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THE EFFECT OF SPECIMEN THICKNESS DURING FATIGUE OF S 355 CONSTRUCTION STEEL

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ABSTRACT

One of the problems in developing fatigue crack growth rate models is allowing for the effect of specimen thickness on the fatigue crack growth rate. Although a lot of data is available on similar materials tested in different thicknesses the inherent scatter in fatigue crack growth rates prevents a proper comparison. To make a good comparison blanks for CCT and CT specimens were cut out of the middle of 30 mm thick S335 steel blocks using the spark discharge technique. This resulted in CCT specimens with thicknesses of 2, 6 and 10.3 mm and CT specimens of 10.3 and 25 mm. CA fatigue tests were conducted at different load ratios to look at the relation between the specimen thickness and the crack growth rate. The results showed that thicker specimens had higher growth rates. Comparison of CCT and CT specimens of the same thickness showed that there are systematic differences in the da/dN versus AK relation between these two specimen types.

KEYWORDS

fatigue, crack closure, thickness effect, steel

INTRODUCTION

The thickness effect in fatigue is phenomenon that is found by many authors. Research has been done, notably by Fleck [1], that suggests that thick specimens have higher crack growth rates than thinner specimens. The usual explanation for this is the difference in plane strain and plane stress plastic zone sizes which causes differences in plasticity induced crack closure. The problem in determining the effect of specimen thickness is that usually specimens from different plates are taken which have slightly different compositions and mechanical properties. As the effect of thickness which is reported is not very big compared to the normal scatter in fatigue is was decided to investigate this effect by producing tests specimens by cutting them out of the centre of 30 thick S 335 steel plates. This steel is a construction steel commonly used in the offshore industry. The original plates had been homogenised to ensure constant through thickness properties. Using CCT and CT specimens allowed for a range of thickness varying from 2 to 25 mm to be tested. CCT specimens of more than 10.3 mm thickness could not be tested on the available equipment. By conducting tests in this way the actual effects of thickness on the fatigue crack growth rate and on the crack closure level can be determined with adequate accuracy.

EXPERIMENTS

Blanks were cut from 30 mm S355 steel plates using spark discharging to cut plates of thicknesses 2.2, 6.2, 10.5 and 25.2 mm from the centre of the plates. Composition and properties of the S 355 steel used are given in tables 1 and 2.

Table 1 : Chemical composition of S 335 steel used (%)

C	Mn	Si	Al	Cu	N	P	S	Nb	Fe
0.187	1.297	0.398	0.048	0.014	0.005	0.014	0.007	0.029	Bulk

Table 2 : Mechanical properties of S 335 steel used

yield stress	460 MPa
ultimate tensile stress	630 MPa

These blanks were ground down to 2,6,10.3 and 25 mm in accordance with the guidelines laid down in ASTM E647-91,[2]. From these blanks CCT specimens of length 340 mm and width 100 mm and CT specimens of length 125 mm and height 120 mm were produced. These specimens were fatigue tested in an MTS 350 kN fatigue testing machine. Pre-fatiguing with load shedding was conducted to ensure the absence of overload effects at the start of the CA test. The crack length was measured using a Howden pulsed direct current potential drop apparatus. Crack growth rates and stress intensities were calculated using the guidelines provided by ASTM E 647-91, [2]. Crack closure measurements were done using an Elber clip on CCT and CT specimens and back face strain gages on CT specimens.

Table 3 : CA tests conducted on CCT specimens, σ_{max}= 113 MPa

Thickness (mm)	Load ratios				
2	0.1	0.3	0.4	0.5	0.7
6	0.1	0.2	0.3	0.5	0.7
10.3	0.1	0.2	0.3	0.5	0.7

Table 4 : CA tests conducted on CT specimens

Thickness (mm)	Maximum load (kN)	Load ratios			
10.3	8.4	0.1	0.3	0.5	0.7
25	20.4	0.1	0.3	0.5	0.7

RESULTS

The tests were conducted in five groups separating them to thickness and specimen size. Each group will be dealt with separately. In addition crack closure measurements were done on some tests.

