Prolongation of Fatigue Life of TiNi Shape Memory Alloy by Ultrasonic Shot Peening

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Abstract. The fatigue property of shape memory alloy (SMA) is one of the most important subjects in view of evaluating functional characteristics of SMA elements. In this paper, ultrasonic shot peening (USP) was applied to induce compressive residual stress on the surface layer of TiNi SMA tape and the influence of USP on the bending fatigue life was investigated. The fatigue life of USP-treated tape is longer than that of the as-received tape. The fatigue life of the tape USP-treated with high coverage is longer than that with low coverage.

Introduction

The shape memory alloy (SMA) is expected to be applied as intelligent material since it shows the unique characteristics of the shape memory effect and superelasticity. In the growing number of TiNi SMA applications, these materials should fulfill high requirements of fatigue, corrosion and wear resistance. On the other hand, the application of SMA has some limitations, particularly in thermomechanical cyclic loading cases, when structural components can be damaged due to fatigue. In these cases, fatigue of SMA is one of the important properties in view of evaluating functional characteristics as SMA elements.

In this paper, we discuss the influence of ultrasonic shot peening (USP) on bending fatigue life of TiNi SMA.

Ultrasonic shot peening

One end of a TiNi SMA tape was gripped during USP treatment. Both flat surfaces of the tape were shot-peened from two opposite directions by steel balls as shot media. The shot media was an SUJ2 steel ball with Vickers hardness *HV* of 850 used for a miniature bearing. Diameters of the steel balls used were 0.8 mm and 1.2 mm. USP was carried out using the ultrasonic equipment produced by SONATS (Toyo Seiko Co., Ltd.). The frequency of the vibrating sonotrode was 20 kHz. Coverages applied were 2000% and 4000%. In the test to investigate the influence of the shot media diameter on the fatigue properties, two diameters of 0.8 mm and 1.2 mm were used for a coverage of 2000%. In the test to discuss the influence of the coverage, two coverages of 2000% and 4000% were applied for a shot media diameter of 0.8 mm.

Tensile deformation property

The stress-strain curves of four kinds of SMA tapes obtained by the tension test are shown in Fig. 1. The tension test was carried out under a constant strain rate of $1.67 \times 10^{-4}\ s^{-1}$ at room temperature in air. All stress-strain curves draw hysteresis loops during loading and unloading, showing the superelasticity. The upper stress plateau during loading appears due to the stress-induced martensitic transformation (SIMT). The martensitic transformation start stress σ_{MS} was obtained from the intersection of two straight lines: the initial elastic part and the upper stress plateau part. Values of σ_{MS} are 370 MPa, 380 MPa, 400 MPa and 410 MPa for the as-received tape, the tape USP-treated with shot media diameter d = 0.8 mm and coverage c = 2000%, that with d = 1.2 mm and c = 2000%, and that with d = 0.8 mm and c = 4000%, respectively. The value of σ_{MS} increases slightly by USP since the influence of USP appears only on the shot-peened surface layer of the tape. Although both the shot media diameter d and coverage c affect the value σ_{MS}, the influence of coverage c is a little higher than that of shot media diameter d.

Bending Fatigue Property

The relationships between the bending strain amplitude ε_a and the number of cycles to failure N_f for four kinds of tapes obtained by the alternating-plane bending fatigue test under a constant frequency f = 150 cpm at room temperature in air are shown in Fig. 2. The bending strain amplitude ε_a was obtained from the bending strain on the surface of the specimen at the fracture point. The specimen was fractured at the midpoint of two grips. As can be seen in Fig. 2, the larger the bending strain amplitude, the shorter the fatigue life is. The fatigue life of shot-peened tapes is longer than that of the as-received tape. The fatigue life of the tape USP-treated with d = 0.8 mm and c = 2000% is almost the same as that with d = 1.2 mm and c = 2000%. The fatigue life of the tape USP-treated with d = 0.8 mm and c = 4000% is longer than that of other shot-peened tapes. The fatigue life of the tape USP-treated with d = 0.8 mm and c = 4000% is 2.6 times at ε_a = 3% and 10 times at ε_a = 1% longer than that of as-received tape, respectively.

