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Evaluation of Mechanical Characteristics and Microstructure of Surface Hardness Coating by Laser Cladding

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Abstract. This study evaluated the mechanical properties and the microstructure of a surface hardness coating layer formed by laser cladding using a Bulk Metallic Glass (BMG) wire. The mechanical properties were measured by tensile strength test and micro-hardness test; microstructure and grain structure were analyzed by using a high-resolution scanning electron microscope and a transmission electron microscope. Surface coating was carried out by laser cladding and the GTAW process. The tensile strengths of the laser-cladded and GTAW coating layers were 2.0GPa and 1.7GPa, respectively. The tensile strength and micro hardness of the laser-cladded coating layer were about 15% and 14.3% higher than those of the GTAW coating layer, respectively. The laser-cladded coating layer showed finer grains and fewer dendrites due to their reduced distribution. The microstructure of the BMG coated layer showed a mix of α-Fe phase and amorphous phase.

Keywords: Welding, GTAW, Laser cladding, BMG, Surface hardness coating, G.1-AW

1 Mechanical Properties

As shown in Fig.1(a), the yield strengths of STS316L, GTAW, and Laser Cladding coated specimens were 292.1, 360.7, and 378.9 MPa, and the tensile strengths were 591.8, 534.8, and 568.9 MPa, respectively. The tensile strength of the substrate (STS316L) was higher than those of GTAW and Laser Cladding coated specimens by 9.63% and 3.86%, respectively, but the yield strengths of GTAW and laser cladding coated specimens were higher than that of the substrate (STS316L) by 19.02% and 22.91%, respectively.

Generally, yield strength is a more important mechanical property than tensile strength for metals used in structural products. This is because elastic deformation does not affect a product’s appearance, but plastic deformation changes a product’s size or appearance, decreasing a product’s value. The yield strength of the coating layer can be obtained by using Eq. (1) as follows.

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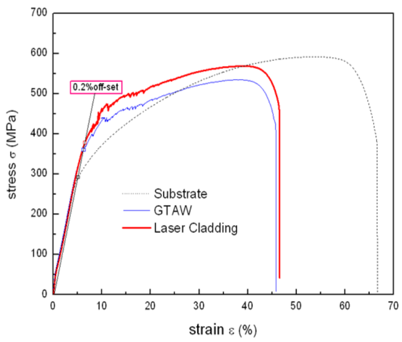
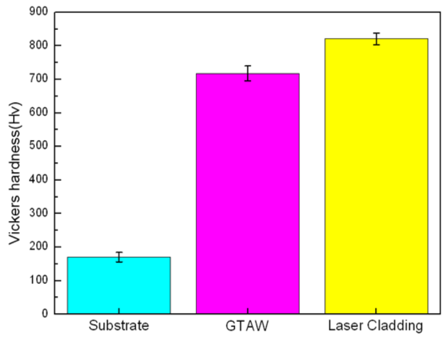
$$\sigma_{Coating} = \frac{A_{Total}}{A_{Coating}}\left(\sigma_{Total} - \sigma_{Substrate} \times \frac{\sigma_{Substrate}}{\sigma_{Total}}\right) \quad (1)$$

where σ : yield strength and A : cross sectional area. Generally, the yield strength of Fe-BMG has been reported to be about 2GPa [1] and [2]. Based on the above equation, the yield strengths of laser cladding and GTAW coated specimens were about 2.0 and 1.7 GPa, respectively. The laser cladding yield strength was similar to the Fe amorphous yield strength, which indicates that laser cladding is a coating process that does not reduce the yield strength of the coating layer.

Fig. 1(b) shows the measured micro hardness values of the substrate (STS316L), GTAW and Laser Cladding coating specimens. As shown in the figure, the micro hardness values of the substrate (STS316), and the GTAW and Laser Cladding coating layers were Hv 170.5±14, 718.1± 21.9, and 821.1±17, respectively.



