depending of creep effects.

Below the creep range, comparison is made between the safety margins used for constant load and for progressive distorsion. It is seen that if the value of the safety factor against excessive distorsion is at least equal to 1.5, no safety margin is requiered against progressive distorsion itself. It appears a great difference safety margins for monotonic and cyclic loading.

When operating temperature is in the creep range, the situation is much more complicated because safety margin against failure are different of the Value it has below the creep range. At low temperature primary stress intensity P is limited to S_m which is less that a third of the ultimate stress. In the creep range, When time effect is noticeable, P is limited to S_t which is only less that two thi

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of the stress leading to rupture in the given time. Therefore limitation of the distorsion resulting from cyclic loading cannot be made on the same basis that at lower temperature.

All these difficulties are analyzed in the paper and a proposition is made of what can be the allowable values to be applied to effective primary stress.

I - INTRODUCTION

Recently a practical rule to appraise ratchet effect has been proposed by P. COUSSERAN and co-workers [1]. This rule is based on the concept of "effective primary stress" which give the ratchetting distorsion. As far as design is concerned the main point is to know the allowable values for the effective primary stress. The aim of this paper is to discuss the choice of these allowable values, first below the creep range, and then when creep effect is significant.

II - DEFINITION OF RATCHETTING EFFECT

One purpose of mechanical analysis of structures, carried out during the design stage, is to prevent any damage that is liable to cause shutdown or collapse of these structures. One of these dangers is progressive distortion (or ratchetting), and it is current practice to take this into account in advanced industries such as the nuclear industry.

This type of damage is characterized by an increase in deformation whenever a load is applied or varied. Figure 1 illustrates two possible types of behaviour under the action of successive loading applications. In the first case, the residual deformation remains stable after a few load applications, denoting a shake-down of the structure. In the second case, the residual deformation increases with every cycle (ratchetting). This phenomenon is liable to cause serious damage ; in particular, our understanding of fatigue behaviour in these conditions is extremely poor.

It must be pointed out that the behaviour illustrated by figure 1b is caused by simultaneous action of primary stress, which is not self limitating and of cyclic secondary stress which are self limitating.

When creep cannot be neglected, that is to say when material behaviour is time-depending, such a simple definition is no longer suitable. In this paper, one will call ratchetting the acceleration of deformation, under controlled load, due to imposed cyclic deformations. In other words, attention is given to the increase of creep elongation in presence of cyclic deformations, such as thermal straining.

With the development of modern techniques, such as Liquid Metal Fast Breeder Reactors, the knowledge of this phenomenon becomes very important, in order to get a safe design. Thus, there is a strong need for convenient, effective, and safe design rules. Concerning the design of nuclear reactors, construction Codes give some indications [2] [3]. When creep is not to be considered, rules are designed to accomodate a pure elastic behaviour, required for the validity of fatigue analysis. At high temperature, various very conservative rules are proposed of which the field of application is very limited.

The rules proposed in the construction Codes result only from theoretical work. Such a situation seems strange because theoretical works are based on over simplified assumptions about material behaviour like perfect plasticity.

This is the reason why Cousseran and co-workers made a comprehensive experimental study in order to obtain a practical rule to appraise ratchetting effect [1] [4] [5] [6].

In this compact it is not possible to make a review of the state of the art, therefore the reader is invited to consult reference [1] which includes a great number of references.

III - METHOD OF APPRAISAL OF RATCHETTING

In most of practical cases, ratchetting occurs when a primary stress of intensity P (due to internal pressure for instance) and a cyclic secondary stress are applied. Secondary stress is elastic computed stress corresponding to an imposed deformation. An example of secondary stresses is thermal stress due to differential dilatations The intensity of the range of secondary stress will be noted ΔQ.

Due to the cyclic secondary stress of range ΔQ, elongation, distortion and damage are greater than it would be if the primary stress P was applied alone. Cousseran and co-workers [1], [5] [6] showed that the distortion (function of time) is equal to the distortion obtained by only the application of a fictitious primary stress called "effective primary stress" P eff. They gave the method to compute P eff :

- Intensity of primary stress P
- Intensity of the range of cyclic secondary stress ΔQ
- Secondary Ratio $SR = \frac{\Delta Q}{P+\Delta Q}$
- P/P eff is given as a function of $(SR)^2$ on figure 2 (efficiency diagram).

