THE MIXED-MODE EXPERIMENTAL INVESTIGATION OF THE FATIGUE CRACK IN CTS METALLIC SPECIMEN

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ABSTRACT

In this paper, the mixed-mode fatigue tests are carried out with the CTS specimen (Compact-Tension-Shear) developed by Richard [1]. In order to analyze the effect of the welded residual stresses on the propagation and the bifurcation of a crack, two types of the specimen are used: non welded specimen and welded specimen. Three loading angles, two loading levels and two materials are selected in the experiments. The effect of loading angle and the filled weld on the crack propagation and bifurcation are analyzed. The photos of crack bifurcation and the results of the crack growth rate in different specimens under different mixed-mode loadings are presented. According to the experimental results, the crack growth rate is related to the loading angle. For the same initial equivalent stress intensity factor K_{eq} (combination of K_I and K_{II}), the crack grows slowest under pure mode I loading. In addition, for the same loading level, the welded compressing residual stresses decrease the crack growth rate in the case of pure mode I loading, but this effect is weak as the crack grows far from the weld zone in the case of mixed mode loading condition. Also, we can observe that the filled weld has low influence on the crack growth direction.

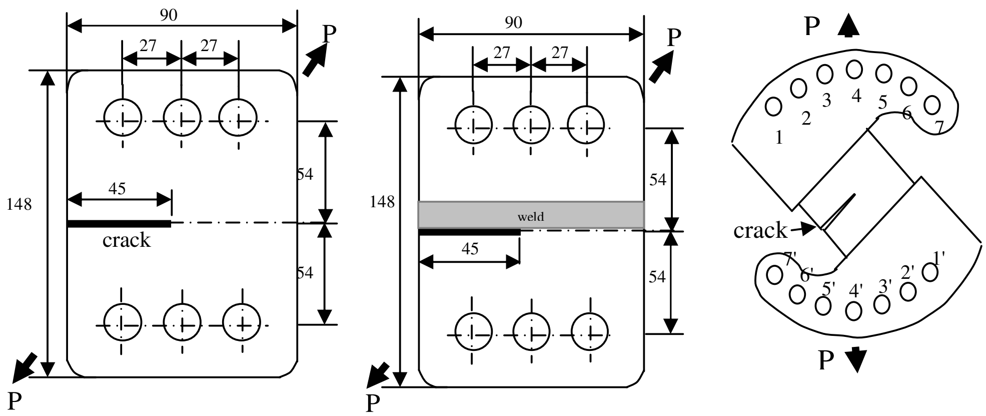
1 INTRODUCTION

The various loading types are often idealized as being pure mode I and pure mode II (2D) based on linear elastic fracture mechanics solutions for crack tip fields. The combinations of loading that involve more than one crack-tip mode are referred to as mixed mode. For mixed mode loading, crack growth behavior is related to the loading condition. In order to study the crack growth process which occurs under mixed mode loading, a series of mixed-mode experiments have been carried out [2-6]. However, most of experiments are performed under static loading. In this work, the experiments of a fatigue crack under mixed-mode loading are performed with CTS (Compact Tension Shear) specimen. The effect of loading angle on the crack growth rate and kinking angle is analyzed. Furthermore, the welded specimens are introduced in the experiments in order to investigate the influence of filled weld on the crack growth rate and on the bifurcation angle.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Material and specimen

The experimental investigations are conducted on the Compact-Tension-Shear (CTS) specimen with the mixed mode loading device which was developed by Richard [1]. Two different types of CTS specimens are used in the work, i.e. the non welded specimen and the welded specimen. All specimens are made from two materials, aluminum alloy 7005 and steel S460. Figure 1 shows the dimensions of the specimens and the loading device. The aluminum alloy specimens are 10mm thickness and the steel ones are 6mm. A pre-crack is introduced up to $a/w \approx 0.5$ in each specimen. 41mm of the pre-crack is machined by electro-erosion, and 4mm of that is performed in the pure mode I fatigue test.



(a) Non welded specimen (b) Welded specimen (c) Loading device

Figure 1 specimens and loading device

2.2 Fatigue experiments

The fatigue tests are conducted on the MTS-810 material test system at room temperature. The CTS specimens are tested with two loading levels and three loading angles 90°, 60° and 30° with respect to the crack axis as shown in figure 2. (a) 90° loading corresponds to pure mode I test. Two specimens are used for each loading condition. During the tests, the load ratio $R\ (= \sigma_{min} / \sigma_{max})$ for all loading angles and all loading levels is kept constant as 0.5. Loads are applied sinusoidally at a frequency of 25Hz.

