

Digital Image Correlation (DIC) Technique for Fracture Toughness Calculation of Microalloyed Steel (38MnVS6)

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Abstract. The present work shows the practical application of digital image correlation (DIC) technique for fracture toughness (K_{IC}) calculation. DIC is a non-contact, optical technique for measuring full-field displacements and strains by comparing an image of a deformed specimen surface to a reference image taken at un-deformed state. These captured images are correlated and the surface displacements are calculated from which the crack mouth opening displacements (CMOD) is determined. Results of DIC fracture toughness (K_{IC}) value is validated by comparison with fracture toughness (K_{IC}) value calculated from clip gauge. It is observed that the results obtained by DIC are in close agreement with the results obtained through conventional methods.

1. Introduction

The main applications of microalloyed steel (38MnVS6) in automobile industries are for manufacturing engine crankshaft, connecting rod, front axle beam, steering knuckle etc. [1]. Microalloyed steel (38MnVS6) forged part are cost effective for manufacturing engine crankshaft in higher production volume. Therefore most of the crankshafts are made by using microalloyed steel (38MnVS6). The Crankshaft undergoes repeated bending & shear stresses during its working condition. It causes fatigue failure of the crankshaft by creating the cracks in fillet and/or oil hole area where strain is most severe [2]. Fatigue failure is the main failure mechanism for crankshaft subjected to dynamic loadings. In general, fatigue failure consists of three stages namely, crack initiation, crack propagation and final fracture. Thus, the whole lifecycle of the any dynamically loaded crankshaft is the loading cycles for crack initiation and crack propagation. The loading cycles of crack initiation depend on crack initiation resistance of material being used. The crack propagation resistance is measured through a material property called fracture toughness (K_{IC}). The fracture toughness (K_{IC}) values may serve as a basis in material characterization, performance evaluation, and quality assurance for typical engineering structures, including nuclear pressure vessels, automotive, ship and aircraft structures etc. [3].

There are numerous techniques are used to determine the fracture mechanics parameter but for accurate determination still required several challenges. This includes the accurate determination of crack length, stress intensity factors, crack tip opening displacement (CTOD), crack opening stress or load (P), etc. by means of costly apparatus and complicated computations. The measurements of crack mouth opening displacement (CMOD) and crack opening load are most important for fracture toughness (K_{IC}) calculation. Due to this evolution research for the same is carried out for precise determination fracture mechanics parameters using direct or indirect means [4]. Today's available techniques for fracture mechanics parameter calculation are costly and too demanding. To avoid all these difficulties a new



technique is developed which called digital image correlation (DIC). DIC uses simple experimental set up and suitable algorithm to find out the parameter using surface strain and displacement. Digital Image Correlation (DIC) is a non-contact, non-interferometric optical technique which gives full-field displacements and strains measurements in a deformed body. The digital image correlation (DIC) technique works by comparing and matching the images taken before loading and after loading of a specimen. The use of non-contact DIC technique for calculating surface displacements and strains during mechanical testing of metallic and non-metallic materials have been investigated and studied by several researchers [5, 6,]. The detail description of this technique is found in literature [7]. The ultimate aim of the present study is to determine fracture toughness (K_{IC}) of microalloyed steel (38MnVS6) using DIC and compared their results with conventional technique.

2. Material selection

2.1 Specimen Preparation

The experiments were carried out on microalloyed steel (38MnVS6) because of its extensive use in forging industry. Yield strength and UTS of microalloyed steel are 630MPa and 935 MPa respectively. Chemical composition is as shown in table1. Fracture toughness test was carried out on compact tension (CT) specimen. The CT specimen drawing details is shown in Figure 1. The specimen surface was polished with fine abrasive paper using conventional metallographic specimen preparation method for creating suitable speckle pattern for DIC analysis. The speckle pattern can be naturally occurring or can be applied. Generally speckle pattern can be created with combination of black and white paint. First, paint the surface with a thin layer of white paint (it could be spray paint) and then apply a black mist of paint (spray paint) to create the black speckles. But in this experiment only white mist of paint was used for creating speckle pattern because specimen surface of microalloyed(38MnVS6) steel is already black so no need of black paint. The resulting speckle pattern is as shown in Figure 2.

Table1. Chemical composition of microalloyed steel (38MnVS6).

