The weldability of Shape Memory Alloy

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Abstract: In this work a Nd:YAG laser was used for welding 2mm thick tapes of Ti–50.9at.%Ni shape memory alloy (SMA). Both reference and laser welded samples were chosen to investigate mechanical and shape memory behaviour. Their mechanical properties were tested by stress–strain measurements respectively. Comparative microstructures of the reference and the welded materials were studied with SEM and XRD analysis. Moreover, hardness measurements allowed further clarification that the modification was induced by the welding procedure. The results obtained on the weld joint material indicate that the stress-induced martensite and the recovery mechanisms are weakly modified by the presence of the welding zone, while the microstructure of the weld joint is strongly affected.

1. Introduction
Due to their special functional properties, namely shape memory effect (SME) and superelasticity effect (SE), and great resistance to fatigue and corrosion, as well as good biocompatibility, TiNi alloys have been found their more and more applications in many fields in recent years [1-3]. However, they were generally utilized to make simple and small components because of their bad formability [4]. Therefore a suitable joining technique must be invented to obtain devices and components with complex geometries. A few welding techniques for joining NiTi alloys have been reported [5, 6]. Tungsten inert gas (TIG) welding is the first welding technique used for joining TiNi alloy not long after it had been invented. TIG welding is approved to cause marked degradation in the mechanical properties of the joint due to an extended heat affected zone (HAZ). Laser welding is one of the most important joining techniques for this class of materials. In addition, the Nd:YAG source is suitable for welding low thickness components due to its high precision and reduced HAZ[7]. Moreover, appropriate control of the process parameters can ensure good reproducibility of the results[8].

The effects introduced by the weld will depend both on the microstructure of the reference material and on the welding process parameters. A deeper understanding of the modification due to the laser welding on the SMA properties needs a spread database and unfortunately very few experimental comparisons between the reference and the welded materials are reported [5].

The aim of the present work is to evaluate the effect of the Nd:YAG laser welding process on the microstructure and shape memory characteristics of Ti–50.9at.%Ni alloy.

In the present work, the martensitic transformation temperatures of the NiTi alloy were measured by differential scanning calorimeter (DSC) investigations. The mechanical and shape memory behaviour was evaluated by stress–strain measurements and thermo-mechanical cycles, and the width of the welded joints were estimated from micro-hardness tests, and the microstructure were investigated from microscopic investigations. Finally, a systematic comparison between welded and reference specimens was carried out.
2. Preparation of the specimens and experiments

The experimental specimens were Ti-50.9 at.% Ni plates with the size of 2mm×25mm×50mm. Two specimens were assembled together to a butt joint. The TiNi specimens were well cleaned before being welded. The welding process was carried out with an Nd:YAG laser source, operating in continuous mode. Argon gas was input to the both sides (facing laser light and back) of specimens in order to protect the welding zone.

Systematic research on the effect of laser welding technical parameters on the microstructure of the TiNi alloy has been carried out, and the optimal parameters were as: welding rate 1.5m/min, and laser power 1500W.

3. Results

![Figure 1. The welded samples.](image1)

In Fig.1, The welded samples are reported. In Fig.2, weld-bead profile geometry are reported.

![Figure 2. Weld-bead profile geometry](image2)

3.1. Micro-hardness tests A subsection

In Fig.3, hardness Hv curves as a function of distance across the weld are reported. The results show that there is significant modification of the hardness values in the welding zone compared with those of the reference material. The welded center zone shows lower Hv values than the reference material, but the fusion-line zone shows higher Hv values than the reference material. The observed mean values for the welded center zone and the fusion-line zone and reference materials are, respectively, 220, 280 and 270 HV0.2. Welding and a molten zone (MZ) of about 4 mm in width was measured.

3.2. Microstructures investigations

Fig.4 shows Micrograph of a cross-section of the welded joint. Fig.5 shows Microscopic graphs of a cross-section of the welded joint. Fig5(a) shows Weld center, Fig5(b) shows Weld-fusion zone.

Fig.6 shows the X-ray diffraction patterns of TiNi specimens. From fig.6 (a) to fig.6 (b), XRD spectra are of the reference metal and the weld, respectively. Base metal displays a typical XRD pattern of single austenite TiNi phase. Similar to the base metal, weld displays a XRD pattern of
mainly TiNi austenite. New diffraction peaks and the broader peaks indicate the formation of some second precipitates phases. The second phases are identified to be Ni$_3$Ti.

Figure 3. Vickers hardness (HV$_{0.2}$) as a function of the distance from the center of the weld (x)

Figure 4. Micrograph of a cross-section of the welded joint

Figure 5. Microscopic graphs of a cross-section of the welded joint. (a) Weld center; (b) Weld-fusion zone.
3.3. Mechanical measurements
In Fig. 7, a comparison between the stress–strain curves of welded and reference material is shown. The test temperature is 20°C. According to the DSC curves, both the welded and the reference are on martensitic transformation condition. In particular, the reference shows a higher stress and strain level than the weld before fracture. During the Ms, the stress of the welded joint equal to 63.7% of the reference and the strain equal to 70% of the reference. This experiment result of this paper is better than those of existing literatures.

4. Conclusions
The effects of the laser welding on NiTi SMA have been investigated through a systematic comparison between welded and reference materials. Evidently, laser welding lead to the microstructural modifications. So the strain and stress of the reference are slightly superior to the welded. However, the laser weld joint is almost equal to the reference. In summary, the Nd:YAG laser welding is suitable for NiTi SMA. Further work has to be undertaken to increase the toughness and ductility of the laser welding joint. The laser welding of NiTi SMA has a wide prospect.

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References
[1] M. H. WU, L. McD. Scetky. Proceedings SMST conference, 2000, 171-182.
[2] Pelton AR, Stöckel D, Duerig TW. Materials Science Forum, 2000, 327–328:63-70.
[3] Fujita H, Toshiyoshi H. Microelectronics Journal, 1998, 29:637-640.
[4] Weinert K, Petzoldt V. Materials Science and Engineering A, 2004, 378:180-184.
[5] Ikea A, Kimura K, Tobush H. J Intelligent Material Systems Structures, 1996, 6:646-654.
[6] Shinoda T, Tsuehiya T, Take-hi H. Welding International, 1992, 1:20-25.
[7] A. Falvo, F.M. Furgiuele, C. Maletta, Laser welding of NiTi alloy: Mechanical and shape memory behaviour. Materials Science and Engineering A, 2005, 412:235-240.
[8] S. Miyazaki, in: T.W. Duerig, K.N. Melton, D. Stockel, C.M. Wayman (Eds.), Engineering Aspects of Shape Memory Alloys, Butterworth-Heinemann, Guilford, UK, 1990, 394.