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MONITORING PART-THROUGH CRACK GROWTH USING COMPLIANCE TECHNIQUE

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ABSTRACT

Specimens with part-through crack were obtained by fatiguing ridged specimens. These specimens were then fatigue tested while simultaneously monitoring crack opening displacement (COD) using a clip on COD gauge.. The depth ‘a’ and the surface length ‘2c’ of the cracks were measured by ultrasonic testing and beach marking technique, and the data obtained from this were compared with COD data. The results showed that automatic monitoring of ‘a’ and ‘2c’ could be carried out through COD.

KEY WORDS

Part-through crack, compliance technique, ultrasonic, beach marking.

INTRODUCTION

One of the most important and essential aspects of fatigue crack growth rate (FCGR) test with part-through cracks is accurate monitoring of crack shape development as the test progresses. The ratio of the depth to half the surface length (a/c) can be used to describe the shape of the cracks and is referred to as aspect ratio of the crack. As the aspect ratio varies with increase of crack length, it is necessary to monitor both ‘a’ and ‘c’ during the experiment. Generally ‘a’ and ‘c’ are measured by beach marking technique, and ‘a’ by potential drop method. On the other hand the on-line crack extension of a through crack can be monitored by a number of methods, e.g., ACPD, DCPD or compliance technique. Of these the compliance technique has proven to be the most popular because it tends itself to easy automation using a clip on crack opening displacement (COD) gauge interfaced to a computer. In this method, displacement, V, at any location of the specimen usually at external knife edges fixed over the crack mouth is monitored continuously along with the load, P. From the (V,P) data obtained during a particular load cycle, the compliance V/P of the specimen is computed. The length of the crack at the instant of the load cycle can be correlated to the compliance through a relation of the form

$$\frac{a}{W} = \mathrm{F(u)} \tag{1}$$

$$\mathrm{u} = \frac{1}{\sqrt{\frac{EBV}{P}} + 1} \tag{2}$$

where W,B are the width and thickness of the specimen, *E* is the Young's' modulus, and F is polynomial function. Such relations are known as compliance crack length (CCL) relations. CCL relations are available for different specimens such as TPB, 4PB, CT, AT, and DCT [1-3]. These relations are not only specific to specimen geometry, but, for a given specimen, to the location of measurement of displacement or compliance. In this paper we have attempted to explore the use of this method for on-line monitoring of both 'a' and 'c' of part-through cracks, through comparison of different techniques such as ultrasonic and beach marking.

EXPERIMENTAL

The material used in testing was A-537 class-I steel , a widely used material for construction of LPG Horton spheres. The chemical composition and the mechanical properties of the steel are given in Tables 1 & 2 respectively.

TABLE 1

CHEMICAL COMPOSITION OF THE STEEL (%WT).

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	V	Nb
0.22	1.26	0.45	0.015	0.003	0.065	0.018	0.026	0.002	0.005	0.003

TABLE 2

MECHANICAL PROPERTIES OF THE STEEL

YS [MPa]	UTS [MPa]	%El
359	555	32

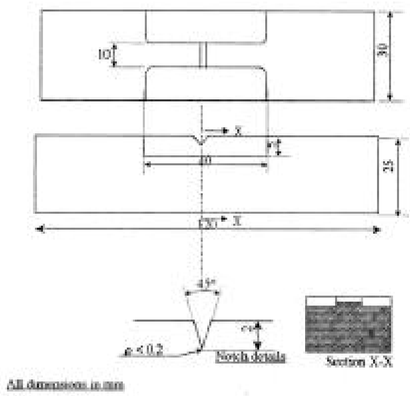

Figure 1: Specimen drawing

Specimens with semi-elliptical cracks were obtained by fatiguing ridged specimens (Fig.1) using a 50 KN Instron servohydraulic testing machine. The surface length (2c) and depth (a) of the cracks were measured by optical microscope, and ultrasonic testing. The specimens were then fatigue tested at different load amplitudes till the crack became through. By changing the amplitude of the load during the tests, beach marks were produced in the specimen. For a few specimens, the tests were stopped in between to measure the length and depth of the cracks by optical microscope and ultrasonic testing. After completion of the tests 'a' and '2c' were measured from the beach marks and the data obtained from this were compared with that of obtained from ultrasonic testing and optical microscope (Table 3). For conducting the ultrasonic tests an Ecchograph 1030 test system from M/s. Karl Deutsch, Germany was employed. The probes used in the test were a normal beam probe of 6mm diameter and 1 MHz frequency; and a 45 angle beam probe of 2 MHz frequency. During the fatigue testing, using a clip on crack opening displacement (COD) gauge, the crack opening displacement 'V' at external knife edges fixed over the crack mouth were monitored continuously along with the load, P. These V/P data were then correlated with the data of 'a' and '2c' obtained from beach marking technique.

RESULTS AND DISCUSSION

A comparison of 'a' and '2c' data obtained from different techniques was made. The data are presented in Table3. The results show that the data obtained from beach marking technique are on the higher side whereas the values obtained from the ultrasonic testing are on the lower side. This is because after unloading, a part of the crack gets closed and as the crack is very fine, the ultrasonic probes are not detecting the actual crack tip. However, the beach marking data are similar to the data obtained from optical microscope. This indicates that beach marking technique is very reliable technique for measuring the surface length and depth of a part-through crack during fatigue tests. It gives a conservative estimation of these values. Moreover it can measure both 'a' and 'c', whereas optical microscopy can measure only 'c'. We, therefore, used the beach marking technique for measuring 'a' and 'c' during the fatigue tests and used these data for correlating them with V/P obtained from COD gauge.