Results for CCT specimens

The fatigue crack growth rates of the tests on 2 m specimens show a significant dependency on the load ratio, a shown in figure 1. The crack growth rate at load ratios of 0.5 and 0.7 shows significant differences. This suggests that plane stress crack closure is working at this thickness.
The fatigue crack growth rates of the tests on 6 mm specimens, shown in figure 2 show a smaller load ratio dependency. The crack growth rates at R=0.3 and higher overlap suggesting that crack closure is disappearing.
The 10. 3 mm specimens have crack growth rates almost independent of the load ratio, as shown in figure 3. This suggest that there is no active crack closure in this thickness.

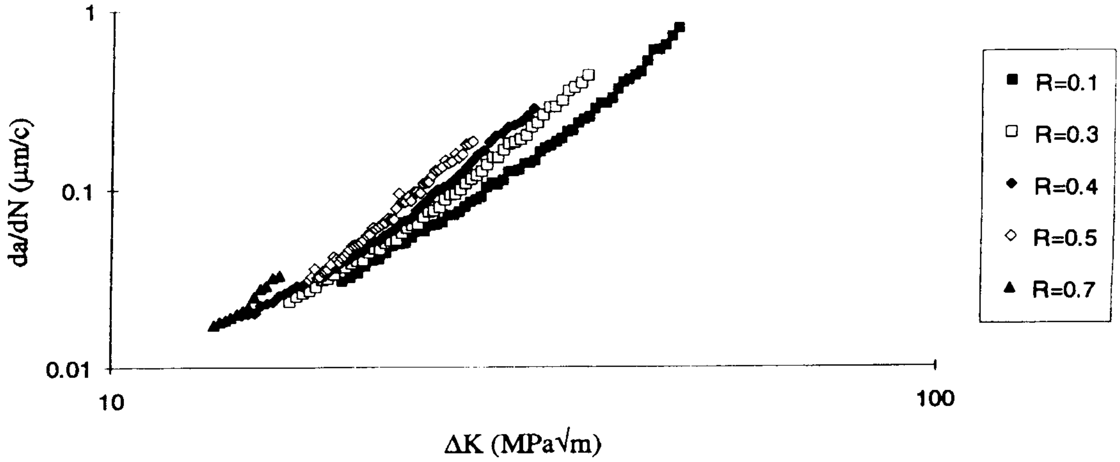

Figure 1: CA Crack growth rate of 2 mm thick CCT specimens at different load ratios

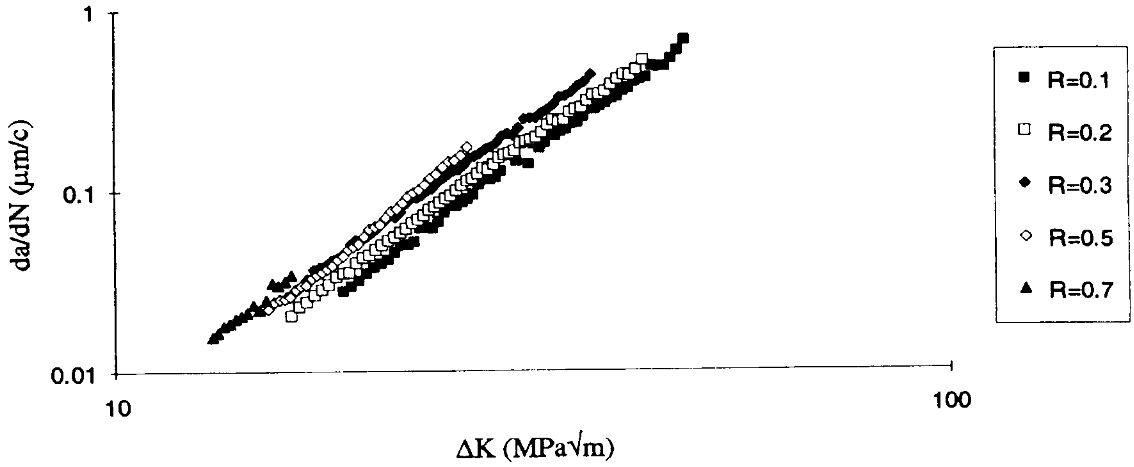

Figure 2: CA Crack growth rate of 6 mm thick CCT specimens at different load ratios

