STABLE GROWTH OF PART THROUGH CRACKS IN MARAGING STEEL SHEETS

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ABSTRACT

Fatigue crack growth of semi-elliptical part through cracks was studied in maraging steel plates and it was found that good predictions were obtained using the Paris law and the computed variations of K along the crack front. Stable crack growth under monotonic loading was then studied. Initiation occured when the average value of K along the crack front reached the K_o value at the bottom of the R curve of the material. The part through crack instability could be predicted, using an equivalent through crack and the R curve, the length of this equivalent through crack being related to the shape of the part through crack by an empirical formula.

KEYWORDS

Part through crack, fatigue crack growth, maraging steel, stable crack growth, R curve.

INTRODUCTION

When full plane strain conditions are not met, crack instability is preceded by stable crack growth. The R curve (ASTM 1973, ASTM 1976) has been used as a method to predict the behavior of through cracks whereas for part through cracks the problem is not well understood. As fatigue crack growth is usualy the first step in the fracture of a metal sheet, the published results (Kawahara and Kurihara 1977, Sommer 1977, Knair 1979) on the fatigue of a part through crack were first reviewer. However, the main emphasis of the present study is to attempt to relate the initiation of stable crack growth of such a crack and its instability to the R curve as measured with through cracks.

MATERIAL AND EXPERIMENTAL TECHNIQUE

The study used maraging steel sheets (type Z2 NKD 18.09.05) commercialy known as Durimphy. Table 1 gives the composition of the steel.

TABLE 1

Ni	Co	Mo	Ti	Al	Fe
18.5	9	5	0.5	0.1	Bal.

The 2 mm thick sheets were homogenized for 1 hour at 815°C and oil quenched. They were then vacuum heat treated for 3 hours at 490°C. This treatment resulted in a yield stress of 1836 MPa and a tensile strength of 1952 MPa. The Young's modulus was 187260 MPa.

The R curves were measured on 40 mm wide centrally cracked tensile loaded specimens.

The part through cracks were initiated in 15 mm wide and 30 mm long specimens from spark machined notches. The tool was 0.5 mm thick and the notch depths were 0.5, 1 and 1.5 mm for aspect ratios a/2c equal to 1/2 and 1/6. The fatigue cracks were grown at 30 Hz using an R ratio of 0.1. In order to produce beach marks on the fracture surface, 30 overloads were applied every 3 to 4 K cycles at a frequency of 0.3 Hz with an overload ratio of 1.5. The growth of the crack was monitored with an optical microscope and using the potential drop method. A DC current of 20 A $\pm$ 2.10^{-3} A was fed to the specimen ends , while the potential leads were soldered on either sides of the crack at a distance of 2 mm from the center. The compliance was measured with a clip gage displacement extensometer.

The final fracture was achieved at a constant loading rate of 28 Ns^{-1} (equivalent to 0.92 MPas^{-1}). The potential drop and the crack opening were recorded.

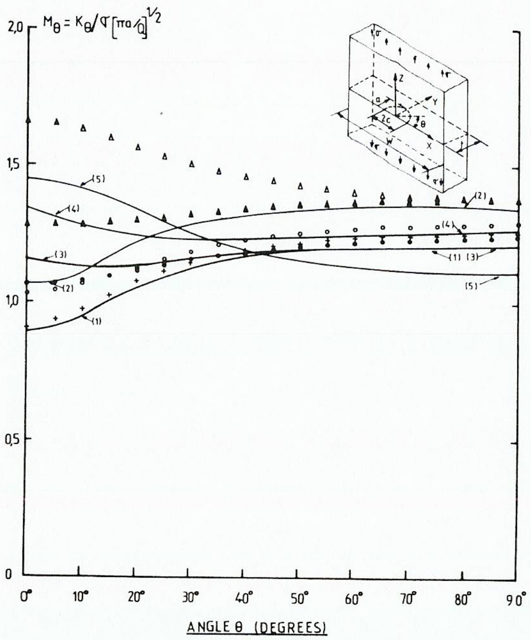
FATIGUE CRACK GROWTH

The fatigue crack growth retardation due to the overloads was measured on the potential drop versus number of cycles curve. It was then possible to correct the crack growth curve, known from the beach marks on the fracture surface, for this retardation. The Paris law of the material as measured with a through crack was found to be :

$$da/dN = 2.364.10^{-11}\ (\Delta K)^{2.41} \quad \text{in m/cycle for} \quad K \text{ in MPa} \sqrt{m}$$

This relationship can be used to calculate the local K value.

The results compared well with Raju and Newman's (1979) computed values of K along the front of a semi-elliptical crack, when the crack depth to thickness ratio was less than 0.6 (fig. 1). For larger ratios the plastic zone interaction with the back surface of the sheet increased the crack depth.



