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Investigation of Fatigue Crack Growth in Superelastic NiTi Alloy by Using Digital Image Correlation Method

B. Katanchi[1*] , N. Choupani[1], J. Khalil-Allafi [2], M. Baghani [3]

[1] Department of Mechanical Engineering, Sahand University of Technology, Tabriz, Iran
[2] Department of Materials Engineering, Sahand University of Technology, Tabriz, Iran
[3] School of Mechanical Engineering, College of Engineering, University of Tehran, Iran

ABSTRACT: In recent years, shape memory alloys, especially NiTi, have received a great deal of attention in industrial applications. Martensitic phase transformation in shape memory alloys is the most important factor in their unique behavior. In this paper, the formation of stress-induced martensite phase in the crack tip of superelastic NiTi (50.8% Ni) samples was investigated by using the digital image correlation method. In particular, single edge cracked specimens were subjected to fatigue mechanical loading, then the crack length and also displacement fields at the crack tip of specimens were measured by the digital image correlation technique. Control of the crack length was performed using a high magnification camera during the fatigue test. In the following, stress intensity factors were calculated according to ASTM standard E647-15. Obtained results from the fracture analysis show that fatigue threshold values are decreased with increasing the load ratio. In the present paper, for a load ratio of 0.05, during the crack propagation, the fatigue threshold value is 17 MPa $m^{1/2}$, while stress intensity factor is estimated about 35 MPa $m^{1/2}$ before the final failure. Also, as a new method in observation of the phase transformation, digital image correlation pictures indicated the formation of stress-induced martensite at the specimen crack tip.

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1. INTRODUCTION

In recent years, shape-memory alloys, especially NiTi, have received a great deal of attention in industrial applications. These alloys are a group of smart materials that show a unique behavior compared to other engineering alloys. From a macroscopic viewpoint, the special behavior of Shape-Memory Alloys (SMA) can be investigated according to two phenomena: namely, the shape memory effect and the super-elasticity [1]. These features come from a solid to solid reversible phase transformation between austenite and martensite phases, in response to thermal and mechanical loadings [2]. Basically, studies about the fracture of SMAs include three groups: analytical investigations, numerical studies and experimental researches to analyze the fatigue and fracture responses under cyclic and quasi-static conditions [3]. In the mentioned studies, determination of the material resistance before the failure is the most important subject. For this reason, as a critical parameter in crack growth, determining the fracture toughness or the stress intensity factor is an essential issue. Until now, a few experimental investigations have been carried out to find the fracture parameters of these alloys [4, 5]. In one of the researches, McKelvey and Ritchie [4] investigated the fatigue crack extension in super-elastic NiTi under plane strain conditions. By using a disk-shaped compact-tension sample, they determined the stress intensity factor of 30 MPa $m^{1/2}$ before the failure. Robertson et al. [5] performed fatigue-load tests using a thin Compact Tension (CT) specimen in plane stress conditions. Their results showed a fracture toughness value of 34 MPa $m^{1/2}$ for super-elastic NiTi. In this paper, the fatigue crack growth in a super-elastic NiTi was investigated by using Digital Image Correlation (DIC) method.

*Corresponding author's email: babakkatanchi68@yahoo.com

2. METHODOLOGY

The specimens were prepared from a commercial super-elastic NiTi sheet with thickness t=0.5mm (50.8 at % Ni-49.2 at % Ti, Type S, Memory, Germany). Fig. 1 indicates the stress-strain response of the material obtained from a loading-unloading cycle.

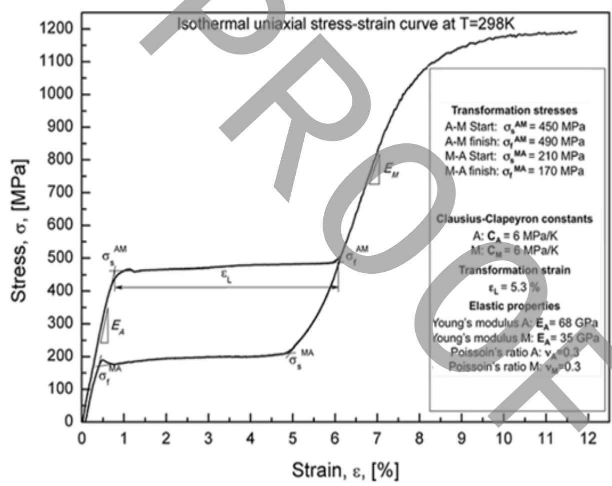

Fig. 1. Stress-Strain response of the super-elastic alloy together with measured thermo-mechanical characteristics

DIC tests were carried out by using a reflection microscope. In particular, based on the VIC-2D commercial software, DIC analysis was performed to obtain the near crack tip displacement and strain fields.

3. RESULTS AND DISCUSSION

Fig. 2 shows the propagation of the crack during the fatigue loading after 5000, 15000 and 25000 cycles respectively.

The contour plot of displacement fields at the crack tip was shown in Fig. 3. In particular, Fig. 3 shows the vertical displacements at the crack tip, with a length ratio of (a/w=0.6), obtained from DIC measurements.

Fig. 4 illustrates the variation of the crack growth rate based on the stress intensity range for the load ratio of R=0.05 and R=0.5. Obtained results from the fracture analysis show that fatigue threshold values are decreased with increasing the load ratio (R). In the present paper, for a load ratio of R=0.05, during the crack propagation, the fatigue threshold value is ΔK_{th}=17 MPa m$^{1/2}$, while stress intensity factor is estimated about 35 MPa m$^{1/2}$ before the final failure. Finally, Fig. 5 shows that the fracture was occurred after about 28000 cycles.

