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WELDING LETTERS

Morphological Characteristics of Widmanstätten Austenite Formed in Laser Beam Welds of Lean Duplex Stainless Steels

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The Widmanstätten austenite is well known precipitates at grain boundaries in duplex stainless steel welds, making the performance of welded joints degraded. That is affected by its morphology. However, the three dimensional microstructure has not been made abundantly clear. Almost all the studies on the morphology of Widmanstätten right now were based two dimensional only. In order to identify the morphology of Widmanstätten austenite, the three dimensional structure was observed by the serial sectioning three dimensional method. The Widmanstätten austenite in the same area observed on different cross-sections shows different morphologies and arrangements. And through the EBSD analysis, the relationship between part of the granular austenite in the ferrite grain and the Widmanstätten austenite precipitated at the grain boundary was determined.

Key Words: Duplex stainless steels, Widmanstätten austenite, Laser beam welding, Serial Sectioning

1. INTRODUCTION

Lean duplex stainless steel has received widespread attention due to its economic characteristics, mechanical properties, and corrosion resistance. As an application, it is now be used in equipment and machinery exposed to various corrosive environments, such as chemical plants, ship related equipment, and heat exchangers. However, when welding, it is well known that the ferrite phase is rich in welds. Especially in laser beam welding, the phase balance may change significantly from base metal due to the high energy density and welding speed, and Widmanstätten austenite will be precipitated in welds[1)].

In the previous research of welds in duplex stainless steel, the austenite precipitated at welds is mainly composed of nitrogen and also affects the growth of Widmanstätten austenite[2,3)]. Meantime, the shape characteristics of the Widmanstätten structure have been described in many studies are primarily classified as elongated needle-like. Significantly, if it appeared in welds of carbon steels, the Widmanstätten structure may affect brittle fracture and toughness[4,5)], has been reported. In recent years, research on Widmanstätten austenite has increased due to the spread of duplex stainless steel. In particular, lean duplex stainless steel, which contains a large amount of nitrogen instead of nickel, has received the most attention. Widmanstätten austenite growth principles of its generation and morphology mainly include the preferential growth direction from grain boundary into ferrite crystal and the nitrogen diffusion mechanism. However, Widmanstätten austenite in the cross sectional will be observed a little differently each time from the experiment, which is a massive obstacle to classifying the precipitation form of the Widmanstätten austenite. Therefore, multi angle, multi position observation is of great significance for understanding the actual morphology and growth mechanism of Widmanstätten austenite. Also, it could support the evaluation of the characteristics of welds.

From the above problems, we have restructured a three dimensional microstructure by combining consecutive slices taken with polishing to observe Widmanstätten austenite in the welds of the duplex stainless steel clearly as possible. This kind of three dimensional model is helpful for a more intuitive understanding of the shape of the microstructures in the weld metal. Moreover, primarily when the shape of the microstructure significantly influences the welds' material properties and corrosion resistance, it can reduce the range of speculation and prediction. In the future, it is necessary to provide processing technology to improve the accuracy of the three dimensional model. As the initial stage of this experiment, EBSD analysis was adopted to verify the viewpoints derived from the observation results of this three dimensional model.

2. EXPERIMENTAL PROCEDURE

2.1 Material used

In this experiment, the lean duplex stainless steel (S32101) was subjected to a bead on plate test by laser beam welding. The specification of the sheet was 100mm (Length) × 100mm (Width) × 3mm (Thickness), and the chemical composition thereof is shown in Table 1 below.

Table 1 Chemical compositions of materials used (mass%)

Material	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	N
S32101	0.021	0.72	5.06	0.20	0.01	1.57	21.35	0.31	0.25	0.215

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2.2 Microstructure observation

The samples are processed by laser beam welding, and the welding conditions are laser output 2000W, welding speed 1000mm/min. After wet polishing and buffing with 1/4 μm diamond spray was performed, etching using a 10% KOH aqueous solution to distinguish the phase between ferrite and austenite.

In addition, The Genus 3D developed by Nakayamadenki Co., Ltd. was used for three dimensional microstructure observation in this experiment. First, surface etching was performed with 10% oxalic acid solution. Then, a three dimensional microstructure model of the duplex stainless steel laser welds was constructed by combining 115 continuous slices taken at a polishing interval of 0.597 μm.

3. RESULT AND DISCUSSION

3.1 Two dimensional microstructure

Figure 1 shows the microstructure in the welds of lean duplex stainless steel observed with an optical microscope after etching with 10% KOH aqueous solution. In this figure, the white part is the austenite phase, the black part is the chromium nitride, and the others are the ferrite matrix.