This method is justified by the analysis of a great number of experimental results obtained at SACLAY [6] or published by different workers [7] . The results of these analysis are shown on figure 3 and it is obvious that the curve of the efficiency diagram is conservative.

As far as design is concerned, the main question is "How to use the effective primary stress computed by this method". The best way to answer this question is comparaison with current practices. As current practices seem different according to creep effect, it is the best way to examine low temperature range and high temperature range separately.

IV - DISCUSSION BELOW THE CREEP RANGE

Effective primary stress give the obtained distortion and an indication on damage, hence, it seems obvious to choice the same allowable values for effective primary stress than for conventional primary stress P eff $< S_m$.

Such a choice must be compared to the rules written in pressure vessel codes like ASME code [2] .

The only requirement about ratchetting is that thermal stress ratchet is not allowed [NB 3222-5] and examples are given. In one case (corresponding to BREE's diagram) the requirements are (if $S_m \geq \frac{2}{3}$ Sy)

$$x = \frac{P}{1{,}5\ S_m} \qquad\qquad y = \frac{\Delta Q}{1{,}5\ S_m}$$

$$0 < x < 0{,}5 \qquad\qquad y < 1/x$$

$$0{,}5 < x < 1 \qquad\qquad y < 4(1-x)$$

The comparison show that allowable P eff intensity is greater than S_m and is near 1,5 S_m (or Sy). Such a value is very much larger than the initial proposition. What is the meaning of this discrepancy ?

It is possible to get an rough idea for elastic perfect plastic material. As $P < S_m < \frac{Sy}{1{,}5}$ there is a safety factor equal to 1.5 between design load and the load leading to excessive distortion. On the contrary there is not safety margin for progressive distortion which lead to the same damage after several load cycles.

The use of austenitic steel is much interesting ~~this~~ example. In current operations S_m = 0,9 Sy and P < 0,9 Sy. This means that, in stable operating condition, the allowable strain for conventional primary stress, does not exceed 0,1 %. On the contrary P eff is only limited to 1,5 S_m and under cyclic loading conditions, the allowable strain may be as larger as 3 % (corresponding to a stress σ = 1,35 Sy).

As a conclusion there is a tremendous difference between what elongation is tolerated under cyclic loading and what elongation is allowed under static load. This difference seems difficult to explain and to justify.

In most of practical cases, the NB 3222-5 conditions are met when NB 3222-2 condition is met. This condition can be written

$$P_{max} + \Delta Q < 3\ S_m$$

(due to the fact that P is varying between 0 and P_{max}). When this condition is applied, the allowed elongation is very larger than the one admissible under static loading. It is interesting to compare this rule to the rule proposed by COUSSERAN and co-workers. To do that it is easiest to write the S_m rule in term of P eff

$$P_{max} + \Delta Q \lesssim 3\ S_m \text{ equivalent to } P\,eff < S_m$$

$$P\,eff = \frac{(P_{max} + \Delta Q)}{3}$$

$$\text{or } V = \frac{1-SR}{3}$$

This is put on the figure 4 and it can be seen that 3 S_m rule is less conservative than the proposed rule when P is near S_m.

V - DISCUSSION IN THE CREEP RANGE

In the creep range, the current practice can be taken out of Code Case N47 [3] . The choice proposed at the beginning of the preceeding chapter can be written

$$P\,eff < S_{mt}$$

leading to limit the value of the elongation at end of life at 1 %. This limitation is really like the limitation included in appendix T of [3] (T 1310). This means that Code Case allows the same distortion under cyclic loading and under static loading and the difference pointed out for operation below the creep range does not appear at elevated temperature. What is the reason why conclusions are different according to the temperature range ?