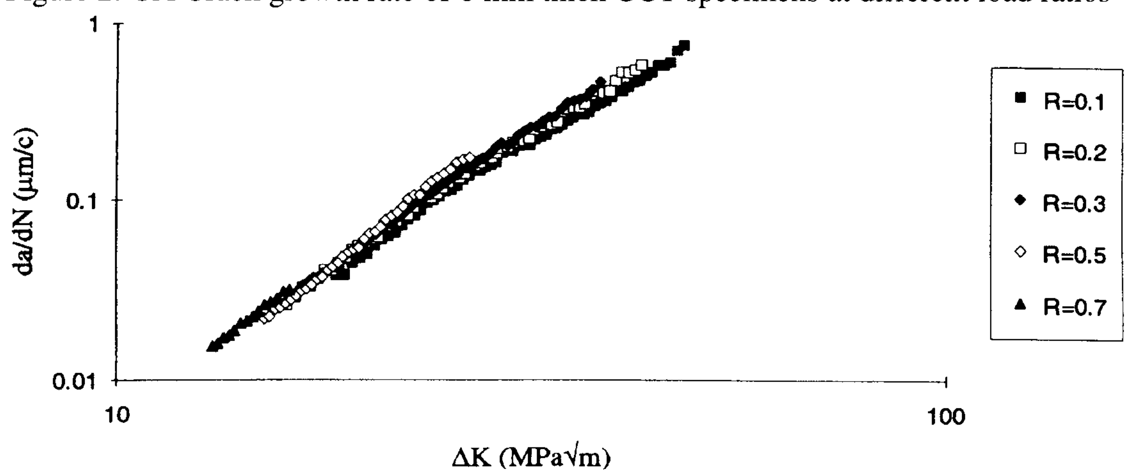

Figure 3: CA Crack growth rate of 10.3 mm thick CCT specimens at different load ratios

Results for CT specimens

The results of the 10.3 mm CT specimens are shown in figure 4 and are similar to those of the 10.3 mm CCT specimens although the load ratio effects appear to be slightly less than in the CCT specimens.
The results from the 25 mm CT specimen, shown in figure 5 are strange in that they show significant load ratio effects at low ΔK but no load ratio effect at high ΔK. These tests were conducted at the same ΔK range as the 10.3 mm specimens using similar pre-fatiguing procedures. Thus overload effects at the start of the CA tests cannot explain the observed differences.

