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MIXED MODE STABLE CRACK EXTENSIONS THROUGH STIFFENED SPECIMENS

Abdel-Hamid I. Mourad,
Mechanical Design Department,
Faculty of Engineering Mataria, Helwan University,
P. O. Box 11718, Mataria, Cairo, Egypt

Eltahry Elghandour, and Faysal A. Kolkailah
California Polytechnic State University
San Luis Obispo, CA 93407

ABSTRACT

This study presents an experimental investigation of fracture mechanics for isotropic material, aluminum alloy D16AT. The problem of stable crack growth (SCG) has been addressed in this paper. Experimental results are presented for symmetrically stiffened and unstiffened three point bend specimens subjected to different modes, mode I and mixed mode. The stiffeners are doubly bonded to the fatigue pre-cracked specimens parallel to the length at a certain distance behind the crack tip using an adhesive Redux 410 NA. Results concerning load displacement variation, growth of plastic zones, instantaneous crack edge profiles, tunneling, are presented.

There is evidence that the whole stable growth can be characterized by the crack opening angle, COA, criterion. The stiffening helps to increase both initiation and maximum fracture loads substantially.

KEY WORDS: Fracture, Stable Crack, Stiffened and Unstiffened, Isotropic Materials

INTRODUCTION

Many materials give rise to stable crack growth before instability. In order to exploit the potential of such a material beyond the initiation fracture load it is necessary to be able to predict the variation of load with crack opening displacement (COD), or length of crack extension (Δa) up to the Point of instability or maximum load. Mode I problems have received a considerable attention in this context. It is now well known that the whole SCG can be characterized in terms of a constant COA or tearing modulus [1-13]

An analysis of mode I problem is facilitated by the in-plane crack growth and the node release method can be easily adapted. In order to develop similar predictive methods for a mixed mode it is necessary to examine the following. What criterion governs the whole SCG? How can the node release method be adapted? There has been some progress in this direction [7-13]. Some results, both theoretical and experimental, are presented here.

Repair patches/stiffeners can be used to enhance the load capacity or life of a component. These have so far been analyzed within the framework of LEFM. Their exploitation beyond the LEPM requires the knowledge of their performance in the elastic-plastic regime. This really calls for an examination of the SCG criteria to select the most suitable one that can characterize the SCG through patched/stiffened specimens, and development of a procedure for analysis of the growth. There have also been some advances in the understanding of this problem [7,8]. Typical results, both theoretical and experimental, are reported here. Results are now available for both compact tension (CT) and three point bend (TPB) specimens. TPB specimens are only of concern here.

EXPERIMENTS

Experiments have been carried out using an aircraft grade aluminum alloy DI6AT with modulus of elasticity $E = 72594$ MPa, plastic tangent modulus $E_T = 1471$ MPa, Poisson's ratio $\nu = 0.3$, yield stress $\sigma_y = 353$ MPa and fracture toughness $J_c = 16160$ J/m^2 (for 10 mm specimen thickness). The material has negligible anisotropy. Specimen geometry is shown in Fig. 1. Mode I specimens are of nominal size 160 mm x 40 mm x 8 mm thickness. Length in the case of mixed mode is 245 mm. Cracks are located parallel to the width, at the center of the span in the case of mode I, and offset by 10% or 20%; span in the case of mixed mode. Specimens are made following some of the ASTM E399 (1981) guidelines. Stiffeners of nominal size 50 mm x 10 mm x 1.82 mm thick are doubly bonded to the fatigue pre-cracked specimens parallel to the length at a certain distance behind the crack tip using an adhesive Redux 410 NA (manufactured by Hindustan Ciba Geigy). The adhesive has a lap shear strength of 32 MPa; with post-curing at 120^0c; the strength is 40 MPa Experiments have been carried out quasistatically on a displacement-controlled machine.

The crack opening displacement has been measured at the mouth using a clip gauge. The load-displacement diagrams are shown in Fig. 2. There is an increase in both initiation and maximum load by about 100% because of the stiffening in almost all the cases.

The crack edge profiles have been obtained by the method of replication. The general observation is that the crack opening angle remains almost constant during the whole SCG irrespective of the mode of loading.

The plastically deformed zone (Fig. 3) around the maximum load has been determined employing an etchant [14]. The white bands adjoining the crack flanks are the plastic zones. The plastic zone normal to the crack path increases in size with the crack extension.

