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Experimental investigations of the influence of material and thickness on fracture under pure mode II loading

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Abstract. Experimental investigation to the effects of thickness and material on mode II fracture were performed. Tension-shear specimens made of aluminium alloy LC4CS and 7050-T7452 with thicknesses of 2, 4, 8 and 14 mm were used. All crack tip appearances and fracture profiles of the specimens were observed. Mode II fracture toughness were calculated. It is shown that material and thickness play an important role in mode II fracture. The fracture of LC4CS appears shear fracture under all kinds of thicknesses, however the fracture of 7050-T7452 is tensile fracture when thickness is larger or equal to 8mm, and shear initiation along the original crack plane, then turnaround and tensile failure when thickness is smaller than 8mm. Mode II fracture toughness is independent of thickness.

1 Introduction

It is well known that under mode I loading condition the specimen thickness have strong influence on the crack tip fields as well as fracture toughness of materials [1-3]. However, the literature still lacks systematic studies of the relation between mode II fracture and specimen thickness. The aim of the present investigation is to study the effect of material and thickness on fracture under mode II loading by means of fracture experiments of various materials and thicknesses.

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2 Experimental procedures

2.1 Specimen

Two kinds of high-strength aircraft structural aluminum alloy LC4-CS and 7050-T7452 were used in this study. Compact tension (CT) specimens were chosen for all fracture tests. The thickness range of specimens chosen for this research included 2, 4, 8, and 14 mm, reflecting various three-dimensional constraint of crack tip. Initial 2mm wide V-rooted notches in the CT specimens were mechanically cut. Before the fracture tests, fatigue precracks were produced under constant amplitude loading with stress ratio R slightly above zero. Fatigue precrack extensions in all the specimens are greater than 1.5mm to eliminate the influence of the V-rooted notches. The shape of a specimen is shown as Figure 1.

2.2 Experimental fixture and procedures

The special loading grip jaw designed by Richard [4] was used. The specimen was fixed by three bolts at each end to the three large inner holes of each grip in the manner shown in Figure 2. Loadings were brought to bear on by means of the outer seven pairs of holes, 1-1' to 7-7'. The seven pairs of holes divide equally the 90°angle. Pure II loading was carried out using the No. 7 and 7′ holes, and Loading angle ϕ, the angle between the load line and the initial crack plane, is 0 degree.

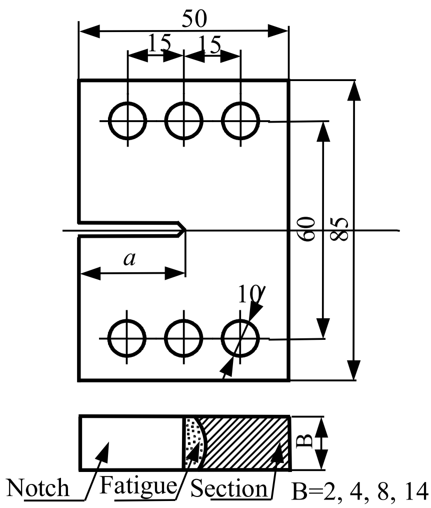


Fig.1. Shape and size of CT specimen (unit: mm)

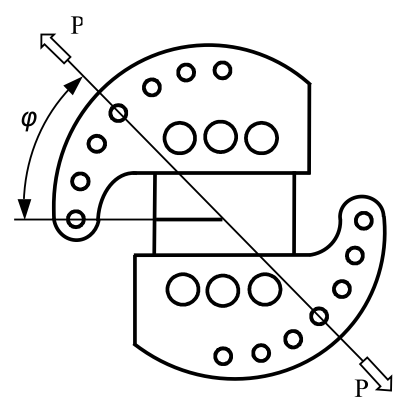


Fig.2. Loading frame

A servo-hydraulic digitally controlled material testing system of 100 kN was used in the investigation. All the tests were performed in displacement–controlled loading mode at a constant cross-head rate of 0.4 mm / min. During the test a COD clip-gauge was mounted for measurement of the crack mouth opening displacement (COD). Traces of load versus COD were recorded automatically by the test system every 0.05 mm of displacement. A zoom-field microscope, a CCD camera, and commercial hardware/software for facilitating the image monitoring and acquisition were used to for crack initiation and growth measurements. The CCD camera output was routed through the digital image acquisition system and into a computer for storage. The fracture morphologies were examined by scanning electron microscope HITACHI S-2700. Figure 3 shows the experimental procedures.