Specimen number 1

$t = 2$ mm
$W = 15$ mm
$a_o = 0.478$ mm
$2c_o = 3.58$ mm

A. VARIATION OF M_θ DEDUCED FROM CRACK SPEED

B. VARIATION OF M_θ COMPUTED BY RAJU & NEWMAN

A	a/2c	a/t
+	0.245	0.463
○	0.280	0.553
●	0.310	0.645
▲	0.328	0.726
△	0.320	

B	a/2c	a/t
1	0.2	0.4
2	0.2	0.6
3	0.3	0.6
4	0.3	0.8
5	0.5	0.8

Fig. 1 : Comparison of the variation of M_θ along the crack front

INITIATION OF STABLE CRACK GROWTH

Examination of the fracture surface shows a planar zone located in the sheet center which progressively decreases in width due to the growth of shear lips which are formed on either faces of the plate. It looks much like the fracture surface of through cracks. Both for those cracks and fort part through cracks, ductile tearing by shear was systematically observed on the surface of the plates before any growth in the center could be detected by the potential drop or the compliance measurements. It thus appears that the crack front of a part through crack during stable crack growth has a very complicated shape which defies a mathematical description.

The initiation of stable crack growth was assigned to the deviation observed either on the potential drop or on the compliance recordings. At these two stages, the average values of K, computed from the variation along the crack front given by RAJU and NEWMAN (1979), were constant for all depth to thickness ratios less than 0.6. On the other hand at initiation the maximum values of K on the crack front showed a greater dispersion. They were close to the value K_0 corresponding to the initiation of crack growth on the R curve.

CRACK GROWTH INSTABILITY

In order to use the R curve (Fig. 2), an equivalent through crack was defined

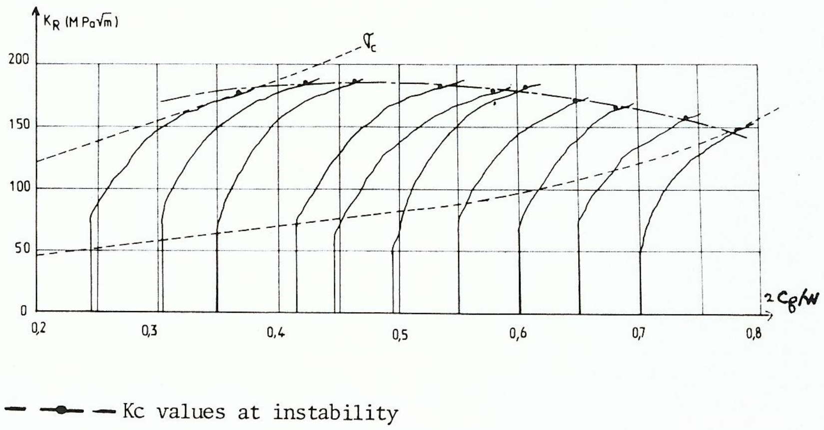


Fig. 2 : R curves obtained on 2 mm thick specimens with different crack lengths

at maximum load. At this point, the load clip gage displacement recording gave the compliance of the part through cracked specimen. Using the formula given by Eftis & Liebowitz (1972) between the compliance and the length 2c of a central cracked tensile specimen, it was possible to compute the length $2c_f$ of an equivalent through crack giving the same compliance (fig. 3). A plot of the ratio a/tQ where t is the plate thickness gave the empirical relation :

$$c_f/t = Z\,(a/tQ)^n \text{ with } Z = 5 \text{ and } n = 3/2 \text{ (fig. 4).}$$

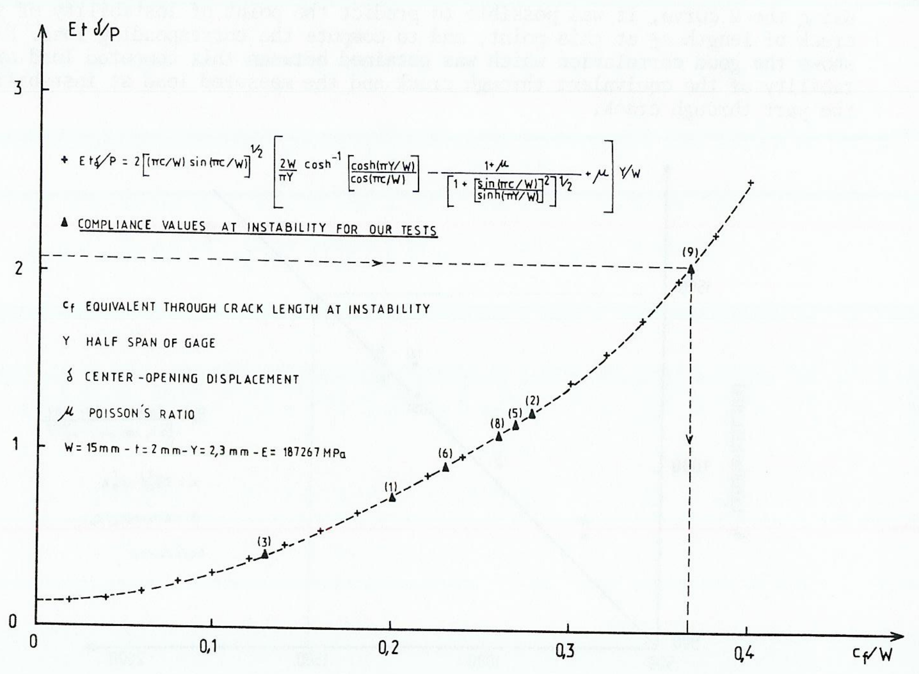


Fig. 3 : Evaluation of an equivalent through crack length for a part through crack