It must be emphasized that current practices are very different. As an example, the safety factor against rupture under constant load is almost equal to 3 at low temperature and almost equal to 1,5 at elevated temperature. In other words it is possible to multiply design load (design pressure for instance) by a factor equal to 2,5 without rupture at low temperature, but it is sure that rupture will be obtained at elevated temperature before the specified life was achieved. Such a difference result from operating experience, but is difficult to explain.

As a conclusion at elevated temperature, the same value of elongation is allowed under cyclic load or static load. But there is a great difference between the safety factors currently used at elevated temperature and those used at elevated temperature. As a consequence there is a strong difficulty to fit elevated temperature rules and low temperature rules in the intermediate temperature range.

The proposed method can be compared with O'DONNEL-POROWSKY method as it is written in T-1324 (test n°3) [3] . The main difference is that COUSSERAN method do not take into account any effect of yield stress value. According to the authors of [1], experimental tests do not show any effect of this yield strength. Therefore the two methods give similar results when $Z = P_{eff}/S_y$ is great, but the COUSSERAN method is more conservative when Z is small.

VI - CONCLUSION

The new method proposed by COUSSERAN and co-workers allow to compute an effective primary stress P_{eff} with the help of an efficiency diagram. Distortion of the structure under cyclic loading is near the distortion obtained by the static application of this effective stress.

At elevated temperature, the limitation of the value of this effective primary stress at S_t, insures the limitation of strain at 1 %. Therefore it is recommended to use for Peff the same allowable value than for conventional primary stress.

Such a recommendation is very different from the current practice at low temperature. It has been pointed out that this current practice tolerate very much larger elongation under cyclic load than under static load. This situation needs to be justified, but this is not obvious to do.

Nevertheless, the above recommendation, limiting the intensity of effective primary stress P_{eff} to the allowable values S_m or S_t seem more logical and safer that the current practice in the low temperature range

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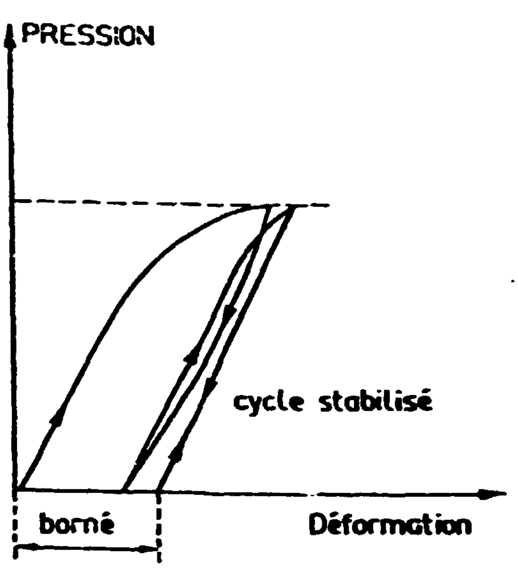
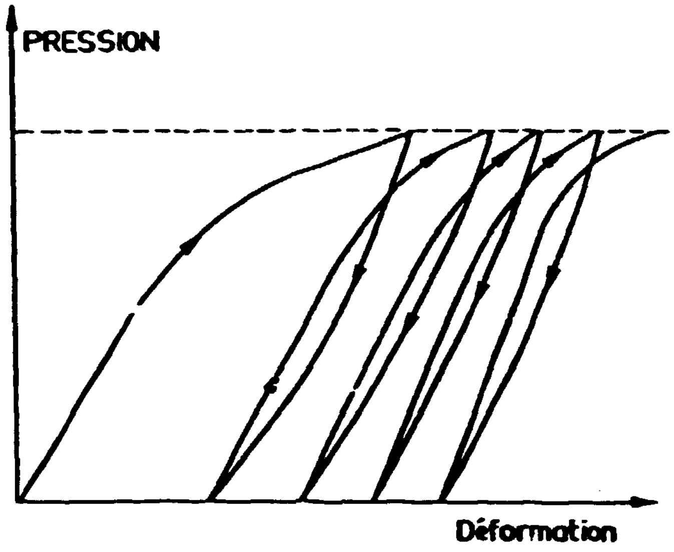
Planche 3