(a) Strain-stress curves



(b) Micro hardness

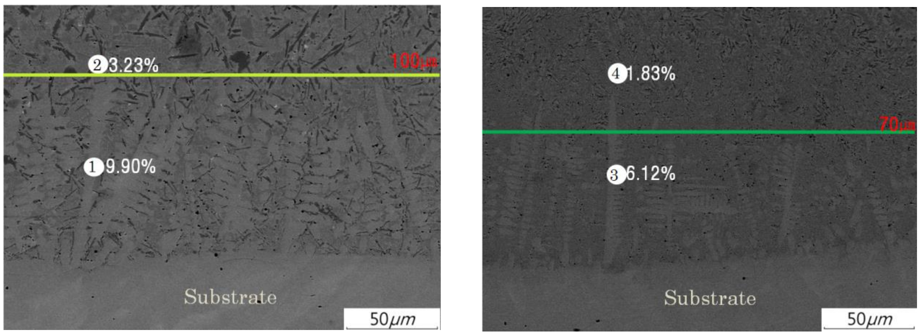
Fig. 1. Mechanical properties

2 Microstructure Evaluation

Fig. 2 shows the GTAW and laser-cladded coating layers, observed using a high-resolution electron scanning microscope. Dendrite microstructures grew to about 100 ㎛ and 70 ㎛ from the interface between the substrate and the coating layer to the inside of the coating layer for GTAW and Laser Cladding, respectively. As shown in the figure, laser cladding yielded smaller and denser grains than GTAW, and less distribution of tree branch shaped dendrites, which form by the compositional difference between the part that solidifies first and the part that solidifies later when melted alloy starts to solidify.

The quantitative analysis of the dendrite microstructure and needle-like structure of the GTAW coating layer showed about (1) 9.90% Ni and (2) 3.23% Ni contents, and the quantitative analysis of the dendrite microstructure and needle-like structure of the laser-cladded coating layer showed about (3) 6.12% Ni and (4) 1.83% Ni contents, as shown in Table 1. The STS 316L mill sheet purchased from Posco had about 12-15% Ni content. However, the filler metal (BMG, Bulk Metallic Glass) developed in our study did not contain Ni. This shows that surface of the substrate (STS 316L) was melted more into the coating layer by the arc discharge based, high heat input GTAW process than by the laser cladding process, which uses lower input heat and heats locally. Therefore, the dendrite microstructure can be considered a structure resulting from the melting and solidification of the substrate (STS316L). This melting/solidification process results in the formation of a substrate/BMG composite material, which greatly contributes to increased adhesive strength [3] and [4].

Fig. 3 shows the BMG coating layer as observed with a transmission electron microscope (TEM). The selected area diffraction of part A is shown as a spot in Fig. 3(a); this is the α-Fe crystal phase. Also, part B is amorphous, as shown in SAD of Fig. 3(b). As revealed by TEM, the BMG coating layer had a mix of α-Fe phase and amorphous phase.



(a) GTAW (b) Laser Cladding

Fig. 2. Microstructure on coating layer

Table 1. Results of quantitative analysis

(wt.%)

	C	Si	Cr	Fe	Ni	Mo	Mn
(1)	4.01	0.30	15.68	67.15	9.90	1.81	1.15
(2)	5.66	0.44	24.69	62.50	3.23	1.91	1.57

(a) GTAW

	C	Si	Cr	Fe	Ni	Mo	Mn
(1)	4.16	1.55	12.68	74.03	6.12	0.37	1.09
(2)	6.15	0.13	31.59	56.17	1.83	2.53	1.59

(b) Laser Cladding

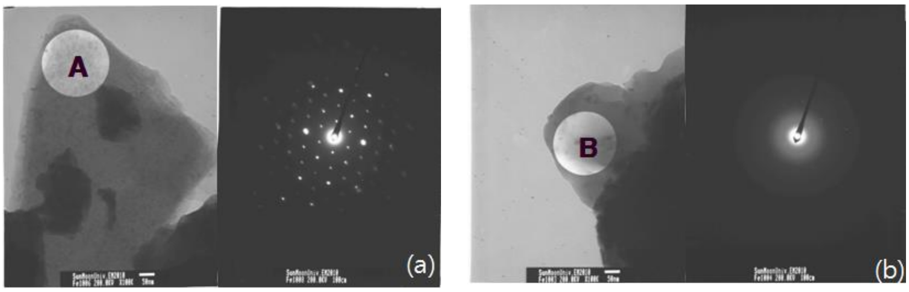


Fig. 3. TEM images of coating layer

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