The influence of laser welding parameters on the microstructure and mechanical property of the as-jointed NiTi alloy wires

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Abstract

The Nd:YAG laser welding was used to join the binary NiTi alloy wires with different compositions (Ti–50.0 at.%Ni and Ti–50.9 at.%Ni) which had the same diameter of 1 mm. The wires were welded with different parameters, including impulse width and welding current. The aim was to assess the influence of the laser-welding process on the microstructure and mechanical properties of the welded joint of binary NiTi wires. The optical microscopy (OM) and the metallographic microscopy (MM) were used to analyze the microstructure of the welded joints. The tensile test and the differential scanning calorimetry (DSC) were carried out to examine the ultimate tensile strength and the reverse martensitic transformation temperatures of the welded joints. It was found that the welding current and the impulse width had great influence on the quality of the welded joints, an optimal parameter combination would remove the pores and micro-cracks appeared in the fusion zone, and result in good mechanical properties such as higher fracture strength and elongation. The laser welding had a few effect on the reverse martensitic transformation temperatures of the welded joints.

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1. Introduction

NiTi shape memory alloys (SMA) exhibited good shape memory effect (SME) and pseudoelasticity (PE), and had been extensively used for industrial applications. Unfortunately a relatively low formability of NiTi alloys had been found during the joint of different NiTi alloys pieces in the device and components. Recently laser welding had gradually become one of the most efficient and important jointing techniques for NiTi alloys, and the welding of NiTi alloys with different compositions had been of great research interest because it allowed the production of smart components with very attractive functional properties [1–4]. The aim of the present work was to investigate the effect of the Nd:YAG laser welding process on the microstructure and properties of the welded joints of binary NiTi wires with different compositions.

2. Experimental procedures

The binary TiNi alloy wires with different compositions (Ti–50.0 at.%Ni and Ti–50.9 at.%Ni) which had the same diameter of 1 mm were used throughout this study. The Ti–50.0 at.%Ni wires were fabricated by hot drawing, and a heat treatment was performed at 850 °C for 0.5 h with water quenching before the welding. The Ti–50.9 at.%Ni wires were fabricated by cold drawing; no heat treatments were performed before welding. The surface oxide layer was removed with a mixed acid solution (HF:HNO\textsubscript{3}:H\textsubscript{2}O = 1:2:10). Wire-to-wire laser butt weld joints were performed using a Nd:YAG laser (HAN’S LASER WELDING SYSTEM W150S) with the wavelength be 1.064 μm. All the samples were welded at the pulse frequency of 25 Hz, the defocusing amount of 0.8 mm and with the
protection of argon atmosphere. The welding process parameters were: impulse width: $t_p=3.5$ ms, welding current: $I=105$A (Route I); impulse width: $t_p=2.5$ ms, welding current: $I=105$A (Route II); impulse width: $t_p=2.5$ ms, welding current: $I=119$A (Route III). No post-weld heat treatments were done on the joints after welding.

The OM and MM were used to analyze the microstructure of the welded joints. The phase transformation temperatures were measured by the DSC measurement for references and welded materials, which were performed using a Pyris Diamond DSC at temperatures ranging from $T=-100 \, ^\circ C$ to $T=150 \, ^\circ C$ under a controlled cooling/heating rate of $20 \, ^\circ C \, min^{-1}$. Specimens for DSC measurement were cut across the welding region, by a low-speed diamond saw, containing the heat affected zone (HAZ). Stress–strain curves measurements were carried out at the room temperature on a Precision 2326

Fig. 1. (A) OM micrograph and (B)–(D) MM micrograph of laser-welded joints, in which (a) HAZ with Ti–50.9 at.%Ni; (b) welded joints; (c) HAZ with Ti–50.0 at.%Ni.
Universal Tester (Instron-3365) with a strain rate of 1 mm min$^{-1}$. The length of tensile specimens was 60 mm and the gauge length was 20 mm.

3. Results and discussion

3.1. Microstructure of welded joints

Fig. 1A depicted the OM micrograph of the welded joints. The left side (a) was the base alloy with 50.9 at.%Ni. The right side (c) was the base alloy with 50.0 at.%Ni. As can be seen, the welded joint (b) had a little excessive penetration. Fig. 1B–D were the MM micrographs of the welded joints. As can be seen, the fusion zone of Route I and Route II exhibited columnar and layer microstructure and the heat affected zone consisted of coarse equiaxed grains obviously. The grain size in the fusion and heat affected zone of Route I was bigger than that of Route II and Route III. The reason might lie in that the impulse width of Route I was longer and the crystal grain grew up more adequately. Some micro-cracks could be seen in the fusion zone of the Route I sample. The low welding current was likely to form the layer microstructure.

3.2. Phase transformation behavior of welded joints

Fig. 2 showed the DSC curves of the base alloys and the welded joints, respectively. The characteristic temperature of the base alloy with 50.9 at.%Ni was about $-5^\circ$C during cooling in Fig. 2 (a). The characteristic temperature of the base alloy with 50.0 at.%Ni was about 55 $^\circ$C during cooling in Fig. 2 (c). However the DSC curves of the welded materials in Fig. 2 (b) showed that there were two exothermic peaks during cooling and the characteristic temperatures were $-50^\circ$C and 55 $^\circ$C. The phase transformation behavior of the welded joints was different from the two base alloys obviously. It was the integration result of two NiTi alloy wires with different compositions. But the characteristic temperature of Ti–50.9 at.%Ni wire fell from $-5^\circ$C to $-50^\circ$C after welding. Welding had been reported to be similar as the solution treatment [5]. It resulted in that the Ni content increased in the matrix of the cold drawn Ti–50.9 at.
50.9 at.%Ni were 1363 MPa and 24%. Fig. 3 showed that the ultimate strength and elongation of the laser-welded joints might be much lower than those of the two base alloys. The average value of the ultimate strength and elongation of Route III was the highest among the welded joints.

3.4. Fracture surface observation after tensile tests

The SEM images of the fracture surface for the laser-welded joints were shown in Fig. 4 with different welding parameters. As can be seen, all laser-welded joints exhibited the brittle fracture features with river markings on the fracture surfaces. The gas pores could be seen on the broken surface of the Route I sample.

The possible reasons for the low tensile strength were due to: (a) No upset force was applied on the welded wires during welding, therefore the assembly of the welded wires was poor. (b) The columnar and layer microstructures in the fusion zone had negative influence on the mechanical properties of the welded joints; (c) When the heating time was prolonged, some harmful elements such as O, H, N would intrude into the weld zone [6]. This caused the generation of the gas pores and the deterioration of mechanical properties. (d) The little welding current might also make the incomplete penetration possible.

4. Conclusions

In summary, the welding current and the impulse width had great influence on the quality of the welded NiTi alloy joints by changing the microstructure and mechanical property at the joint position. The highest fracture strength and elongation of the welded joints were obtained with 119 A of the welding current and 2.5 ms of the impulse width. The laser welding had a few effect on the reverse martensitic transformation behavior of the welded joints. All laser-welded joints exhibit the brittle fracture features with river markings on the fracture surfaces. The functional properties (SME and PE) of NiTi welded joints would be investigated as a future work and reported later.

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References