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LASER FABRICATION OF TiB_2/TiC/Al ON EN AW-6082-T651 ALUMINIUM ALLOY SURFACE

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Abstract: A diode pumped Ytterbium fibre laser used to clad TiB_2/TiC/Al onto the surface of aluminium alloy EN AW-6082-T651. Aluminium was added to TiB_2-TiC ceramic precursor mixture to improve adhesion of the ceramic coating to the substrate, whereby retaining the characteristics of the ceramic components. The resulting coating was studied by means of a microstructural and mechanical analysis. Good adhesion of the coating to the substrate with no cracks and low porosity was observed. Microhardness in the coating is 82 % higher than uncoated alloy. Wear resistance of the coated surface was found to be 8 times higher when compared to the uncoated alloy. The coefficient of friction was found to be 0.57.
Keywords: laser coating, aluminium alloy EN AW 6082-T651, ceramic components TiC-TiB_2, microstructure, microhardness, wear

1. INTRODUCTION

Aluminium and its alloys are attractive candidates for many industrial and structural applications due to their height strength-to-weight ratio, good ductility, lightweight, availability and low cost [1]. However, the surface properties of aluminium alloys, in particular the hardness and wear resistance are insufficient to fulfil many requirements [2]. Surface engineering may be used to improve the required mechanical and chemical properties of different substrate materials. Žagar and Grum [3] report the improved resistance of aluminium alloys 6082-T651 and 2007-T351 to fatigue, resulting from micromechanical hardening of the surface by means of shot peening. The improved mechanical properties and resistance to corrosion of aluminium alloy 6082- T651, obtained through laser shock peening, were observed by Trdan et al. [4] and [5]. Sušnik et al. [6] reported the increased hardness of the surface layer of aluminium alloy AlSi12CuNiMg, achieved via laser surface remelting. Furthermore, ceramic composite coatings on aluminium alloys produced by lasers have considerable potential for improving surface properties; especially better wear resistance [1-2, 7-8]. The laser coating process enables good repeatability and produces a good metallurgical interface and lower porosity. Furthermore, laser technology enables additional heat treatment or remelting of the material, improving the final properties of the product.

Coating of ceramic compositions on aluminium alloys is a difficult approach, mainly due to involvement of two material systems of totally different physical properties. Often these material systems possess a large difference in the melting point [2] and coefficient of thermal expansion [1, 2]. Furthermore, the wetting of Al on most ceramics is usually poor [9]. It is important in the coating of aluminium alloys that ceramic compositions contain additives that provide good wettability at high temperature during the partial melting of pre-deposited powder on the substrate.

The present study investigates the deposition of ceramic composite coating TiB_2-TiC with added aluminium on EN AW 6082-T651 aluminium alloy AlSi1MgMn performed by laser coating. TiC and/or TiB_2 attract much interest from the industry as a coating material [1- 2, 7, 10-12]. These ceramics possess unique physical and chemical properties, such as the high melting point, hardness, elastic modulus and electric conductivity. Coatings that consist of two ceramic components such as, TiC and TiB_2, exhibit even better mechanical properties than coatings containing only one ceramic component [13]. Two-component ceramic coatings with different ratios of TiC-TiB_2 enable higher hardness and good wear resistance of the coating, as well as high fracture toughness. The hardness of the TiC-TiB_2 ceramic composite at room temperature is lower than the hardness of a one-component ceramic coating of the same kind. Even so, at the elevated temperature of about 600°C the hardness value of two-component coating TiC-TiB_2 exceeds the hardness value of a one-component coating TiC or TiB_2 [14].

2. EXPERIMENTAL PROCEDURE

2.1 Specimen preparation and laser coating

Aluminium alloy EN AW-6082-T651 samples were machined into rectangular block with 25 × 50 × 10 mm. Its nominal chemical composition in wt.% is 0.7-1.3 Si, 0.6-1.2 Mg, 0.4-1.0 Mn, ≤ 0.5 Fe, ≤ 0.25 Cr, ≤ 0.2 Zn, ≤ 0.1 Ti, ≤ 0.1 Cu and balance Al [15]. The samples were degreased and sand-blasted prior to the coating process for better adhesion and to remove any surface contaminants.

The precursor ceramic powders TiB_2 (99.5% purity and average powder size of 45μm), TiC (99.5% purity and average powder size of 2μm) and Al (99.5% purity and average powder size of 45μm) were obtained from Global Tungsten & Powder Corp (Towanda, Pennsylvania, USA). Aluminium was added to TiB_2-TiC ceramic precursor mixture to improve adhesion of the ceramic coating to the substrate, whereby retaining the characteristics of the ceramic components.

The powders were mixed with the water based organic binder (LISI W 15853) and reducer (LISI W15833) obtained from Warren Paint and Color Company (Nashville, TN, USA) and this precursor slurry was spray deposited on to the substrate with an average thickness of 150 ± 25 μm. The moisture from precursor deposit specimens was removed by air-drying for 24 hours.