Pas de déformation progressive



Déformation progressive

Planche 4

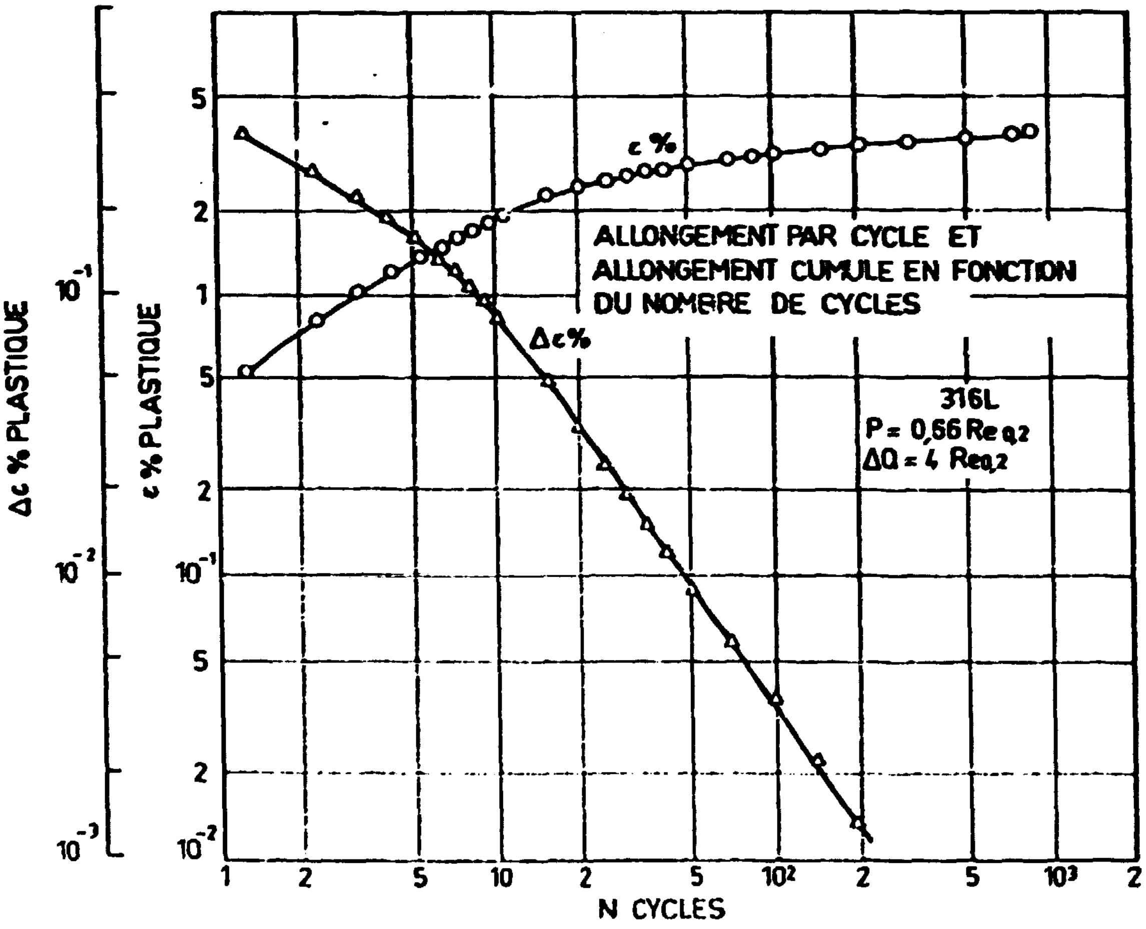


Planche 11