	C	Mn	Si	P	S	Cr
Comp	0.38	1.37	0.57	0.01	0.027	0.24
	Ni	Mo	Al	Cu	V	Ti
Comp	0.26	0.03	0.015	0.17	0.02	0.02

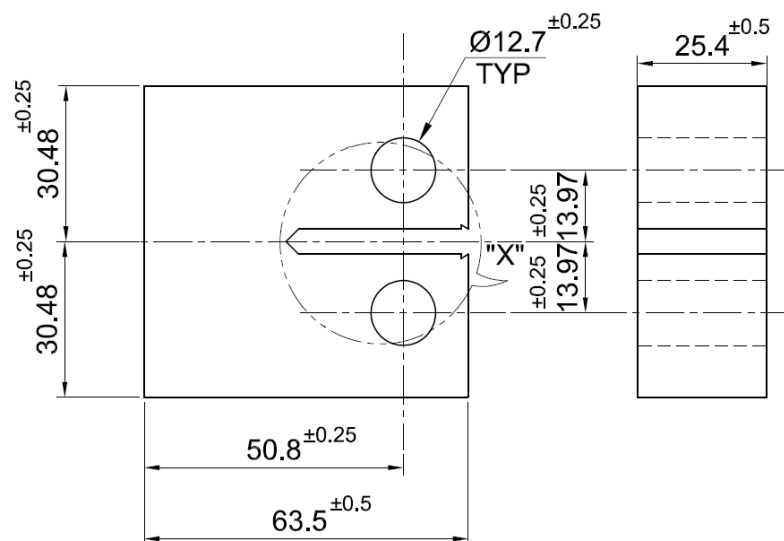


Figure 1. Compact tension specimen drawing



Figure 2. Speckle pattern created on specimen surface

2.2 Fracture Toughness Test

The fracture toughness test was carried out on Lloyed LS100K plus UTM machine. Images were taken from start to end of the experiment up to fracture. A first measured image was used as the reference image. Finally DIC was performed on each image using software 'VIC2D'. Then DIC displacement measurement gauge was placed on notch mouth to measure crack mouth opening displacement (CMOD). A Navitar 12X zoom lens was used with a Bassler CCD with maximum resolution of 1600 x 1200 pixels for image capturing. Subset size of 50 by 50 pixels was used during analysis. National Instruments DAQ System with Lab-View software was used to acquire load data during testing. Camera and lens are mounted on rigid tripod stand. Lighting was provided with halogen lamp. Figure 3(a) shows the experimental setup of fracture toughness test using DIC. For validation of result, the test was also carried out on servo hydraulic MTS machine of capacity 250kN as shown in Figure 3(b) under same loading condition.

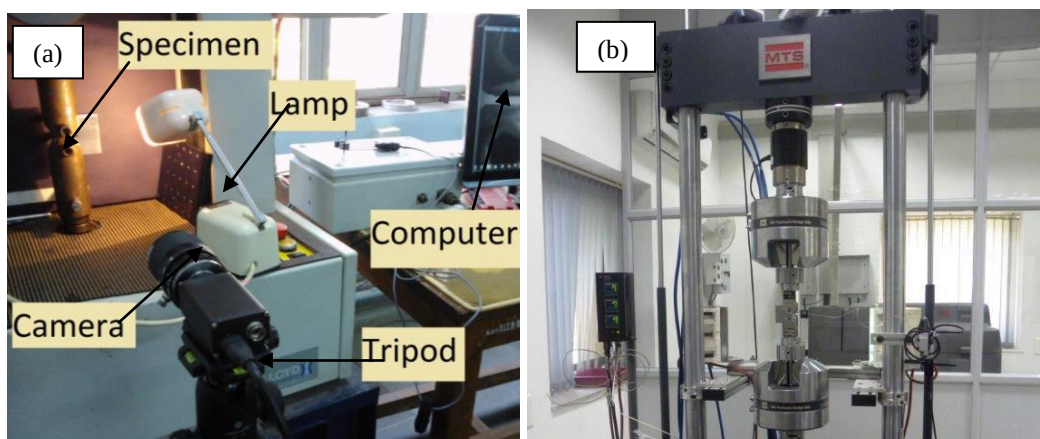


Figure 3. Experimental setup of fracture toughness test using,
(a) Digital image correlation (DIC) (b) Clip gauge

3. Results and discussion

3.1 Crack Mouth Opening Displacement (CMOD) Measurement

DIC extensometer is a virtual gauging tool available in software which is generally used for measurement of displacement or change in displacement between two specified points. DIC

extensometer gauge (or displacement gauges) was used for CMOD measurement. DIC extensometer gauge is placed at crack mouth to measure crack mouth opening displacement (CMOD) as shown in Figure 4.