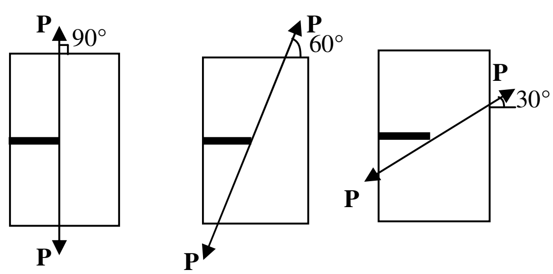


Figure 2 loading angles

2.3 Experimental results

The cycle numbers N and the crack length a are measured during the process of the experiments. The stress intensity factor K is calculated by FEM. The equivalent stress intensity factor K_{eq} is the combination of K_I and K_{II}, it is written as follows [7]:

$$\Delta K_{eq} = \left[\Delta K_I^4 + 8\Delta K_{II}^4 \right]^{0.25} \tag{1}$$

2.3.1 Effect of loading angle on the crack propagation

Firstly, the aluminum specimens with or without weld are tested under mixed mode loading condition (shown in Fig.2). Figures 3 and 4 give us the results of crack growth rate in aluminum specimen. In each figure, the specimens are subjected to 90°, 60° and 30° loading respectively. The same initial K_{eq} is preferred for the comparison.

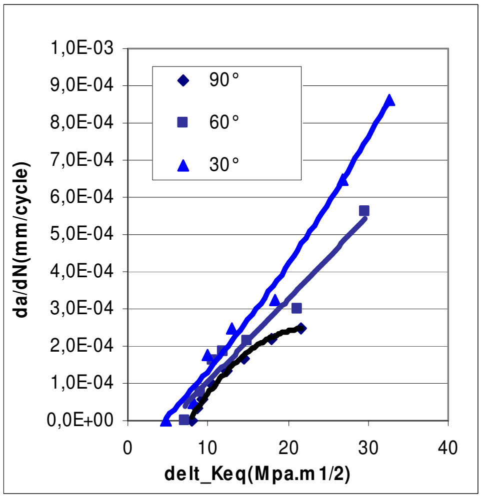


Figure 3 non welded Alu. specimen

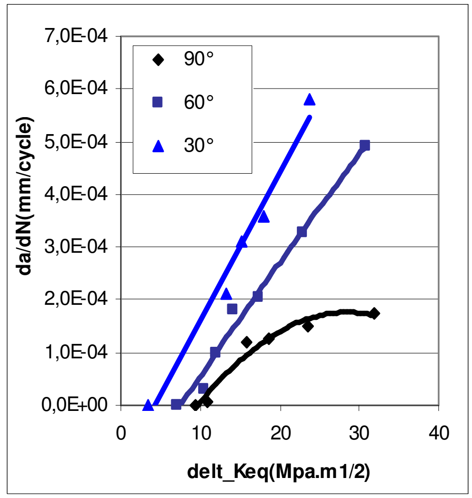


Figure 4 welded Alu. specimen

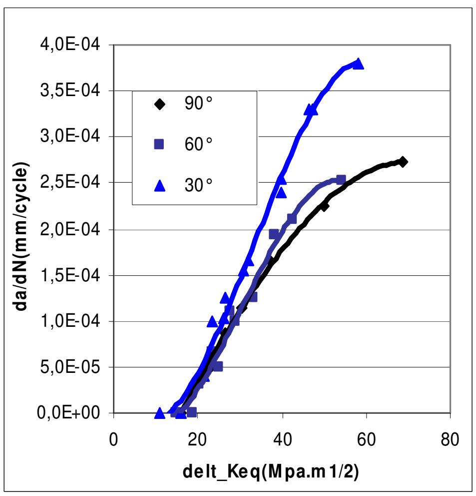


Figure 5 non welded steel specimen

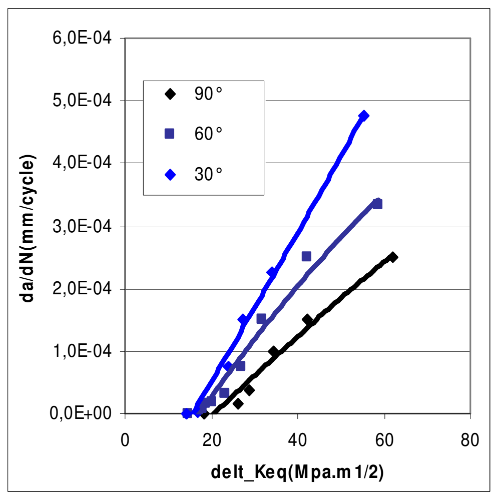


Figure 6 welded steel specimen

Then, the same experiments are performed with the steel specimens. We get the same tendency. Figures 5 and 6 show the crack growth rate of steel specimen. From these results, it can be found that for the same initial K_{eq}, the crack grows faster in the case of 30° loading than that of 60° and 90° loading. For obtaining the same K_{eq}, the closer to pure mode II, the greater the load is. Therefore, the crack growth rate is the lowest when the crack is subjected to pure mode I loading whatever the material is, whatever with or without weld.