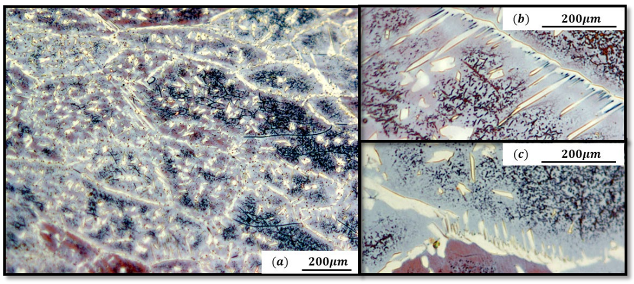

Fig. 1 (a):Microstructures in laser welds of duplex stainless steel (S32101), (b)(c): Widmanstätten austinite at grain boundaries.

Almost all of the austenite precipitated in the laser welds of the lean duplex stainless steel is grain boundary austenite and a few granular austenites in the ferrite grains. Also, because of the increase of the nitrogen content in the base material, the chromium nitrides precipitation was found in the ferrite grains of the laser welds, as shown in Fig.1(a). Fig.1(b) and (c) enlarged the grain boundary where could observe Widmanstätten austinite.

Widmanstätten austenite precipitates along the grain boundary austenite, and it grows from the boundary to ferrite grain by maintaining a specific direction like the K-S relationship and grows up by obtaining the nitrogen in ferrite[7,8]. Therefore, the substances like chromium nitride, which also require nitrogen for precipitation and growth, are almost impossible to precipitate near the grain boundary austenite and at the end of the Widmanstätten austenite. Because in ferrite around that area, nitrogen becomes very scarce. Figure 1 (a) and (c) show the Widmanstätten austenite at different grain boundaries under the same welding conditions. Its size, shape, and arrangement are entirely different. By analyzing the crystal orientation, the thermal history to varying positions of the welds, the concentration of surrounding nitrogen, etc., the reasons for the difference can be explained to a certain extent. However, all metallographic structures have three dimensional shapes, equiaxed or non equiaxial, limited to two dimensional plane observation, and the analysis results have a contingency. Therefore, it is not conducive to understanding the actual morphology of Widmanstätten austenite, and it will also cause significant obstacles to the establishment of three dimensional simulation models in the future.

3.2 Three dimensional microstructure

The three dimensional microstructure model[9] in this experiment was reconstructed in three dimensions from the stacked image data by repeating surface observation and grinding using an optical microscope based on the serial sectioning method as shown in Fig.2.

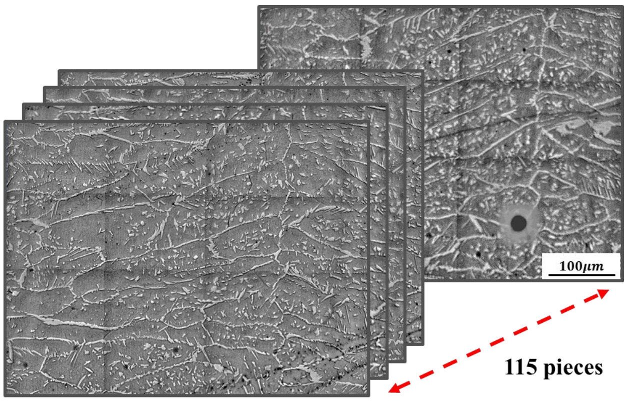

Fig. 2 Image diagram of serial sectioning method.

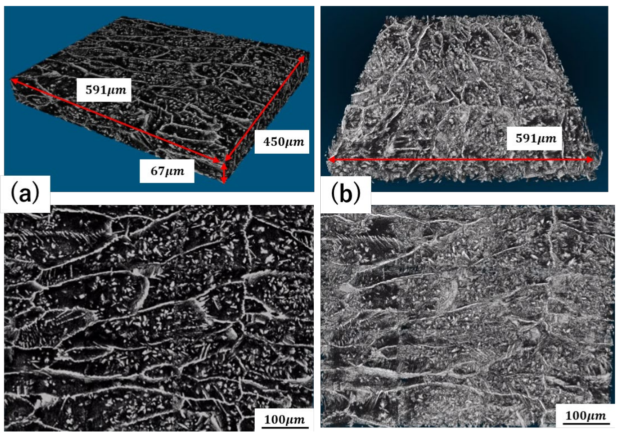

Fig. 3 (a): The three dimensional model of welds rebuild by serial sectioning method, (b): The three dimensional model of welds only retains the austenite phase.