Typical photographs of fractured samples, crack tunneling and fracture surfaces are presented in Fig. 4. The fractured samples show very negligible plastic deformation. There is a substantial tunneling - 4 to 6 mm in the case of mode I and 5 to 7 mm in the case of mixed mode. The fracture surfaces are mostly flat; there is a marginal slant fracture near the surfaces,

CONCLUSIONS

From the results reported here and presented elsewhere (7-11), it appears that the COA criterion can characterize the whole stable crack growth in both mode I and mixed mode. Although the stiffening in a sense gives rise to some loading on the crack flanks at a location not so far away from the crack tip, the COA criterion still characterizes the crack growth in such a situation. The stiffener can help to increase the load capacity of the specimens by as high as 100%. The load-displacement variation can be predicted reasonably accurately. The adhesive shear stresses are highest at the crack flanks.

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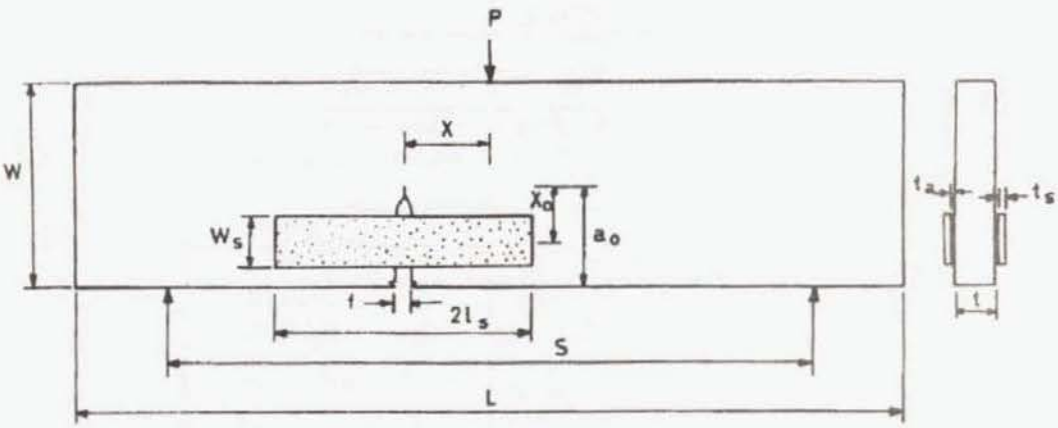
Table 1 J at various stages of onset of extension.

Stage	ΣΔa (mm)	unstiffened		Stiffened	
		P/P_i	J_{avg} (Nm/m^2)	P/P_i	J_{avg} (Nm/m^2)
		Mode I			
		Pi= 4943'86 N		Pi= 14540.36 N	
1.00	0.00	1.00	8440.67	1.00	8573.17
2.00	0.40	1.24	16163.33		
3.00	0.80	1.33	20626.67		
4.00	1.20	1.39	25708.33		
5.00	1.60	1.41	29491.67		
6.00	2.00	1.43	33518.33		
		Mixed Mode			(0.1S)
		Pi= 435S.00 N		Pi = 12856.54 N	
11.00	0.00	1.00	8948.50	1.00	8506.30
2.00	0.40	1.26	11696.67	1.31	11003.30
3.00	0.80	1.39	16575.00		
		Mixed Mode			(0.2S)
		Pi= 5750.5G N		Pi=16174.00 N	
1.00	0.00	1.00	8901.80	1.00	7978.17
2.00	0.40	1.26	12033.30	1.33	11528.33
3.00	0.80	1.38	17041.70		
4.00	1.20	1.44	20610.00		
5.00	1.60	1.50	25530.00		
6.00	36557.00	1.52	29928.30		

