The Significance of General Yielding Fracture Mechanics in the Brittle Fracture Evalution of Structural Steels.

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It is well recognized now that it is impossible for a structure to be entirely free from defect ; to admit some defects, we must have a failure criterion for predicting fracture and also for selecting materials. LEFM provides such a criterion (K_{IC}) but only applies when fracture occurs in plane strain conditions ; when large plastic deformations occur, other concepts such as the COD and the path independent J integral have been proposed to predict fracture.

The Crack Opening Displacement (COD) concept.

When a notched or cracked specimen is loaded, it is possible to observe at the tip of the crack a local displacement without propagation. This displacement is the COD and is used as a criterion of fracture (1, 2). In plane strain conditions, the critical COD is related to K_{IC} but when plastic deformation occurs, this relation is no longer valid ; the COD still exists and can be considered as a logical extension of LEFM.

A method for calculating the COD at the tip of the crack as a function of the displacement at the surface of the specimen has been defined (3), assuming that the faces of the crack rotate about an apparent centre of rotation situated at a depth $\frac{W-a}{n}$ below the tip of the crack (fig. 1). This centre of rotation moves during the test from a position close to the tip of the crack to a position close to the centre of the uncracked section. The value n = 2 initially adopted was changed later to n = 3 but the results which we obtained for different steels (4) have shown that this last value gives too conservative results for the usual CODs and overestimated va-

lues for the small CODs. We have found that n is constant and nearly equal to 2.5 when the displacement δ_p at the surface is equal to a certain value, function of the product $\sigma_y \times B$ (yield strength x thickness) (fig. 2). If δ_s is the actual displacement at the surface, we adopt n = 2.5 when $\delta_s > \delta_p$ and n = 4 when $\delta_s < \delta_p$.

Though there are two possibilities of guarding against brittle fracture (preventing from initiating or from propagating), the economic point of view gives rise to a tendency of adopting the principle of preventing initiation of fracture. In the Charpy test, the absorbed energy is due both to initiation and to propagation of the fracture ; moreover some important factors are fixed arbitrarily (strain rate, thickness, radius of the notch). The COD test is a pure fracture initiation test and simulates to an optimum degree what actually happens in practice : the thickness of the specimen is that of the product, the crack is of realistic acuity (fatigue crack) and the strain rate corresponds to that in the actual structure.

Some comparisons between Charpy and COD tests on base metals and welded joints have shown (5) that the COD test could be proposed as type test to provide reference levels for the quality control test. In order to complete the comparison four steels (σ_y : 32 to 43 kg/mm2) have been used to produce decimetric heads FD1500 by two forming processes (hot forming and cold forming). COD and Charpy tests were performed on specimens taken from zones which had been subjected to similar deformations (6). The results of the two types of test are qualitatively equivalent : the hot forming does not result in a substantial change in resilience and COD but the cold forming results in a deterioration of the ductility whatever the criterion used. Care must be taken in interpreting the Charpy test : for example, at 0°C, the cold formed product has still a satisfactory resilience whereas the COD shows a substantial drop in ductility.

We can conclude that the Charpy test remains a valuable quality control test for classifying steels of a same type or to provide a qualitative classification for the different states obtained in a single grade of steel during production. For comparing the ductility of the various zones in a welded joint or of different types of steel, it is necessary to use a test such as the COD test which is more representative of the structures in service.

The J Integral concept.

Recently, the COD has suffered some criticism due to the fact that it focuses attention to the region immediately surrounding the crack tip where the accuracy of the analysis becomes uncertain. This is not the case for the path independent J integral proposed by Rice (7) which applies to both elastic and plastic behaviour and is easy to determinate. Specifically, the J integral is the negative rate of change of the potential energy P with respect to crack extension : $J = - dP/da$. For linear elastic behaviour, the J integral is identical to G so that the use of J provides a means of extending fracture mechanics from linear elastic to fully plastic behaviour.

