Microstructure Control of Titanium Weld by Addition of Boron*

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Reinforcement of titanium by using titanium mono-boride is being applied to weld metal of Commercial Pure-titanium. In this presentation, the effect of re-hating for the boron-added weld metal is accessed by taking into account the multi-pass welding. The boron-added weld metal is re-heated and its microstructure change is in-situ observed by using High temperature Laser Scanning Confocal Microscopy (HSLCM). The formed microstructure is also analyzed in detail and compared with CP-titanium and boron-added weld.

Key Words: Weld metal, Pure titanium, titanium mono-boride, eutectic reaction

1. Introduction

The grain size of titanium weld is much larger than the base metal and then its mechanical properties are less than base metal as it is easy to estimate with Hall-Petch law. Reinforcing the titanium weld is important technique for producing safer weld construction.

The reinforcement of titanium with titanium mono-boride (TiB) is widely applied in the field of casting and powder metallurgy, as summarized by Tamirisakandala et al1). The forming of TiB reinforces the titanium metal due to the effect of grain refinement and high modulus of TiB itself. In our research group, reinforcement of titanium by using titanium mono-boride is being applied to weld metal of Commercial Pure (CP)-titanium2). The boron is pasted on the CP-titanium and it is melted with Gas Tungsten Arc (GTA) welding process. During the welding process with boron pasting, TiB was formed in eutectic reaction at cell boundary. It was very unique distribution in the case of welding2). The grain size of the weld metal was smaller than base metal and the Vickers hardness increased due to the effect of grain refinement and high modulus of TiB. Those results show potential of the application of TiB-reinforcement technique to the weld metal.

In the present work, the effect of re-hating for the boron-added weld metal is accessed by taking into account the multi-pass welding. The boron-added weld metal is re-heated and its formation process is in-situ observed with High-temperature Laser Scanning Confocal Microscopy (HSLCM) to reveal the formation process. The microstructure, grain size, hardness for pure titanium, TiB-reinforced weld metal and re-heated weld metal are compared and those differences are made clear.

2. Experimental procedure

The CP titanium was prepared and the boron with ethanol solvent was sprayed on the half area of the plates. The bead-on plate welding was carried out on the plate2). In the present paper, the bead with boron and without boron was referred to as CPW and TBW, respectively. The welding conditions are summarized in Table 1. The plate size was 150L×30W×1.5T mm. The welding current was 100 A with the argon shielding gas (torch-shielding 20 l/min, after-shielding 30 l/min). The arc length was kept in 1.5 mm and the welding speed was set in 1440 mm/min. After the GTA welding, boron content in the weld metal was analyzed and resulted in 0.5 mass%. The cylindrical sample was extracted from the TBW and the sample was heated to 1495 °C at the 3.3 °C per second and cooled at the 37.5 °C per second by using infrared image furnace which is part of HSLCM system. The microstructure change is also in-situ observed with the HSLCM system. The details of HSLCM experiments are described in elsewhere3-4). The thermal cycle simulated the one in re-heated zone of weld metal. The re-heated TBW is referred to as RHW in this paper. The microstructures between CPW, TBW and RHW were observed with Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM). For SEM observation, etchant (HF 2 ml+HNO3 5 ml+distillated water 100 ml) was used. TEM thin foil specimens, 3 mm in diameter, were prepared by mechanical thinning followed by electrolytic polishing. Conventional TEM observation was performed by using Hitachi H-800 operated at 200 kV. The crystallographic

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*Received: 2008.11.18
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analysis was also carried out with Electron Back Scatter Diffraction (EBSD) technique with Orientation Imaging Microscopy system (TSL Company).