Table 2 : J at various stages of completion of unloading

Stage	ΣΔa (mm)	unstiffened		Stiffened	
		P/P_i	J_{avg} (Nm/m^2)	P/P_i	J_{avg} (Nm/m^2)
		Mode I			
		Pi= 4943'86 N		Pi= 14540.36 N	
1.00	0.40	1.00	9649.83	1.00	8948.17
2.00	0.80	1.24	17331.67		
3.00	1.20	1.32	22296.67		
4.00	1.60	1.39	'28103.33		
5.00	2.00	1.41	32335.00		
6.00	2.40	1.43	36818.33		
		Mixed Mode			(0.1S)
		Pi= 435S.00 N		Pi=12856.54 N	
1.00	0.40	1.00	5090.67	1.00	4222.20
2.00	0.80	1.26	12380.00		
3.00	1.20	1.39	18023.33		
		Mixed Mode			(0.2S)
		Pi= 5750.5G N		Pi=16174.00 N	
1.00	0.40	1.00	5095.30	1.00	4002.33
2.00	0.80	1.26	12668.30		
3.00	1.20	1.38	18586.70		
4.00	1.60	1.44	22730.00		
5.00	2.00	1.50	28438.30		
16.00	2.40	1.52	33316.70		



L=160 mm (245 mm)* S=125 mm (165 mm)* W=40 mm t=8 mm
f =3 mm 2LS=50 mm W_s=10 mm t_s=1.8 mm t_a=0.22 mm
a_o =20 mm x_o=11 mm x=0 (0.1S, 0.2S)*