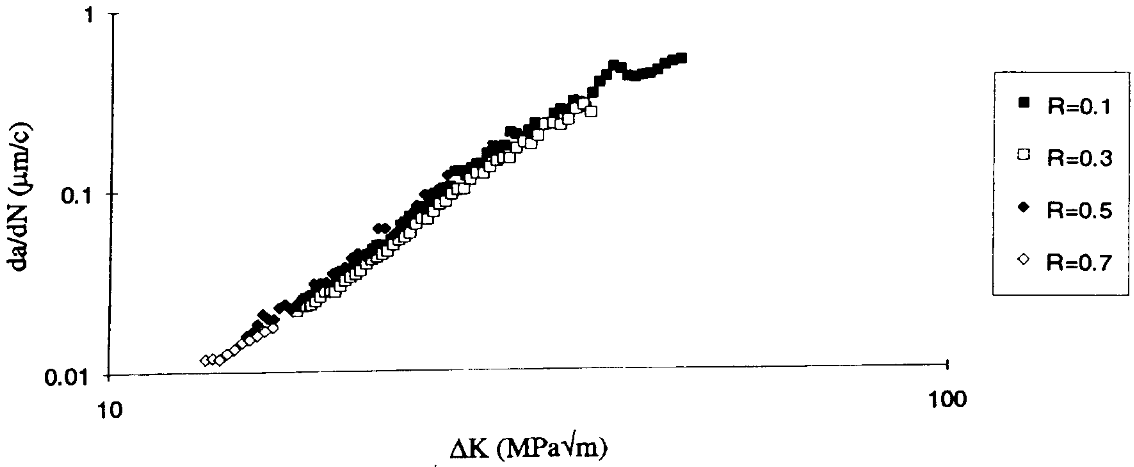

Figure 4: CA Crack growth rate of 10.3 mm thick CT specimens at different load ratios

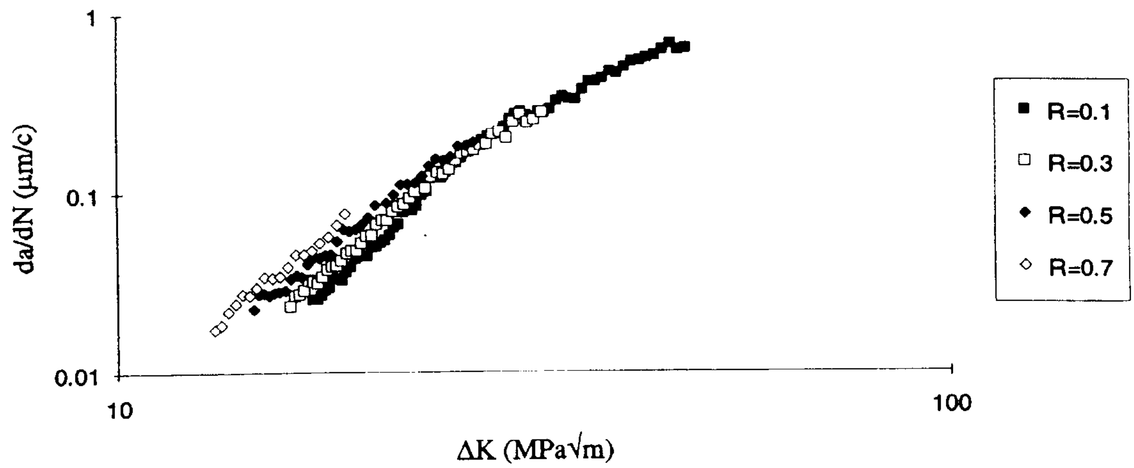

Figure 5: CA Crack growth rate of 25 mm thick CT specimens at different load ratios

Results of crack closure measurements

The crack closure measurements were confusing. The Elber clip suggested the presence of crack closure at low load ratios even on thick specimens. Figure 6 shows the results of an Elber clip measurement and a back face strain measurement on a 10.3 mm CT specimen tested at load ratio 0.1. The crack growth rates in this thickness is independent of the load ratio suggesting the absence of crack closure, which is confirmed by the back face strain gage. The Elber clip suggests the presence of significant crack closure at low load ratios, even in thick specimens. This suggests that the Elber clip is only reliable in specimens of 2 mm thickness or less.