3. Result and discussion

Figure 1 shows SEM micrographs for CPW, TBW and RHW. For CPW, large grain was observed. For TBW, the cell network was observed. The boundary of the cell consisted of aggregates of thin crystals and it made contract of cell network. In the case of welding, solidification sub-grain is well aligned due to constraint growth15. Then the unique morphology was observed. For RHW, the cell network disappeared as shown in Fig. 1 (c). Furthermore, the grain size was much finer than PTW (Fig. 1 (a)) and small precipitate was distributed. The morphology was drastically changed by re-heating process of TBW. The extreme change of morphology was chased by using HLSCM. Figure 2 shows HLSCM images during heating process. Around 1250 °C, the precipitates begin to appear as showed with arrow. Around 1350 °C, the cell-network disappeared and precipitate (1.0-2.0 μm size) was randomly distributed. Those changes were clearly shown in image at 1495 °C in Fig. 2. Figure 3 shows HLSCM images during cooling process. The beta-alpha transformation started at 850 °C and alpha-titanium with acicular plate morphology was formed. The precipitates marked in Fig.3 looks like supplying the nucleation site of acicular alpha-titanium. There is a possibility that the precipitates supply the substrate for the alpha-titanium nucleation. Tamirisakandala et al6) suggests that the presence of TiB could enhance the kinetics of alpha phase transformation by providing additional nucleation site in titanium alloy casting. In order to discuss the stimulation of nucleation of alpha titanium at TiB precipitates, nano-order analysis of interface7) is need in future. Finally, microstructure with interlocking morphology was formed as shown in image at 807 °C.

Figure 4 shows TEM micrograph for TBW. For The cell-network corresponds to figure 1 (b). The SAD pattern shows the cell-network consists of alpha-titanium and TiB (Structure: B27). The dark-filed image (Fig.4 (b)) was for TiB diffraction spot and it suggested that the TiB has a thin plate shape. Then, the cell-network was formed with thin-plate TiB and beta-titanium during eutectic reaction.

Figure 5 shows TEM micrograph for RHW. The precipitate
observed in Fig. 2 was analyzed. It was identified as TiB (Structure: B27) phase. The size was distributed from 1 to 2 μm and it corresponds to results in Fig. 2 and 3.

Summarizing the results from Fig. 2-5, the drastic change of microstructure morphology was explained as follows. The TBW was formed in rapid cooling process of welding. Then, the eutectic microstructure is retained as a cell-network at the room temperature. When temperature increased during re-heating process, the TiB could agglutinate and the distribution of TiB was drastically changed. During its cooling cycle, it looked like that the precipitates acted as the nucleation agent for the alpha-titanium. The fine alpha-titanium is formed with interlocking morphology. It is as same as acicular ferrite formation in high strength and low-alloy steel. Figure 6 shows EBSD maps for CPW, TBW and RHW. CPW had large grains and its average diameter was 63 μm. In the case of TBW, it was clear that cells formed one grain with showing same color for one grain. Then, the average grain size was 29 μm. for the RHW, interlocking morphology was clearly observed and the average grain size was only 6 μm. Those maps clearly showed the grain refinement and morphological change from CPW to RHW. It is clearly estimated that the strength of RHW is the highest and the lowest for CPW. In order to evaluate the strength, the Vickers hardness value was measured for three samples. Figure 7 shows the results of hardness test. As expected the highest value was for RHW. The size of TiB for RHW was much larger than TBW and it was randomly distributed without forming aggregate. The size effect and the distribution stimulated the alpha-titanium
nucleation during beta-alpha transformation. It caused the grain-refinement and the higher value of hardness. The heat cycle of HAZ is spatially changed from fusion line. Then, the various cycle of HAZ is applied and the corresponding microstructure is analyzed in future. Furthermore, the amount of fusion zone is very small with the boron pasting method used in the present work. Then the mechanical test was restricted. The boron addition method should be improved.

4. Conclusion

The titanium mono-boride was dispersed in weld metal of CP-titanium by adding the boron during welding. The microstructure of weld metal and the effects of re-heating process on the weld metal were analyzed in detail. The main conclusions obtained are as follows:

1) The titanium mono-boride was distributed as the aggregate of eutectic product in the sample after welding with boron pasting. On the other hand, it was distributed as the larger-size precipitates in the weld metal after re-heating.

2) The microstructure change during re-heating process was in-situ observed by using HLSCM system. The break-down of the cell-network and precipitates agglomeration in the heating process were observed. At cooling process, the precipitates acted as the nucleation agent of acicular alpha-titanium and fine alpha-titanium plate was formed. The Vickers hardness of re-heated sample was harder than that of as-welded sample.

References