2.3.2 Effect of weld on the crack propagation

In this part of the experiment, the welded and non welded specimens are subjected to the same loading angle and to the same loading level. Figures 7 and 8 show the results of crack growth rate in the aluminum specimen.

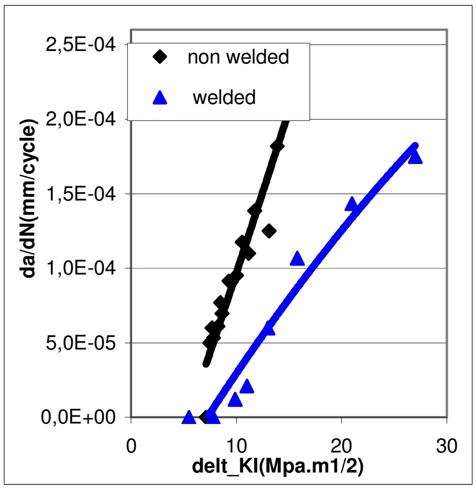


Figure 7. 90° loading for Alu. specimen

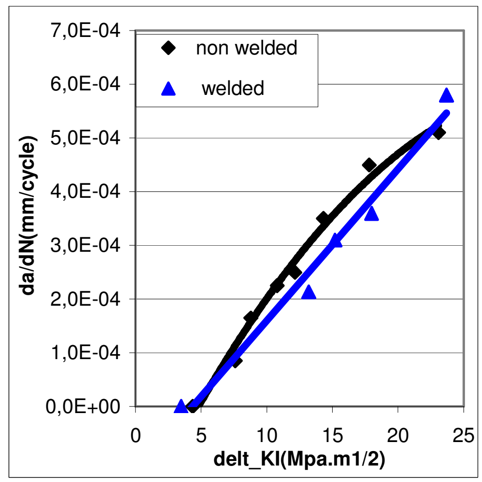


Figure 8. 30° loading for Alu. specimen

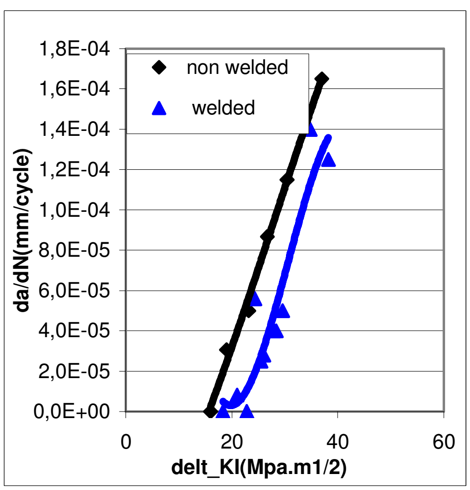


Figure 9. 90° loading for steel specimen

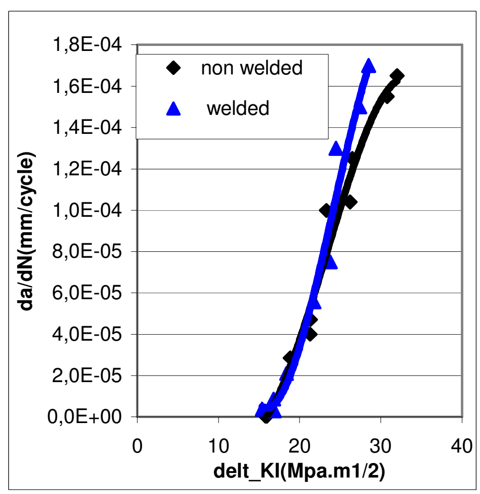


Figure 10. 30° loading for steel specimen

From figures 7 and 8, for the same loading level, the crack growth rate is greater in non welded specimen than that in welded specimen. It is means that the weld introduces the compressing residual stresses near the weld. These residual stresses decrease the crack growth rate. When the specimens are subjected to pure mode I loading condition, this influence is more obvious than in the case of 60° and 30° loading because of the difference of the crack growth path.