Figure 3 shows the full view of the three dimensional model of welds. In Fig.3(a), the black areas are ferrites and the white regions are austenite. Also, the model could be edited to retain only austenite, as Fig.3(b). Through this model, the microstructure of the welds could be observed from different cross sections, such as the section along the welding direction, the cross section of the welds profile and, the front side of the welds, and the reverse side of the welds.

This three dimensional model can observe the welds from different cross sections and positions, unlike the traditional observation method, because the shape and size of the metal cross section may vary greatly depending on the cutting position. So it is difficult to determine the shape and size of these tissues. In addition, due to the high welding speed, such as laser welding, when the columnar crystals in the weld grow along the welding direction, it is difficult to accurately prepare the specimen along the growth direction of the weld structure.

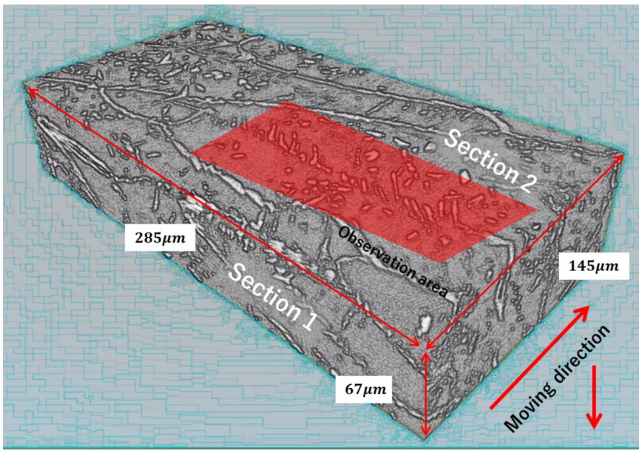

Fig. 4 Observation area and moving direction in the three dimensional model.

Figure 4 selects a portion of the 3D model of the weld metal to observe and compare the morphological changes of Widmanstätten austenite in the red shaded area by the viewing direction of section 1 (side) and section 2 (front).

Figures 5 and 6 show the morphological changes of the same row of Widmanstätten austenite observed at different depths after continuous polishing of the weld metal from different sections 1 and 2. Figure 5 shows that after continuous polishing along section 1, it can be observed that at first, the Widmanstätten austenite precipitates from the grain boundary, with a thickness, and maintains a specific interval of growth likes lath plate (a). Then it transformed into slender needles of different sizes (b). After that, a part of it showed a granular morphology and was no longer connected to the grain boundary. Similarly, Figure 6 shows the austenite morphology of the Widmanstätten austenite after continuous polishing along section 2. First, the morphology of the Widmanstätten austenite observed under different sections is entirely different. It shows that the three dimensional morphology of Widmanstätten austenite should be very complicated. From (a) to (c), the polishing depth approaches the grain boundaries gradually. Widmanstätten austenite also changes in size and morphology, a tooth-like (a) from near the top of the metallographic structure, with continued polishing then to a plate-like (b, c). Meanwhile, the precipitation behavior of Widmanstätten austenite also changes from the direct precipitation at the grain boundary to the precipitation on a austenite plate at the grain boundary. Through the application of this three dimensional model, in the observation of Widmanstätten austenite, examining its size, morphology, and precipitation behaviour, not only the welding conditions and processing details need to be taken

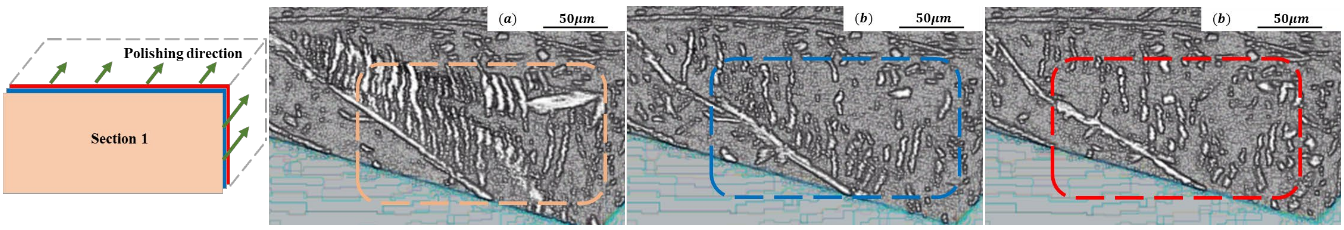

Fig. 5 Observation results of the same Widmanstätten austenite at different depths of section 1.