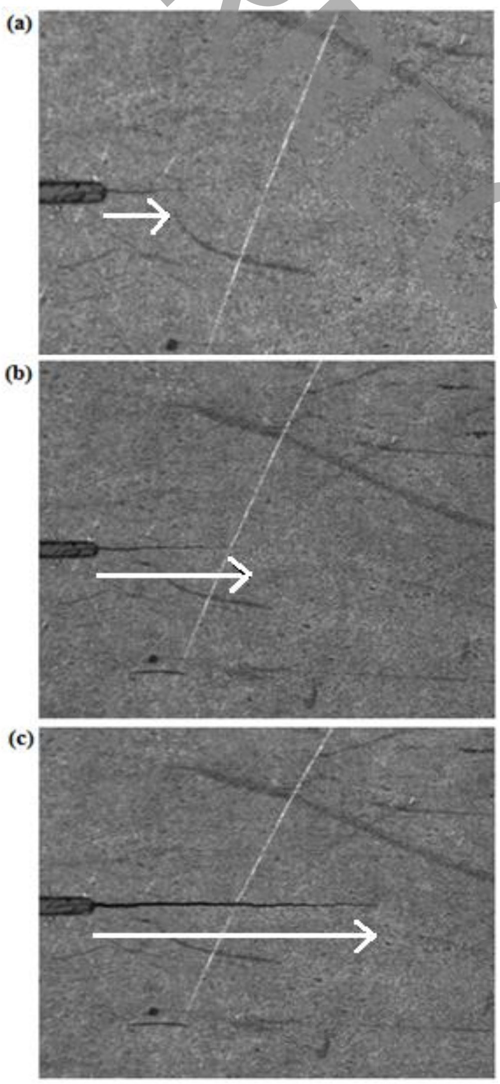

Fig. 2. Crack growth during fatigue loading after a) 5000, b) 15000 and c) 25000 cycles.

4. CONCLUSIONS

In this paper, the fatigue crack growth in a superelastic NiTi alloy was investigated by using DIC method. In particular, using Single Edge Cracked (SEC) specimens under fatigue mechanical loading, stress intensity factors were calculated according to ASTM standard E647-15. Obtained results indicated that the fatigue threshold values were decreased

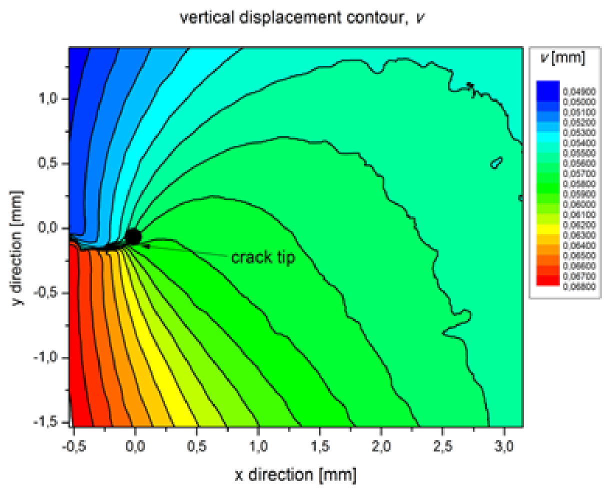

Fig. 3. Vertical displacement fields at the crack tip obtained from DIC method

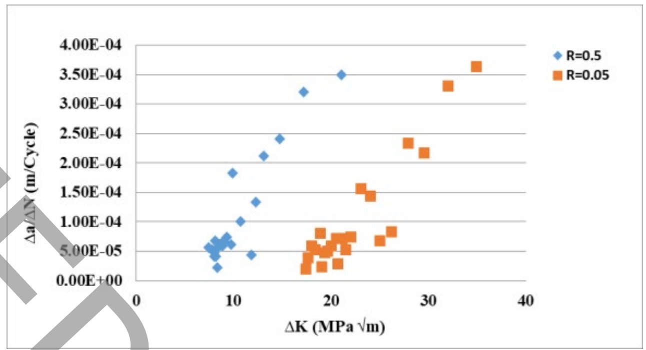

Fig. 4. Variation of the crack growth rate based on the stress intensity range for load ratio of R=0.05 and R=0.5.

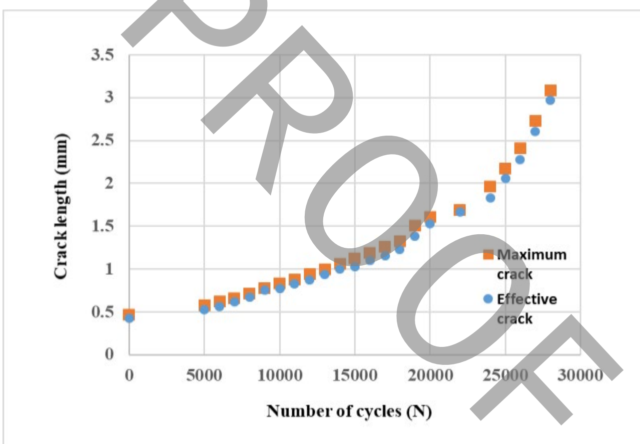

Fig. 5. Crack length variations plotted as a function of fatigue loading cycles for the maximum crack length and the effective crack length.

with increasing the load ratio (*R*). Also, as a new technique in observation of the phase transformation, DIC analysis showed the formation of stress-induced martensite at the specimen crack tip.

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