Research on Laser Welding Organization Performance of Fe-Mn-Si Alloy

Linlin Liu¹, Huajun Dong¹, Xiaochi Wang¹, Chaoyu Zhou²,
¹School of Mechanical Engineering, Dalian Jiaotong University, Dalian, Liaoning, 116028, China
²Department of Mechanical and electrical, Weihai, Shandong, 264210, China
*Corresponding author’s e-mail: good_linlin@163.com

Abstract. The crystal morphology and formation of the microstructure of the laser weld of Fe-Mn-Si memory alloy were analyzed by metallographic microscope and scanning electron microscope(SEM) and X-ray diffractometer (XRD). The results show that the welding seam microstructure of Fe-Mn-Si memory alloy crystallizes symmetrically from the fusion zone on both sides to the weld center. The γ→ε martensite transformation occurs in the welding seam and its adjacent tissues due to laser welding. This is because of the residual stress generated in the welding process, and this kind of ε martensite transformation and its deformation relaxes the residual stress of the weld, thus affecting the mechanical properties of the weld.

1. Introduction
Laser welding has recently attracted research attention because of its unique properties, which include good directivity, precision machining, small heat affected zone of weld, small welding deformation, etc. [1-4]. The repetitive rate of excellent weld formation can be realized through proper adjustment of laser process parameters; therefore, laser welding is one of the most important methods of structural parts welding. However, at present, there are few reports on laser welding shape memory alloy [5-6]. In this paper, the crystal morphology and formation of the microstructure of the laser weld of Fe-Mn-Si memory alloy were analyzed by metallographic microscope and scanning electron microscope, and the phase transformation of the microstructure during laser welding was discussed.

2. Experiment Material and Method
In this study, backing materials for Fe-17Mn-5Si-10Cr-5Ni (wt%) (shortened form A alloy) were prepared by vacuum medium frequency furnace; the cast ingot was first homogenized at 1200 °C, reheated to 1100 °C for 1 h. Specimens with dimensions of 5 mm×2 mm×1 mm were wire cut by electrical discharge machine. The solution treatment was carried out by austenitizing at 1000 °C for 1 h in the presence of argon atmosphere.

A continuous wave (CW) CO₂ laser of 10 μm wavelength (5 kW maximum power) was utilized for material processing, and the optimal welding process parameters were obtained through orthogonal test: P=2000 W, V=250 mm/min, z=0.5 mm.

Metallographical specimens were observed by OLYMPUS G×51 microscope. The sample was polished with No. 1200 water sandpaper. In order to further analyze the microstructure of the weld, etched with a solution of 3 g CuSO₄+10 mL HCl+30 mL H₂O and followed by etching with a solution of volume ratio of 3:1 HCl+HNO₃. XRD specimens was complemented by the D/max-3B

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
X-ray diffraction apparatus of Japan electrical machine, using CuKα radiation, 35 kV work voltage, 100 mA electric current, 2 °/min scanning velocity. Microstructure morphology of weld was analyzed by scanning electron microscope (SEM).

3. Result and Discussion

Figure 1 shows microstructure of cross section of A alloy welding seam. It can be seen that there are no obvious defects in the welding seam, and the overall appearance is T-shaped. The upper surface of the welding seam is wider than the lower surface, and there is a long distance from the upper surface to the lower surface with equal width, which indicates that the laser energy is distributed evenly along the direction of plate thickness, which is extremely powerful for the welded joint. Figure 2 shows microstructure of welding material far from welding seam. As can be seen from the figure, the welding base material remains pure austenite phase at a distance from the weld, and no ε martensite is found.