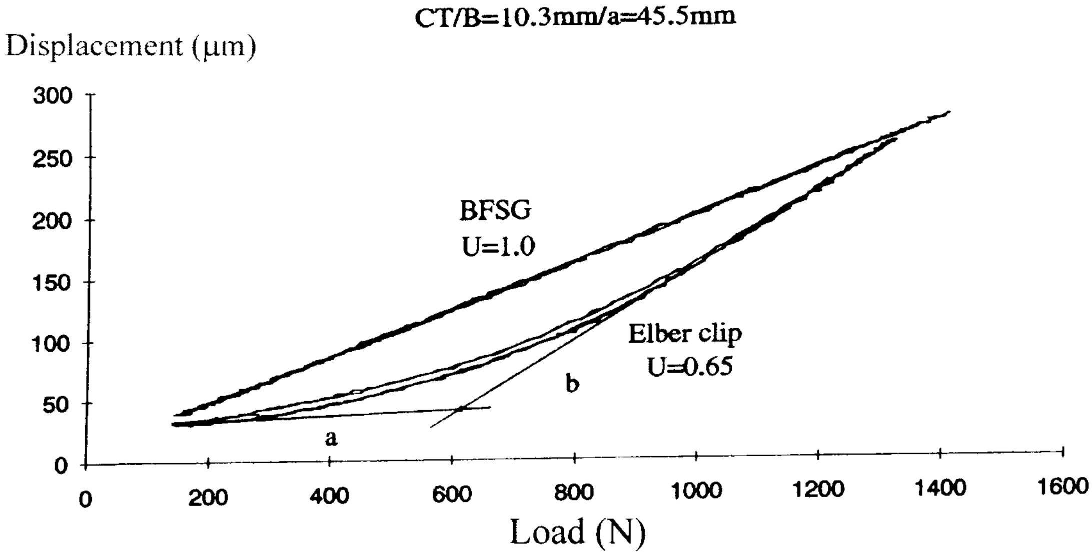

Figure 6: Crack closure measurement results in 10.3 mm thick CT specimen tested at R=0.1

DISCUSSION

The thickness effect is as expected going from 2 mm thickness to 10.3 mm thickness. This can be explained by crack closure changes going from plane stress domination in 2 mm specimens to plane strain domination in specimens of 10.3 mm. The crack closure measurements and the dependency of the crack growth rate on the load ratio support this view. The unexpected presence of a load ratio effect on the crack growth rate in the 25 mm thick specimens at growth rate of less that 0.15 μm/c suggests the situation is more complicated.

Another puzzling result is that the crack growth rates between the 10.3 mm CCT and CT specimens show a systematic difference as shown in figure 7. The CCT specimens have an increased crack growth rate at crack growth rates less than 0.2 μm/c. This small difference is reproducible and suggests a small error in the stress intensity, either in the formulation or possibly in the clamping of the CT specimens.

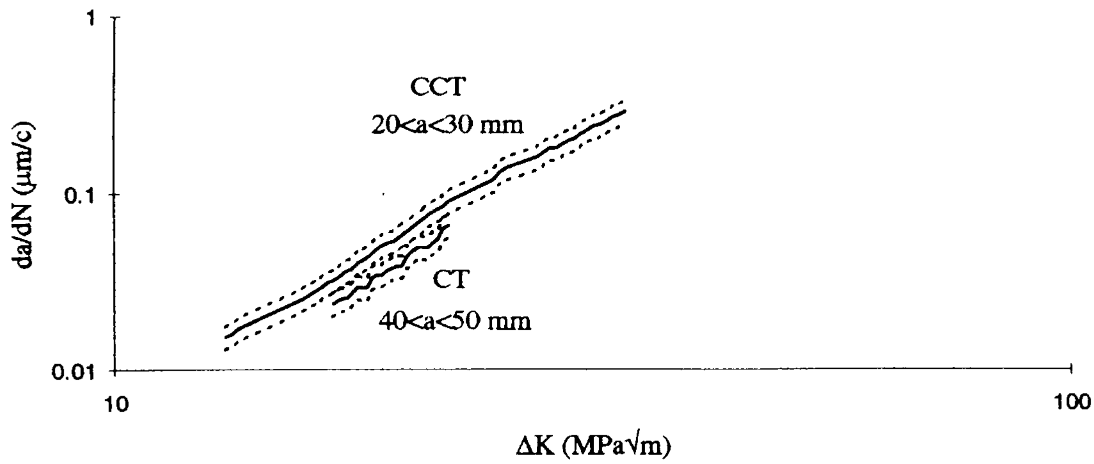

Figure 7 : Crack growth rates in 10.3 mm CCT and CT specimens

Another puzzling result is that the load ratio dependency in 2 mm thick CCT specimens can be described by a single relation such as proposed by Schijve, [3], for aluminium alloys.