RESULTAT DES ESSAIS CEA

Acier inoxydable 316L

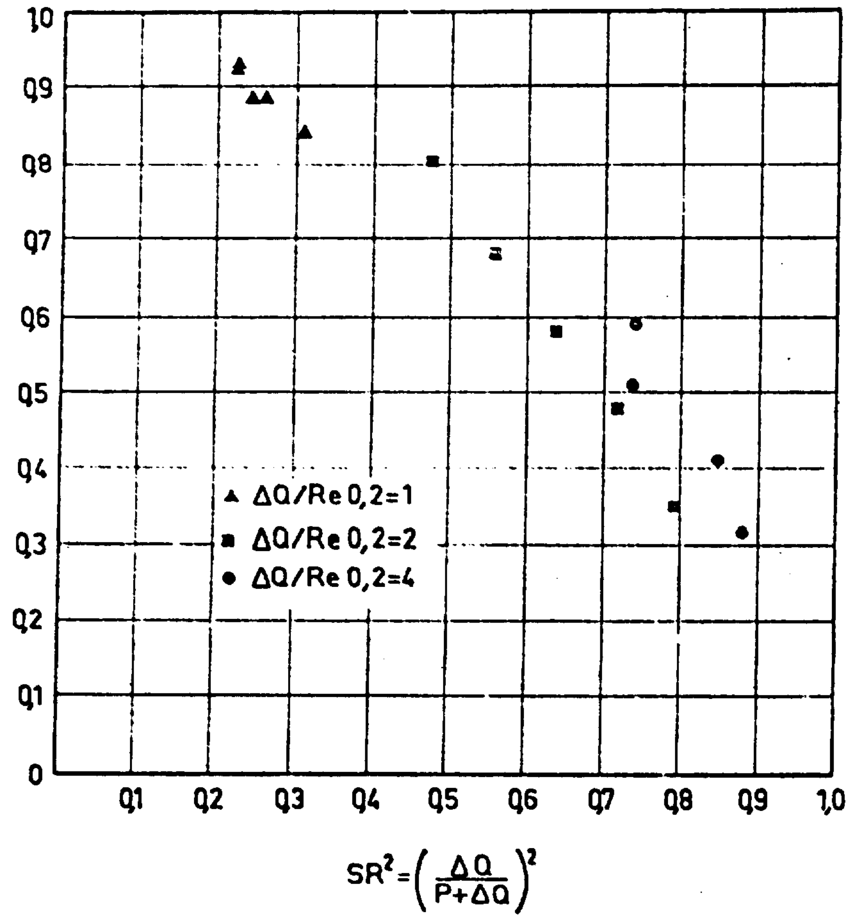
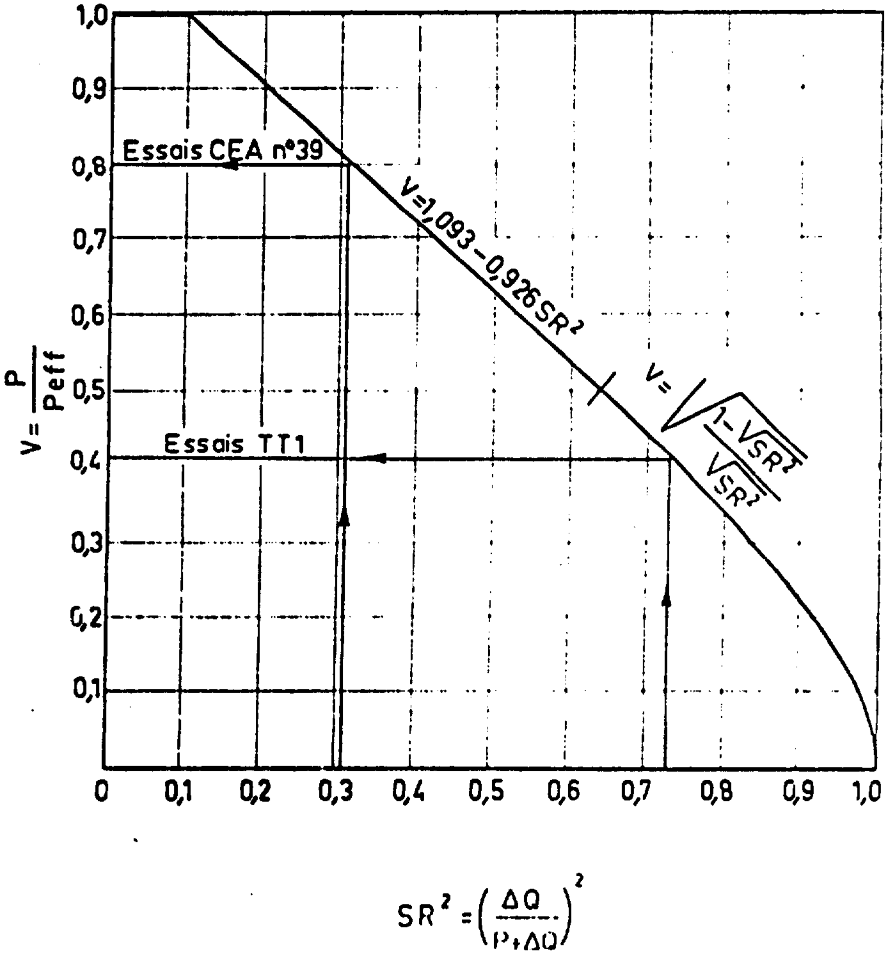