Figure 3 shows microstructure of fusion zone of A alloy welding seam. As can be seen from the figure, there is a fusion zone with a width of about 80 microns between the weld and the base metal, and the microstructure on both sides of the fusion zone is very different. Further magnification shows that the structure of the base metal on the left side of the fusion zone is composed of the raustenite and a small amount of epsilon martensite, as shown in figure 4. This is because during laser welding, the weld metal undergoes the melting and solidification process, which leads to expansion and contraction of the weld metal, and such deformation is constrained by the surrounding cooler metal, resulting in the occurrence of residual stress in welding [7]. The results show that γ→ε martensite transformation occurs in the welding seam of A alloy and its adjacent tissues due to laser welding. This is because of the residual stress generated in the welding process, and this kind of ε martensite transformation and its deformation relaxes the residual stress of the weld (i.e., the stress self-adaptability), thus affecting the mechanical properties of the weld.
Figure 5 shows XRD patterns of A alloy welding seam and figure 6 shows XRD patterns of welding materials far from welding seam. After comparison, it is found that there is ε martensite in the welding seam microstructure after laser welding, as shown in figure 5, which indicating that the weld metal had ε martensite transformation during the welding process, which is caused by the $\gamma \rightarrow \varepsilon$ martensite transformation induces by residual stress of laser welding. The base material far away from the weld still retains a single $\gamma$ austenite phase, as shown in figure 6. This is consistent with the results of the previous experiment.

Figure 7 shows microstructure of A alloy welding seam center. As can be seen from the figure, the weld microstructure is composed of a large number of afterbrith-like twig crystals in the side of the weld near the fusion zone, and the crystals gradually change from afterbrith-like twig crystals to twig crystals from the fusion zone to the weld center. The afterbrith-like crystals structures in the weld area are equivalent to refining the bulky columnar crystals, which are very beneficial to the strength and toughness of the weld area. However, the neighboring afterbrith-like crystals belonging to the same twig crystals have the same phase. Therefore, in the future, the phase of ε martensite formed in the same twig crystals are the same, when the stress induced $\gamma \rightarrow \varepsilon$ martensite transformation occurs though denaturation, belonging to the same variant, which can maintain good crystallography reversibility when the heat is reversed and be beneficial to shape memory effect [8].
4. Conclusion

(1) The welding seam formation of welding joint of Fe-Mn-Si memory alloy is well, and the cross section morphology of the weld is T-shaped. The welding base material remains pure austenite phase at a distance from the weld, and no ε martensite is found.

(2) The welding seam microstructure of Fe-Mn-Si memory alloy crystallizes symmetrically from the fusion zone on both sides to the weld center. The width of the fusion zone is about 80μm, and a large number of tiny afterbirth-like crystals are distributed in the fusion zone. From the fusion zone to the weld center, the crystals gradually change from afterbirth-like twig crystals to twig crystals.

(3) The γ→ε martensite transformation occurs in the welding seam and its adjacent tissues due to laser welding. This is because of the residual stress generated in the welding process, and this kind of ε martensite transformation and its deformation relaxes the residual stress of the weld (i.e., the stress self-adaptability), thus affecting the mechanical properties of the weld.

References

[1] Lu W.W., Chen Y.H., Huang Y.D..(2014) Microstructure and mechanical property analysis about NiTiNb laser welding joint around heat treatment. Chinese journal of lasers, 41:1-5.
[2] Li H. M., Sun D. Q., Dong P..(2012) Analysis and prevention of cracks in laser-welded joint of TiNi shape memory alloy and stainless steel. Transations of the china welding institution, 33:41-45.
[3] Yang C. G., Shan J. G., Ren J. L..(2014) Effect of aging treatment on reverse phase transformation temperature of TiNi alloy laser welded metal. Materials science and technology, 22:19-23.
[4] Wang H.Y.. (2017) Development and prospect of laser welding technology. Engineering technology and application, 1:52-53.
[5] Xia W. G., Wang X., Wu X. Q..(2014) Phase transformation of NiTi shape memory alloys under the action of laser-induced shock wave. Acta armamentar, 35:198-202.
[6] Yang J., Chen P., GUO Z. B..(2015) Effect of laser welding on the microstructure and properties in weld zone of Fe-Mn-Si based shape memory alloys. Journal of functional materials, 46:14130-14133.
[7] Yang C.G.,Shan J.G.,Ren J.L..(2013) Phase transformation temperature control of weld metal of laser welded TiNi shape memory alloy joint.Acta metallurgica sinica, 49:199-206.
[8] Ueda Y, Kim Y C, Yuan M G. (1989) A prediction method of welding residual stress using source of residual stress. Jour. Trans. of JWRI., 18(1):135-138.
[9] Qiao Z.X., Li Z.M., Liu Y.C.. (2007) Study on microstructure and shape memory effect in weld joints of an Fe-Mn-Si-Cr-Ni alloy. Journal of functional materials, 38:1645-1647.