* for mixed mode

Figure.1 Specimen geometry

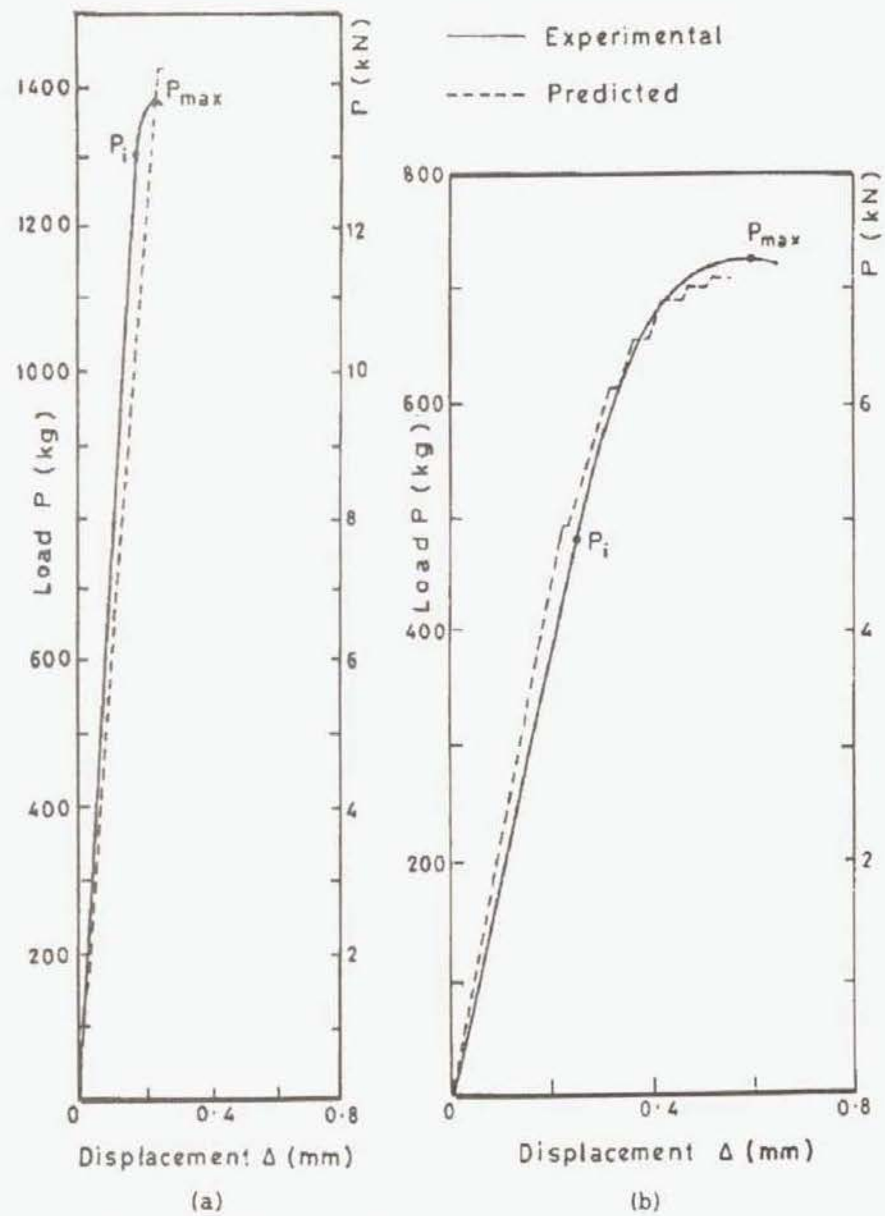
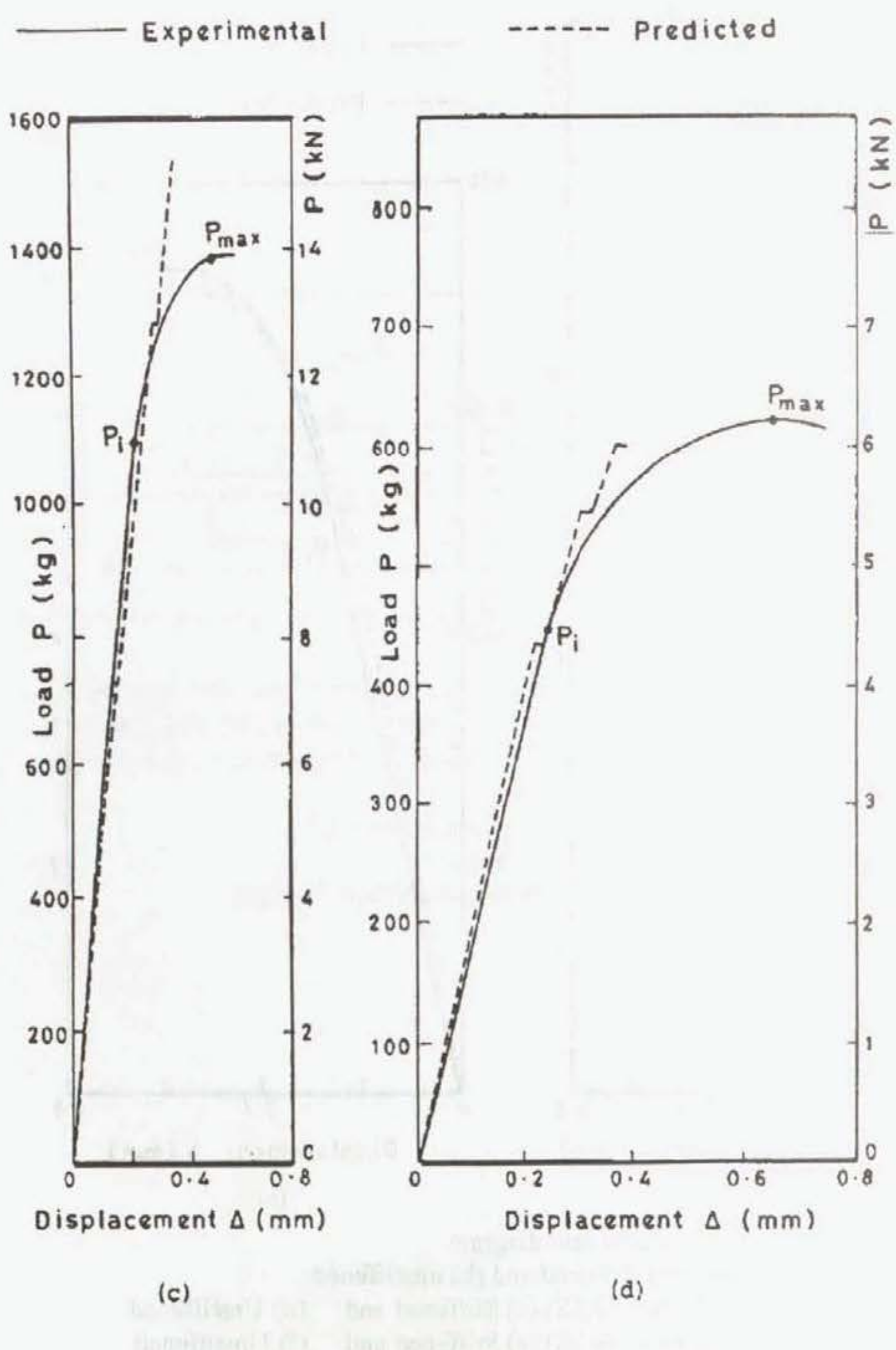


Fig. 2 Load-displacement diagram.
Mode I (a) stiffened and (b) unstiffened.
Mixed mode (0.1S) (c) Stiffened and (d) Unstiffened.
Mixed mode (0.2S) (e) Stiffened and (f) Unstiffened.