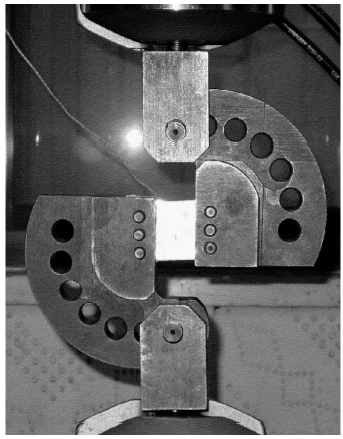
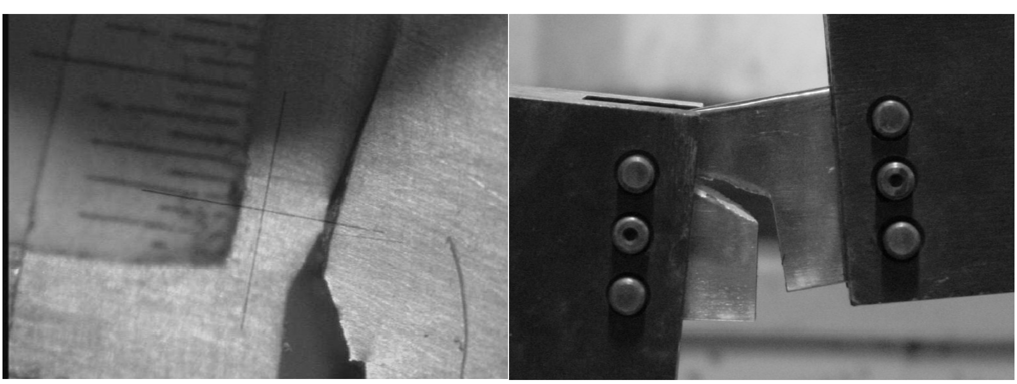


Fig.3. Experimental procedures

3 Experimental results and analyses

3.1 The effect of material on fracture

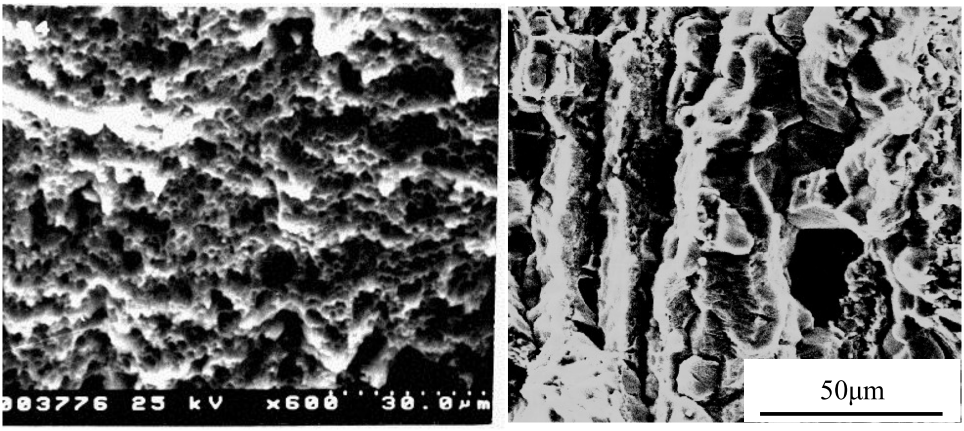
For the same thickness B=8mm, two kinds of fracture types were obtained in the specimens under pure mode II loading. Figure 4(a) is the macroscopic fracture appearance of LC4CS. It is seen that surfaces of the crack tip have slipped obviously, and the crack initiated and propagated almost along the crack plane. However, the specimens of 7050-T7452, shown in Figure 4(b), fractured in the direction that kinked at a large angle with the crack plane, and there was not obvious distortion before fracture.