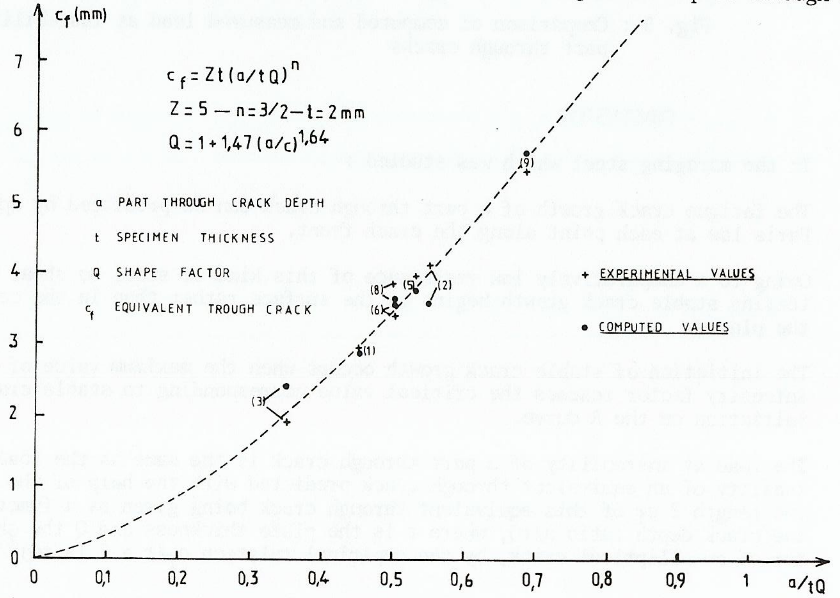


Fig. 4 : Plot of the ratio cf versus a/tQ

Using the R curve, it was possible to predict the point of instability of a through crack of length c_f at this point, and to compute the corresponding load. Fig. 5 shows the good correlation which was obtained between this computed load at instability of the equivalent through crack and the measured load at instability of the part through crack.

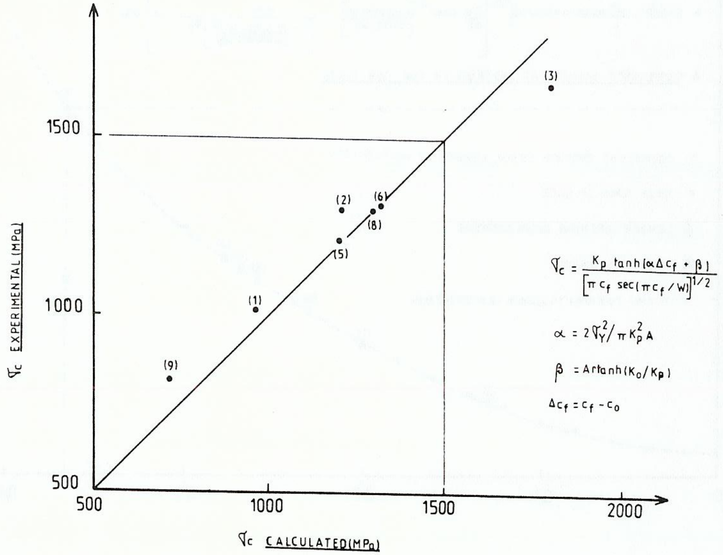


Fig. 5 : Comparison of computed and measured load at instability of the part through cracks

CONCLUSION

In the maraging steel which was studied :

The fatigue crack growth of a part through crack can be predicted by applying the Paris law at each point along the crack front.

Owing to a comparatively low resistance of this kind of steel to shear ductile tearing stable crack growth begins on the surface rather than in the center of the plates.

The initiation of stable crack growth occurs when the maximum value of the stress intensity factor reaches the critical value corresponding to stable crack growth initiation on the R curve.

The load at instability of a part through crack is the same as the load at instability of an equivalent through crack predicted with the help of the R curve, the length 2 c_f of this equivalent through crack being given as a function of the crack depth ratio a/tQ, where t is the plate thickness and Q the shape factor of an elliptical crack, by the empirical relation $c_f/t = 5\ (a/tQ)^{3/2}$.

AKNOWLEDGMENT

This research was supported by a DGRST contract n° 75.7.1206

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