At a limited number of test temperatures, we have performed COD and J integral tests on three steels (σ_y : 23.5 - 37.1 - 40.7 kg/mm2). As shown in figure 2, a relation has been established between the critical COD and the J_{IC} values ; these results have however to be confirmed with other steels at other temperatures and also with welded joints.

Some questions are still to be solved as regards the applicability and the interest of the J integral :

- the J integral being presently defined for two dimensional behaviour (plane strain or plain stress), what are the limits of its application ?
- have different geometries (same thickness and metallurgy) identical values of J_{IC} ?
- is J_{IC} to be defined in association with a parameter such as thickness or not ?

Concluding remarks.

The COD test has proved to be very useful in the philosophy of fracture initiation in order to establish the actual ductility of the various parts of a structure and also to admit some defects on a rational basis owing to possible relationships between the COD, the overall deformation and a characteristic dimension of the defect. The J integral concept is also an attractive way to extend the philosophy of LEFM to the cases where fracture is preceeded by large plastic deformations but some questions are still to be solved as to the conditions and limits of its application.

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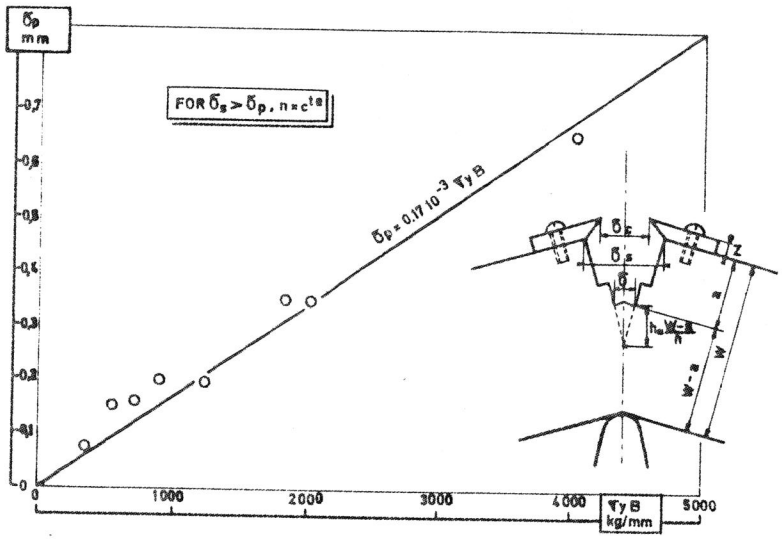

FIG.1

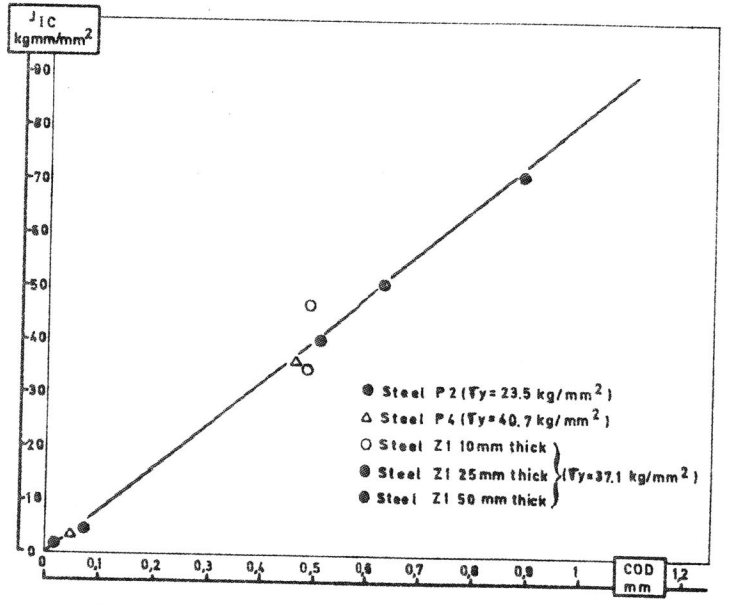

FIG.2