$$U=0.5 + 0.5R - 0.35\ R^2\ ,\ 0.1 \leq R \leq 0.7\ (1)$$

Using this relation to calculate ΔK_{eff} allows us to plot all crack growth rates on a single curve, as is shown in figure 8.

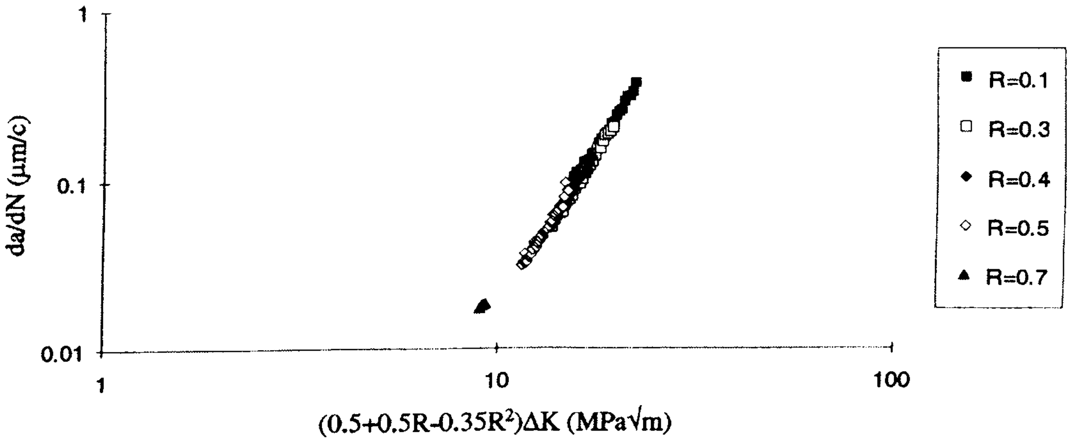

Figure 8 : Crack growth rate in 2 mm CCT specimens plotted against ΔK_{eff}

Puzzling is why S355 steel CCT specimens of 2 mm should show behaviour so similar to that of other alloys, while thicker specimens of the same steel show different behaviour. In Aluminium 2024-T351 the load ratio effect is the same in CCT specimens of 2 mm, 6 mm and 10.3 mm, as shown by Veer, [4]. As this steel was specially selected for its homogeneity through the thickness and all specimens thus have an identical micro-structure the observed differences should be the result of mechanistic effects. These will be the object of further study.

CONCLUSIONS

- There is a significant effect of the thickness on the crack growth rate.
- This effect from 2 mm to 10.3 mm can be explained by the changes in crack closure going from dominant plane stress to dominant plane strain.
- The load ratio effects found in the 25 mm thick specimens cannot be explained by crack closure changes.
- The Elber clip method of measuring crack closure is unreliable except for thin specimens.
- The load ratio effects in 2 mm thick specimens can unified to a ΔK_{eff} calculated using an quadratic U relation similar to that introduced by Schijve for Aluminium alloys.

REFERENCES

1 N.A. Fleck, "An investigation of fatigue crack closure", PhD thesis, Cambridge university, Great Britain, November 1983.

2 1991 Annual book of ASTM standards, vol. 3, Philadelphia, 1990

3 J. Schijve, "fatigue crack closure : observations and technical significance", ASTM STP-982, Philadelphia, 1988

4 F.A.Veer , "The effect of shear lip, loading transitions and test frequency on constant ΔK and constant load amplitude fatigue tests, PhD thesis, Delft University of Technology, Delft, the Netherlands, 1993.