(a) LC4CS (b) 7050-T7452

Fig.4. Macroscopic fracture appearances of the same thickness under pure II loading

Figure 5 show SEM observations of the above fractured specimens. It can be seen from Figure 5(a) that the specimen of LC4CS fractured in a shear manner, and specimen of 7050-T7452 fractured in a tensile manner from Figure 5(b).



(a) LC4CS (b) 7050-T7452

Fig.5. SEM of the same thickness 8mm under pure II loading

3.2 The effect of thickness on fracture

Fracture of LC4CS appears shear fracture under all kinds of thickness conditions. Fracture of 7050-T7452 is tensile fracture when thickness is larger or equal to 8mm, and shear initiation along the original crack plane, then turnaround and tensile failure when thickness is smaller than 8mm. The results are summarized in Table 1.

Table 1. The effect of material and thickness on fracture type

	LC4CS		7050-T7452	
	> 8mm	< 8mm	> 8mm	< 8mm
Pure II	Shear fracture	(shear fracture)	Tensile fracture	Shear initiation Tensile fracture

3.3 The thickness effect on fracture toughness

For the CTS specimens used in this researches, mode II stress intensity factor K_{II} is given by [4]

$$K_{II} = \frac{P}{wB}\sqrt{\pi a}\, f_2\left(\frac{a}{w}\right)$$
$$f_{II}\left(\frac{a}{w}\right) = 0.4086 + 2.038\left(\frac{a}{w}\right) - 0.2264\left(\frac{a}{w}\right)^2 \qquad (1)$$

The variation of K_{II} with thickness under crack initiation loads is shown in Figure 6 for 7050-

T7452. The curve reveals that mode II critical stress intensity factor K_{IIC} does not undergo any significant with increasing thickness B.

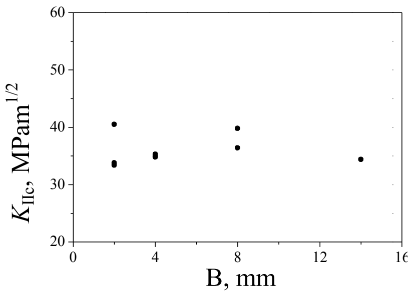


Fig. 6. K_{IIc} vs. thickness for 7050-T7452

4 Discussions

In LC4CS, yielding occurs at the crack tip and Linear Elastic Fracture Mechanics (LEFM) is no longer applicable. An elastic-plastic fracture toughness J-integral should be used. However, the load-COD curves of LC4CS under pure II condition could not be obtained for the COD clip-gauge dropping, J-integral of LC4CS was incapable of determining. Fortunately, researches of the thickness effect on JII were found in reference [5]. In reference [5], mode II tests were carried out on an aircraft aluminium alloy, Al 7075-T7351; a series of specimens of six thicknesses between 5 and 16mm are employed for testing. A rigid plastic analysis and elastic-plastic finite element analysis were employed to show that for non dimensional crack length a/W of about 0.5

$$J_{II} = 0.9 \frac{A}{B(w-a)} \tag{2}$$

A is area under a load-crack sliding displacement record. B is specimen thickness, and (w-a) is uncracked ligament.

The measured J_{II} values are shown in Table 2. It would appear that J_{IIC} did not vary with thickness.

Table. 2 J_{IIC} values for different specimen thicknesses B

B Mm	a/w	J_{IIC} $MPam^{1/2}$
5.0	0.51	39.2
6.4	0.50	40.1
7.4	0.51	36.7
10.0	0.52	41.2
12.6	0.51	41.5
16.2	0.51	42.7

The results in the paper and in references show that mode II fracture toughness is independent of thickness.

5 Conclusions

Pure mode II loading fracture experiments were made by various thickness CTS specimens made of aircraft structural aluminum alloy LC4CS and 7050-T7452. The effects of material and thickness on pure mode II fracture were analyzed. It is shown that material and thickness play an important role in mode II fracture. The fracture of LC4CS appears shear fracture under all kinds of thicknesses, however the fracture of 7050-T7452 is tensile fracture when thickness is larger or equal to 8mm, and shear initiation along the original crack plane, then turnaround and tensile failure when thickness is smaller than 8mm. Thickness has no effect on mode II fracture toughness.

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