Shape Memory Characteristics in Welded SMA Alloys

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Abstract—This paper mainly studies the laser welding properties of shape memory alloys. Phase transformation of the laser welded SMA alloys was investigated through XRD and DSC. The stress-strain behaviors and shape memory effects of the laser weld joints were investigated with tensile tests at room temperature or variable temperature, respectively. DSC test project is the result of the effect and influence of the test welding process on the heat affected zone. The results show that laser welding alloy is beneficial to the refinement of weld structure and improves the mechanical properties and shape memory of weld.

1. INTRODUCTION
SMA alloys are widely used. SMA alloys have been widely used in aeronautical technology, energy development, medical devices, mechanical appliances, electronic equipment, automobile industry and daily life[1]. Nowadays, the composition design and preparation technology of SMA alloys are becoming more and more mature, and it has entered the practical stage. With the further research on SMA shape memory alloys in the more extensive application, the strength and shape memory property of the welded joint of shape memory alloy are improved. The high-quality welded joint is obtained in various fields, it is the key to the preparation of complex structure components and the broadening of shape memory alloy. Therefore, it is more important and urgent to carry out the research of SMA alloys welding technology.

The welding methods of shape memory alloy, such as plasma beam welding, argon arc welding, resistance welding and laser welding. The results of the study were reported in public journals [2-4]. Laser welding is a kind of fusion welding technology. The advantages of the laser welding are that the source is concentrated, the welding speed is fast, and the efficiency is high[5]. During the laser welding, the laser beam has good directionality, It can be processed precisely, Heat Influence Zone on Weld Edge is narrow, the welding deformation is small, the laser welding joint has great flexibility, it can be used for long-distance welding. The weld formation can be ensured by properly adjusting the laser welding parameters. A number of processing methods can be used to process sma alloys. Therefore, For SMA alloys processing technology, laser beam welding is one of the most suitable methods [6-7].

However, due to the obvious structure change between the weld and the original base metal after laser processing of the SMA alloys, under the action of instantaneous high energy density of the laser beam, the weld structure is coarse and the strength, plasticity and toughness are reduced. It is an urgent problem to improve the properties, shape memory performance of laser welded SMA alloys. A variety of heat treatments improved the shape memory performance and mechanical properties of SMA alloys.

For SMA alloys, the improvement and influence of shape memory function and mechanical properties of laser welding method are summarized.
Phase transformation and phase-transition temperature of laser welded SMA alloys through DSC testing, the improvement and influence of shape memory function and mechanical properties of laser welding method are summarized in this paper. At last, a comprehensive comparison is made between the weld and the base metal to draw a conclusion.

2. PREPARATION OF THE SPECIMENS AND EXPERIMENTS

The SMA alloys of 2 mm thick for experiment preparation. The base metal and weld were heat treated at 400 degrees Celsius for 40 minutes. This heat treatment process in order to reduce residual stress during processing and welding of SMA alloys. The Ms temperature of the SMA alloys dropped to 58 degrees after heat treatment. All the base metal and laser welds were tested for mechanical properties and shape memory function. Effect of Laser Welding on Mechanical Properties and Shape Memory Properties of SMA Alloys have been researched, A sample of the weld is machined to the same axial load direction as the weld. The specimens were well cleaned before being welded.

The influence of laser welding parameters on SMA alloy properties and microstructure was studied. Laser welding parameters were adjusted to match laser power 1000W and welding speed rate 1m/min.

DSC tests Liquid nitrogen cooling system (to -170℃), secondary mechanical refrigeration unit (to -80℃), temperature range :-170℃~730℃, measured heating rate of 5℃/ min. Weighing sample quality and corundum pot quality, put into the furnace, reference empty corundum pot. The gas flow rate is 60 ml/min and 20 ml/min.

Weld samples were cut from the middle of the laser weld including weld heat affected zone. The change of phase transition temperature between base metal and weld sample was verified by experiments. Martensite start temperature $M_s$, Martensite end temperature $M_f$, Beginning temperature of austenite $A_s$, End temperature of austenite $A_f$.

Loading status with 200 g, test weld Vickers Hardness evaluate the status of weld heat affected zone.

3. EXPERIMENTAL RESULTS AND RESEARCH

3.1. X-ray flaw detection

X-ray flaw detection is a kind of inspection method that uses X-ray to penetrate metal materials, and because of the different absorption and scattering effects of materials on the ray, the film sensitivity is different, so different images with different blackness are formed on the negative film, and then the internal defects of materials are judged, which is called RT for short.
Radiographic inspection is applicable to check the quality of welds. It has the advantages of intuitionistic defect detection, accurate and reliable inspection results, and can keep the negative film for future reference.

The SMA alloys weld under different process conditions are inspected in batches according to the flaw detection standard, among which the flaw detection photos without defects are as shown in Fig. 1(a), and the flaw detection photos of welds with pores and cracks are as shown in Fig. 1(b).

Through the X-ray flaw detection analysis, no cracks and over sized pores were found in the laser weld under the condition of normal welding process parameters.

3.2. DSC
There are three different phases in SMA alloys: B2 parent phase with cubic CsCl structure, B19' monoclinic martensite phase and R phase. In these phases, the following phases may occur: B2 → B19', B2 → R and R → B19', as shown in Fig. 2. The aging conditions have an effect on the transformation of NiTi alloy. There is a phase transition of R, i.e. B2 → R → B19'.

The results show that there is only one martensitic transformation in the weld without intermediate R transformation, i.e. B2 → B19', the peak amplitude of martensitic transformation in the weld is lower than that in the base metal, while the peak amplitude of martensitic transformation in the weld is higher than that in the base metal. The ratio of Ms to Mf in the weld without filler is basically the same as that in the base metal, while the ratio of Ms to Mf in the weld with filler is lower than that in the base metal, while the ratio of Mf is higher. The temperature range of martensitic transformation between the base metal and the weld is narrowed obviously.

During the temperature rising process of the reverse transformation of the Maraging treatment, only one transformation of B19'→B2 occurs in the base metal, there is no intermediate R-phase transformation in the weld join. As and Af of the weld joint without filling rare earth are basically the same as the base metal, while as and Af of the weld joint are increased, and the temperature range of the martensitic transformation is significantly narrower than that of the weld joint. The hysteresis temperature range (as Ms) of the weld is narrowed obviously.
Fig 2. Transformation temperature curve of weld and base metal

3.3. Microstructure analysis of joint
In Figure 3, the welded joint by YAG laser is composed of base metal, heat affected area of weld, and weld. The grain of the base metal make the obvious directivity, the whole matrix grain is very fine, and the grain size is 8th grade, which is the B2 ordered phase of TiNi. The weld structure is formed by the radial growth of grains perpendicular, from the heat affected zone to the center, during the solidification of the molten metal, the grain size is 4-5th grades. During the solidification process, the central area of the weld has the highest heatheat quantity, Shortest

Because of the high temperature processing time and the longest cooling time, so very coarse columnar crystal were forming with grain size of 2th grade.
4. CONCLUSION
From the existing research results, laser welding has a broad prospect. When gas tungsten arc welding and electron beam joining SMA alloys, the joint becomes brittle due to the dissolution of O, H and N. the metal in the heat affected zone loses the ability of shape memory effect and elasticity. There are brittle gap compounds of Ti₂Ni and TiNi₃, which affect the shape memory effect. In recent years, the laser welding method of shape memory alloy is more active. Because of the concentration of laser heat source, narrow heat affected zone and high welding geometric accuracy, it shows a good application prospect.

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