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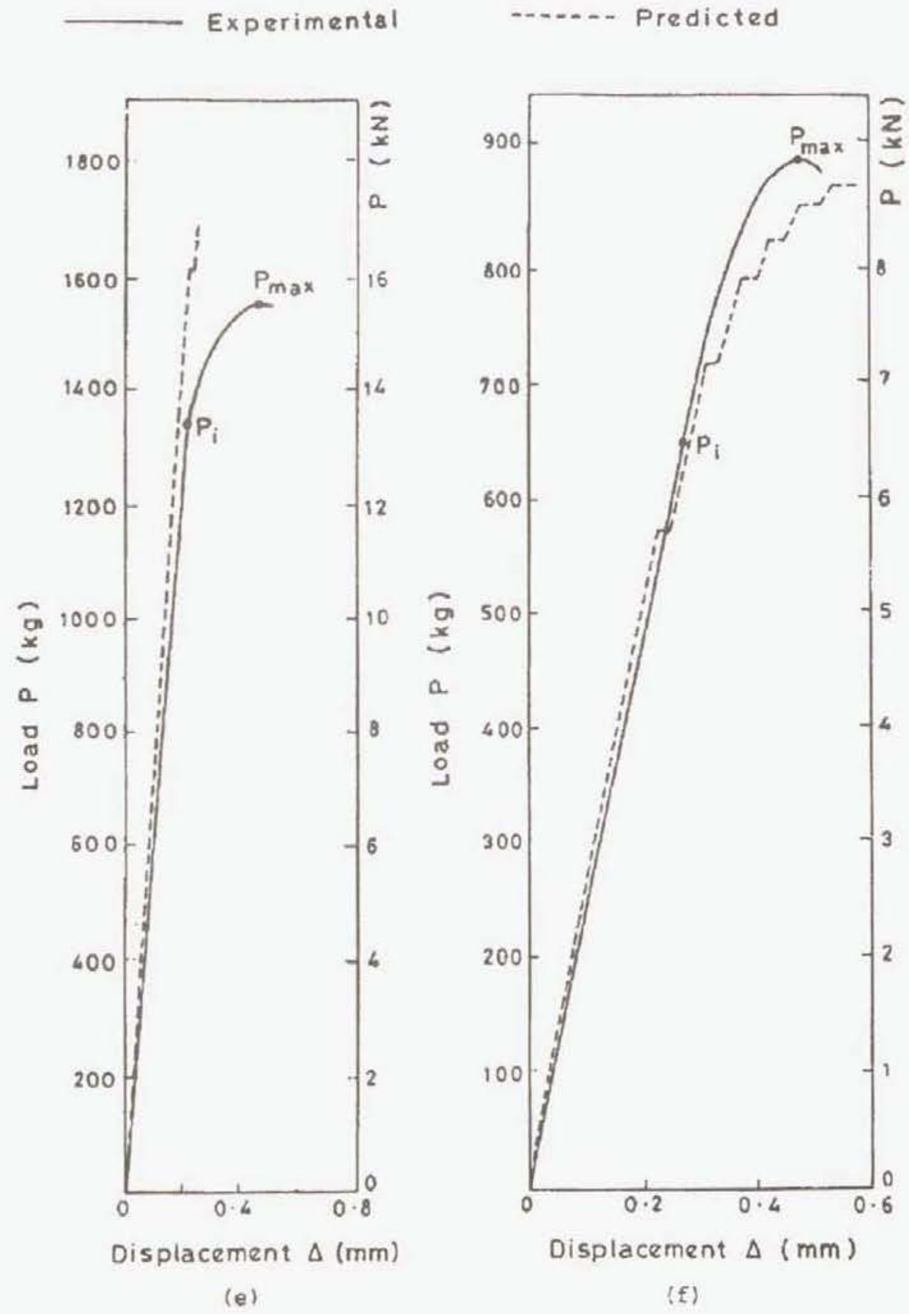