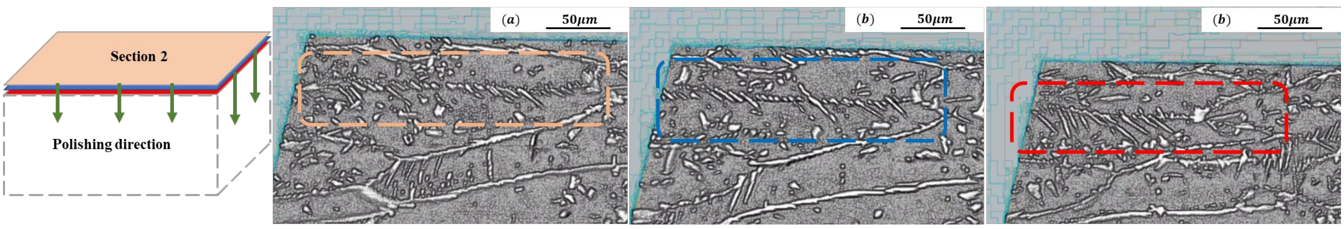

Fig. 6 Observation results of the same Widmanstätten austenite at different depths of section 2.

into considerations, but also the direction of observation and the depth of the cross-section show the corresponding significance.

3.3 EBSD analysis results

To further verify the crystallographic relationship between intragrain austenite and grain boundary austenite in the ferrite matrix, crystallographic orientation analysis of EBSD was conducted on the parts which have similar austenite precipitation morphology as shown in Fig. 5(b) and (c). The EBSD results confirm that the intracrystalline austenite in the pink part has the same crystallographic orientation as the grain boundary austenite, as shown in Fig. 7. The Widmanstätten austenite has a complex three dimensional morphology, resulting in different depths of the cross sectional observation having a significant influence on the Widmanstätten structure morphology. Future, more high precision polish, and corrosion are required to make a better three-dimensional observation. Figure 8 shows an image diagram and SEM diagram of the Widmanstätten austenite like the autumn leaves. Figure 8(b),(c) imitates the results of the cross sectional structure at the cut line 1-3 under this three dimensional morphology. It can be observed that the Widmanstätten austenite morphology is different, but it is consistent with the current planar observation results.

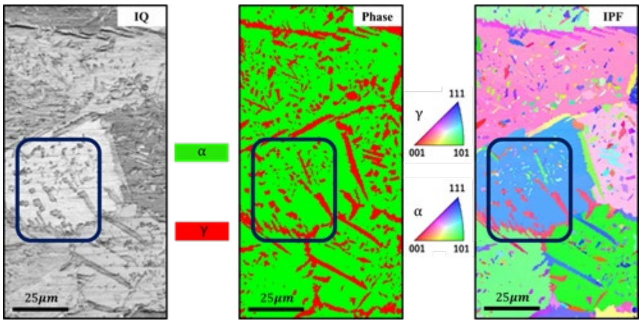

Fig. 7 EBSD analysis results of Widmanstätten austenite in welds.

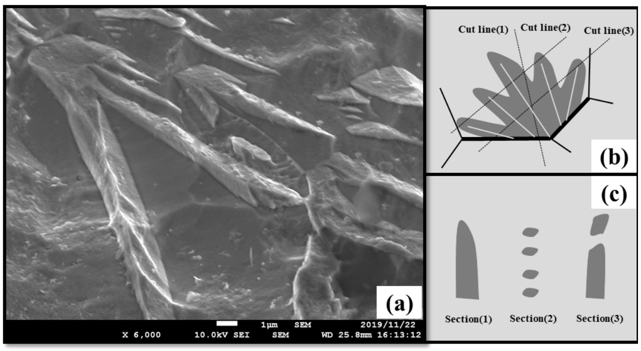

Fig. 8 One single Widmanstätten austenite growth like autumn leaves.

4. CONCLUSIONS

Compared with traditional microstructure observation, the three dimensional model reconstructed through the serial sections is more effective for observing the morphological changes of Widmanstätten austenite in the laser welds of duplex stainless steel. At the same time, this observation method also realized the three dimensional observation and comparison of the microstructure from different sections and depths.

The results show that some granular austenite is from the Widmanstätten austenite, and most Widmanstätten austenite actually precipitates from a boundary austenite plate. Observations of different cross sections and the same cross sectional with varying depths at the three dimensional model and the results of EBSD crystal orientation analysis have proved a correlation between them. Through various profiles from different cross sections, one single Widmanstätten austenite may grow like autumn leaves.

Acknowledgments

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