TABLE 3

VALUES OF '2C' AND 'A' MEASURED FROM DIFFERENT TECHNIQUES

Sl.No.	ΔP [KN]	N [cycles]	a [mm]		2C [mm]	
			Ultrasonic	Beach Marking	Microscope	Beach Marking
0	30	396,000	6.3	8.6	14.5	14.9
1	22.5	20,000	6.9	9.03	15.3	15.4
2	30	16,465	10.6	10.8	18.5	19.02
3	20	43,533	13.2	13.45	-	28.24
4	25	33,673	-	14.77	Through	Through

As mentioned above, the on-line crack extension of a through crack can be monitored by a number of methods, e.g., ACPD, DCPD or compliance technique. Of these the compliance technique has proven to be the most popular because it tends itself to easy automation using a clip on crack opening displacement (COD) gauge interfaced to a computer. We, therefore, explored here the use of this method for on-line monitoring of both 'a' and 'c' of part-through cracks during fatigue tests. The values of 'a' and '2c' obtained from beach marking technique and their corresponding V/P values obtained from COD gauge for three different specimens are given in Table 4. These results were then plotted as (a, 2c) vs. V/P, and are shown in Fig 2 for two specimens.. As can be seen from these figures that there exists an almost linear relationship between (a,2c) and V/P. This indicates that COD gauge can be used for continuous monitoring of 'a' and '2c' during fatigue experiments. However, to find a general empirical relation more work has to be carried out.

TABLE 4

VALUES OF 'A' AND '2C' MEASURED BY BEACH MARKING TECHNIQUE AND THEIR CORRESPONDING 'V/P' VALUES FOR THREE SPECIMENS FATIGUE TESTED AT DIFFERENT LOADS.

specimen Id .No.	Fatigue crack growth stage	a (mm)	2c (mm)	V/P (mm/MN)
PTC 1	0 (initial)	2.66	11.66	2.228
	1	5	16.66	2.763
	2	7.33	25.33	3.855
PTC 2	0 (initial)	2.33	12	2.398
	1	5	16	2.929
	2	7.33	21.68	3.615

	3	8.33	26.33	4.487
PTC3	0 (initial)	1.66	10.33	1.564
	1	4	13.33	1.927
	2	6.66	18.33	2.362
	3	8	23.33	2.930
	4	9	26.66	3.619

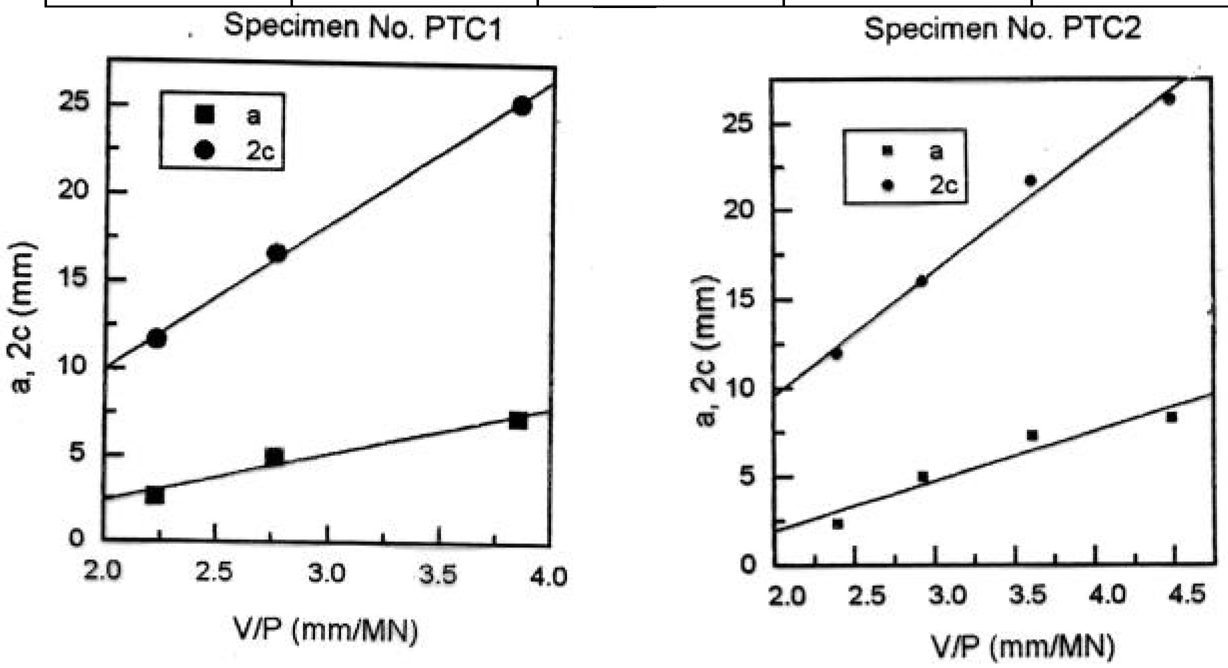

Figure 2: a, 2c vs. V/P for two specimens

CONCLUSIONS

From the above the following conclusions can be drawn.

1. Beach marking technique is the most reliable technique for the measurement of ‘a’ and ‘2c’
2. Automatic monitoring of ‘a’ and ‘2c’ can be carried out through COD.

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