When loading angle is 60° and 30°, the crack grows obviously far from the weld. Therefore, there is only a little influence on the crack propagation. Figure 8 shows a mixed-mode example of 30° loading.

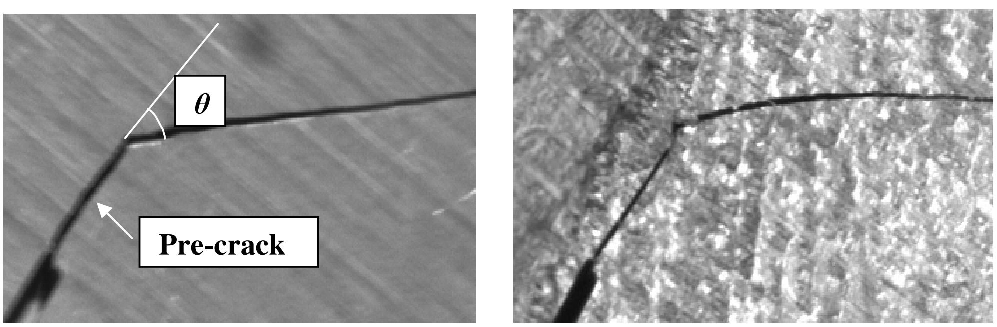
The same effect of weld is obtained from the steel specimen (Fig. 9 and Fig.10). Because the steel specimens are less thick than the aluminum ones, so the influence of the welded residual stresses is less than that of in aluminum specimen.

2.3.3 Crack bifurcation angle under mixed mode loading

Table 1 lists the direction of crack growth. Figures 11 and 12 show the photos of the mixed mode crack growth path. According to table 1 and the photos, it can be observed that there is not great difference of crack growth path between the welded specimen and non welded specimen. The welded residual stresses have no obvious effect on the crack bifurcation angle.

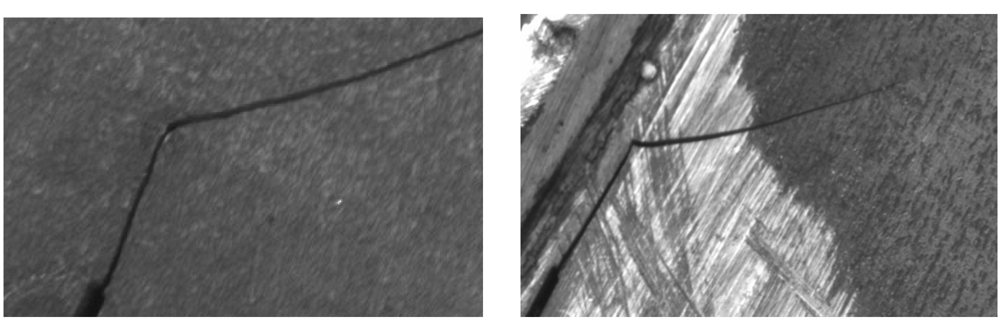
Table 1 mixed mode crack bifurcation angle (θ)

Materials	Specimens	60° loading	30° loading
Aluminum alloy	Non welded	-32°	-46.5°
	Welded	-33°	-47°
Steel	Non welded	-26°	-45°
	welded	-29°	-46°



(a) Non welded (b) Welded

Figure 11 crack growth path of 30° loading of aluminum specimen



(a) Non welded (b) Welded

Figure 12 crack growth path of 30° loading of steel specimen

3. DISCUSSION AND CONCLUSION

The propagation and bifurcation of a crack in CTS specimens under mixed-mode loading conditions are studied experimentally in this investigation. Two types of the specimen and two ductile materials are used. The experimental observations indicate:

- The crack growth rate is related to the loading angle. For the same initial K_{eq}, 60° and 30° loading angles need higher loading level than 90° loading. Therefore, the crack grows slowest under 90° loading due to the lowest loading level.
- For the same loading level, the welded compressing residual stresses decrease the crack growth rate in the case of pure mode I loading, but this effect is weak as the crack grows far from the weld zone in the case of mixed mode loading condition.
- The filled weld has low influence on the crack growth direction

Only the experimental results are introduced in this work. Furthermore, we have developed a numerical model of a fatigue crack considering the welded residual stresses. The stress intensity factor is modified in the propagation law. The numerical simulations showed that the lifetime of the welded specimen is longer than that of the non welded specimen. That's the same tendency with the experimental observations. The numerical model will be presented later in another work.

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