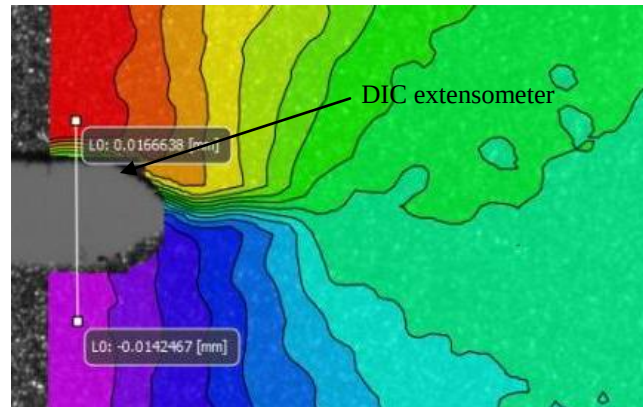


Figure 4. DIC displacement gauge for crack mouth opening displacement (CMOD) measurements

3.2 Fracture Toughness Calculation

Load (P) and crack mouth opening displacement (CMOD) data was recorded for determination of P_Q load. K_Q was calculated from P_Q by taking 5% secant and after running all validity checks given in ASTM E-399 [8], the K_Q was declared K_{IC} . It was found to be $61 \text{ MPa.m}^{1/2}$. Figure 5 shows load (P) vs. crack mouth opening displacement (CMOD) plot obtained from DIC. Fracture toughness (K_{IC}) value was also calculated using conventional method where crack opening displacement measurement was done with clip gage. The value of fracture toughness (K_{IC}) was found to be $58 \text{ MPa.m}^{1/2}$ using clip gage measurement. The observed result was quite logical therefore it is suggested that the DIC technique is feasible for fracture toughness testing.

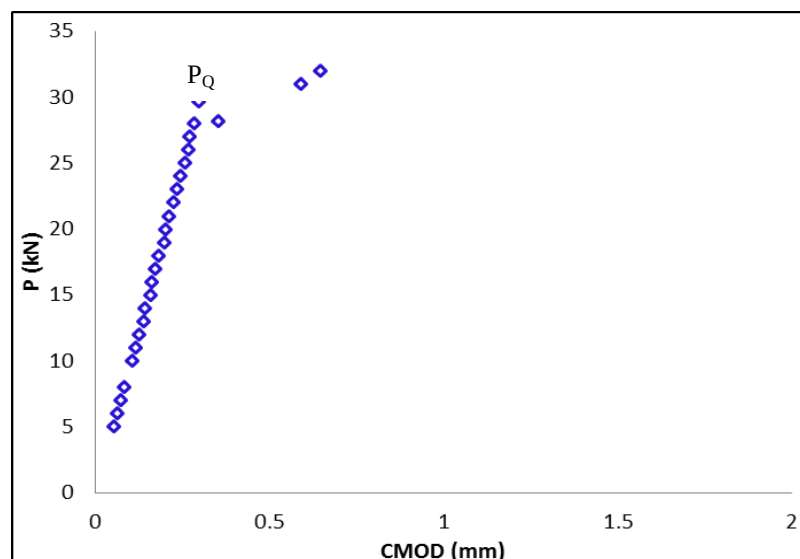


Figure 5. Load (P) vs. crack mouth opening displacement (CMOD) plot obtained from DIC

4. Conclusion

In current research the capability of digital image correlation (DIC) technique to determine the fracture toughness (K_{IC}) of microalloyed steel (38MnVS6) has been studied. Existing work proved the practical

application DIC for calculating fracture toughness (K_{IC}) of microalloyed steel (38MnVS6). Fracture toughness value of micro alloyed (38MnVS6) steel via DIC method was found to be $61 \text{ MPa.m}^{1/2}$, where the same was found to be $58 \text{ MPa.m}^{1/2}$ via clip gauge technique. It can be concluded that the simple DIC technique can be a very useful and an economical substitute against clip gages.

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