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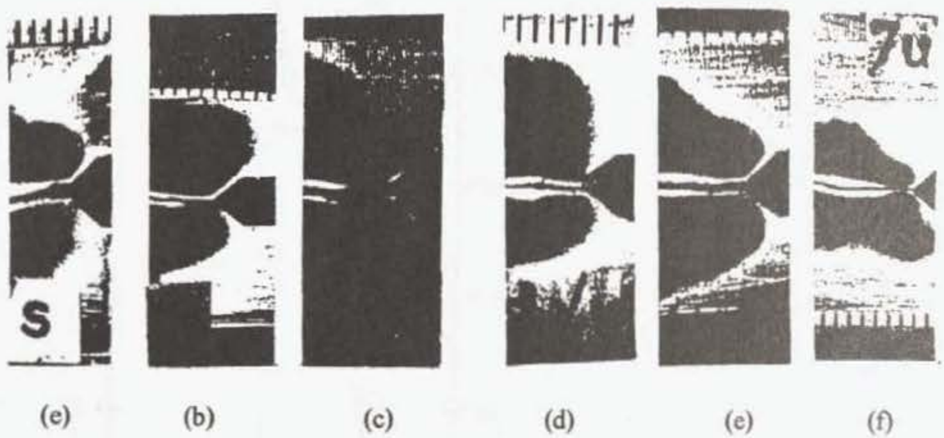

Fig. 3 Plastic wakes. Stiffened (a) mode I, (b) mixed mode (0.1S) and (c) mixed mode (0.2S). Unstiffened (d) Mode I, (e) mixed mode (0.1S) and (f) mixed mode (0.2S)

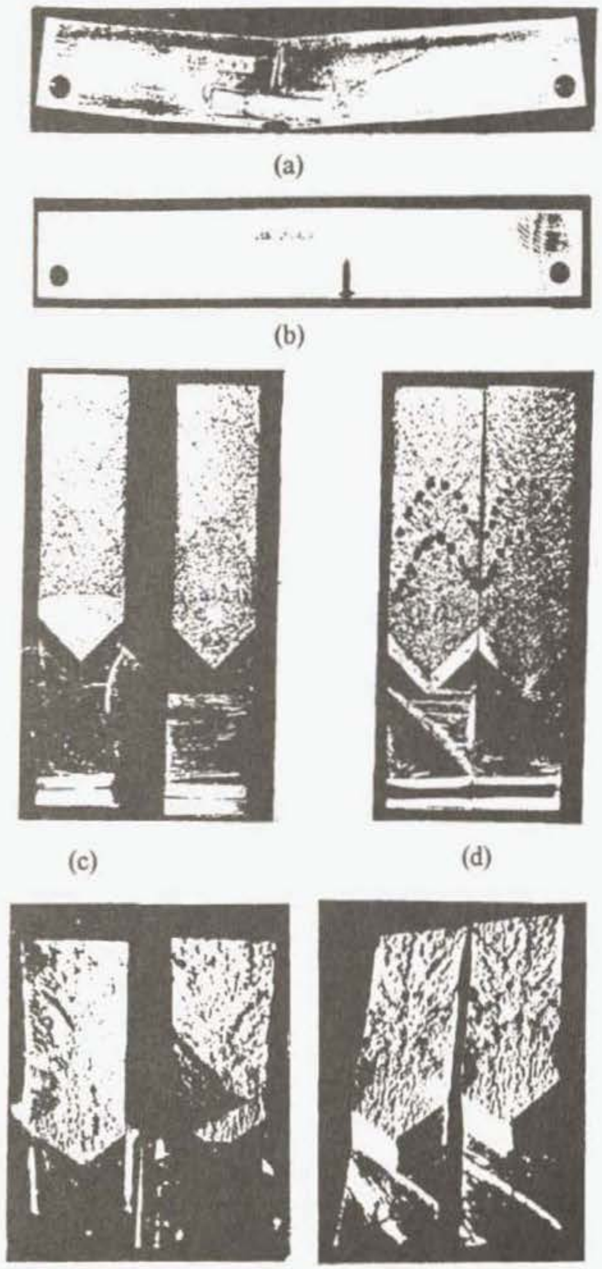

Fig. 4 Fractured specimens, crack tunneling and fracture surfaces.

Fractured specimens: (a) Stiffened and (b) Unstiffened.

Crack tunneling: (c) Stiffened and (d) Unstiffened.

Fractured surfaces: (e) Stiffened and (f) Unstiffened.