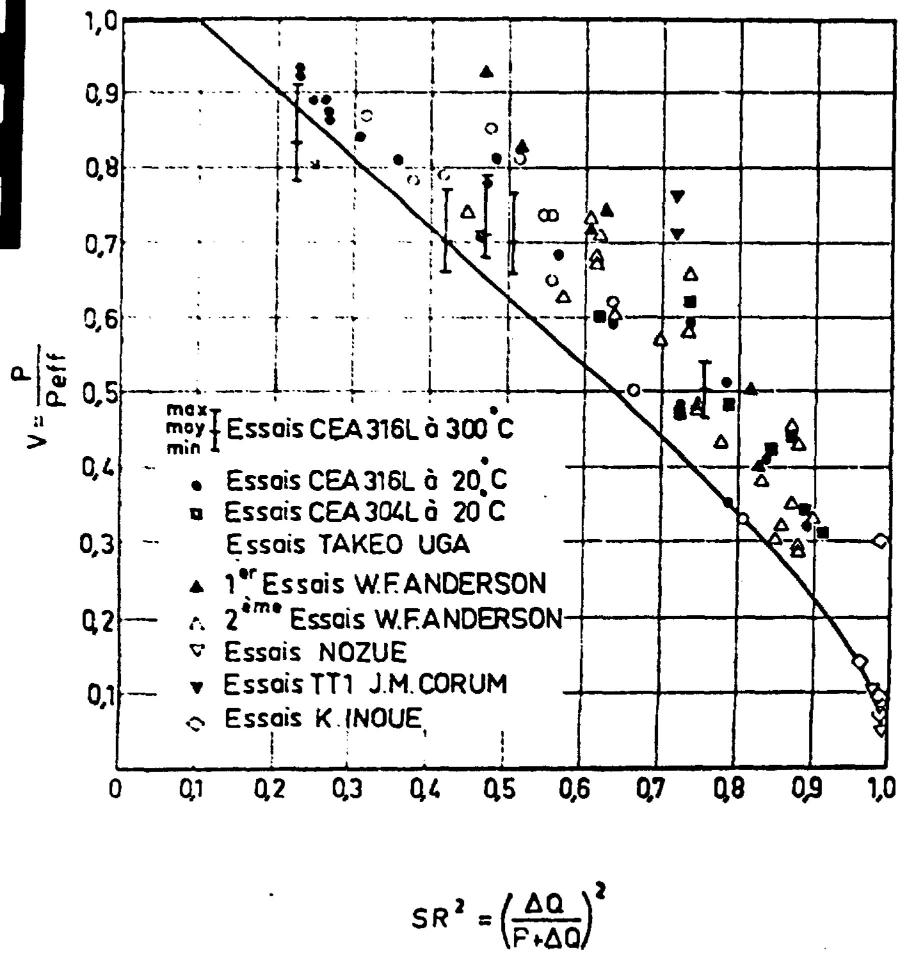


Planche 12

DIAGRAMME D'EFFICACITE



RESULTAT DES DIFFERENTS ESSAIS



COMPARAISON AVEC LA REGLE DES 3SM