Investigation of fatigue crack growth in superelastic NiTi alloy by using DIC method

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ABSTRACT

In recent years, shape memory alloys, specially NiTi, have received more attentions 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 DIC method. In particular, SEC specimens were subjected to fatigue mechanical loading, then the crack length and also displacement fields at the crack tip of specimens were measured by DIC 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 (R). In the present paper, for a load ratio of R=0.05, during the crack propagation, the fatigue threshold value is $\Delta K_{th} = 17$ 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, DIC pictures indicated the formation of stress induced martensite at the specimen crack tip.

KEYWORDS

NiTi shape memory alloys, Martensitic phase transformation, Crack growth rate, Fatigue, Digital image correlation method.

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1. Introduction

In recent years, shape memory alloys, specially NiTi, have received more attention in industrial applications. These alloys are a group of smart materials that show a unique behavior compared to other engineering alloys. From macroscopic viewpoint, the special behavior of SMAs can be investigated according 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 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. performed fatigue-load tests using a thin 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 DIC method.

2. Methodology

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

Digital image correlation (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.

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

3. Results and Discussion

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

Figure 2. Crack growth during fatigue loading after a) 5000, b) 15000 and c) 25000 cycles.
The contour plot of displacement fields at the crack tip was shown in Figure 3. In particular, Figure 3 shows the vertical displacements at the crack tip, with length ratio of (a/w=0.6), obtained from DIC measurements.

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

Figure 4 illustrates the variation of crack growth rate based on stress intensity range for 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 $\Delta K_{th} = 17 \text{ MPa m}^{1/2}$, while stress intensity factor is estimated about $35 \text{ MPa m}^{1/2}$ before the final failure. Finally, Figure 5 shows that the fracture was occurred after about 28000 cycles.

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

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

4. Conclusions

In this paper, the fatigue crack growth in a superelastic NiTi alloy was investigated by using DIC method. In particular, using 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 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.

5. References