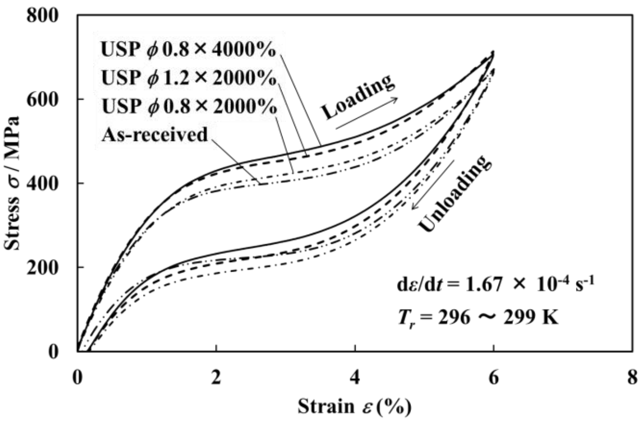

Fig. 1 Stress-strain curves

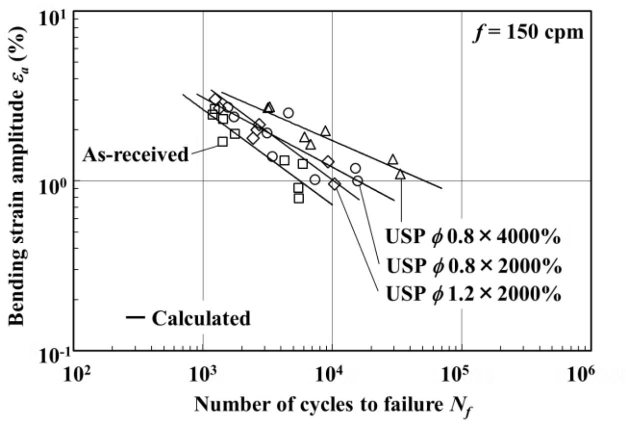

Fig. 2 Relationship between bending strain amplitude and the number of cycles to failure.

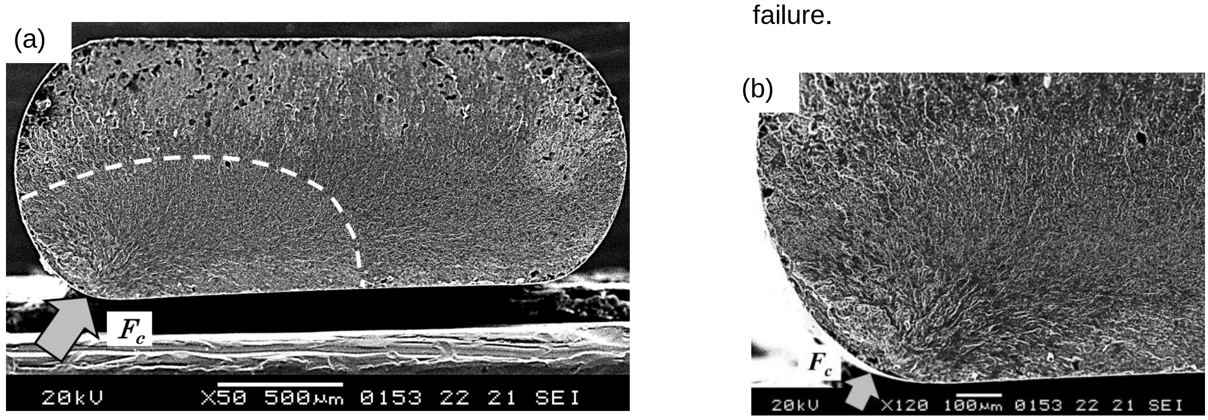

Fig. 3 SEM photographs of fracture surface of USP tape with d = 0.8 mm and c = 4000% for ε_a = 1.64% and N_f = 6788: (a) whole fracture surface, (b) crack initiation part

The relationships between the bending strain amplitude ε_a and the number of cycles to failure N_f shown on the logarithmic graph are almost expressed by straight lines for all materials. The relationship therefore can be expressed by a power function as follows:

$$\varepsilon_a \cdot N_f^{\beta} = \alpha \qquad (1)$$

where α and β represent ε_a in N_f = 1 and the slope of the log ε_a - log N_f curve, respectively. The calculated results of Eq. (1) are shown by solids lines in Fig. 2. The overall inclinations are well approximated by the solid lines.

Fracture surface

SEM photographs of a fracture surface for the USP tape in the case of a bending strain amplitude ε_a = 1.64% are shown in Fig. 3. The tape was USP-treated with shot media diameter d = 0.8 mm and coverage c = 4000%. In the case of as-received tapes, the fatigue crack initiates at the central part of the flat surface subjected to maximum bending strain. As can be seen in Fig. 3, the fatigue crack of USP-treated tape initiates at the point F_c on the corner different from the flat surface subjected to maximum bending strain.

Conclusion

The TiNi SMA tapes were USP-treated, in which both flat surfaces were shot-peened from two opposite directions, and the influence of shot media diameter and coverage on the fatigue life of alternating-plane bending was investigated. The results obtained are summarized as follows.

1. The fatigue life of USP-treated tapes is longer than that of the as-received tape. The fatigue life of the tape USP-treated with high coverage for the same shot media diameter is longer than that with low coverage.
2. The fatigue crack nucleates at the central part of the flat surface of the tape in the case of the as-received tape. The fatigue crack nucleates at the corner near the flat surface of the tape in the case of the USP-treated tape.
3. In practical applications of SMAs, the fatigue life of SMA elements increases if USP is treated not only on the surface at the maximum stress point but also on the surface in the region near the maximum stress point.