To provide good chemical bonding between the coated layer and substrate, a 3-kW diode pumped Ytterbium fiber laser (IPG YLS 3000) with a continuous wave and a wavelength of 1070 nm was employed. The coating was applied to specimens at three different laser beam power values (800 W, 1000 W and 1200 W), two different ratios of clad material (60 wt.% TiB_2 / 20 wt.% TiC / 20 wt.% Al and 40 wt.% TiB_2 / 40 wt.% TiC / 20 wt.% Al) and with clad track overlapping value 30 % and a uniform spot size on the specimen surface (1.0 mm) and a constant traverse speed of 60 mm/s. A variation in the laser beam powers changes the input energy density. Thus, the input energy varied as 13.3 J/mm², 16.7 J/mm² and 20 J/mm² with increasing laser beam power.

2.2 Characterization

Microstructural analysis was conducted on scanning electron microscopes Nova™ NanoSEM 230 and JEOL JSM-6500F. The thickness of the coating and its porosity were determined by means of the Orthoplan optical microscope at magnification of 100×. The samples in cross-section were prepared by polishing with emery papers of different grits ranging, from 220 μm to 800 μm in succession followed by disc polishing with colloidal silica of 3 μm and 1 μm to get a mirror finished surface. The polished samples were etched with solution of 2ml HF + 3ml HCl + 5ml HNO_3 + 90ml H_2O.

The Vickers hardness tests were performed on a Leitz-Wetzlar tester to determine the microhardness value under a normal load of 100 g and indentation time of 15 s. The measurement in coating was conducted at half thickness of the coating. Sixteen iterations were performed horizontally in a randomly selected position, at intervals of 500 μm and calculate average microhardness in the coating.

To determine the weight loss and coefficient of friction, a TE 77 (Phoenix Tribology Ltd.) reciprocating sliding friction tribotester was employed. The mean sliding speed was 0.01 m/s under normal load of 30 N. Dry wear tests were done at room temperature (20 – 25 °C) and used Al_2O_3 polished ball as a counterpart. Relative path of the ball was 18 m.

3. RESULTS

3.1 Microstructural and micromechanical analysis

Figure 1 shows scanning electron microscopy images of a cross-section in a ceramic coating on the aluminium alloy processed with 40/40/20 ratio of clad material and energy density of 20 J/mm². The average thickness of the coating was approximately 100 ⊚m. The coating was free of cracks and low in porosity. The average estimated porosity of the coating is 2 %. As has already been established in practice, such porosity has no effect on the final properties of the coated layer. The bonding between the coating and substrate appeared to be sound. After laser coating, no partial or complete dissolution of TiC and TiB_2 or chemical reaction between molten aluminum and TiC and TiB_2 was observed. Quantitative analysis of the micrograph in figure 1 indicates that reinforcement particles occupy around 60-65 % of the total volume in the coating. The reinforced particles in the coating are relatively large, of various sizes, and are uniformly distributed in Al matrix. Liang et al. [16] report that the phase type may be determined on the basis of the facet shape. They agree with Du et al. [11], who claim that elongated or rectangular particles belong to TiB_2, whereas the spherical particles belong to TiC.

The region under coating reveals a dentritic structure, which is typically observed in cast aluminium alloys. These observations indicate that the temperature rise at the interfacial region of the substrate was sufficiently high to cause complete melting of the substrate which, subsequently, due to the locally rapid quenching rates transformed to a dentritic structure. [12].

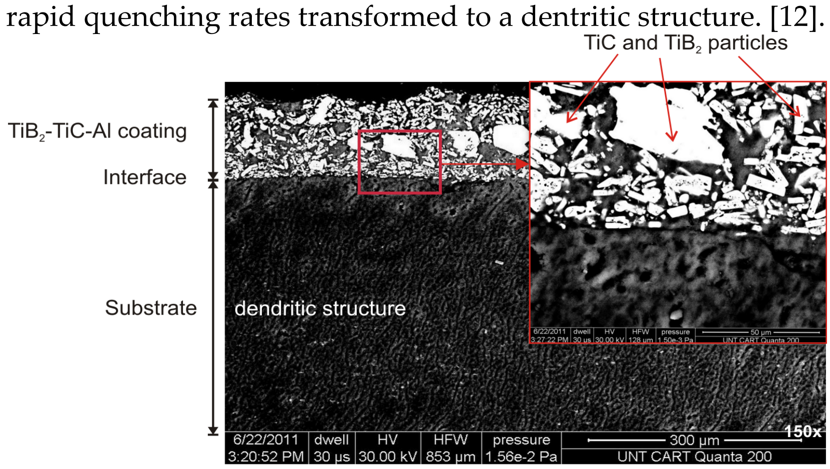

Figure 1. SEM micrograph of the overview of the cross-section of the TiB_2/TiC/Al coated EN AW-6082-T651 specimen

3.2 Microhardness in the coating

Microhardness values obtained in the coating illustrate that there are differences, resulting from TiC and TiB_2 particles that are different in size and unevenly distributed in the coating. Figure 2 shows measurements conducted in two different positions in the coating. The first measurement was taken in the big carbide particle. The corresponding microhardness value was 1097 $HV_{0.1}$. The second measurement was conducted in the region devoid of TiC and TiB_2 particles and the corresponding microhardness value was 93.6 $HV_{0.1}$, which is very close to the hardness value of uncoated aluminum alloy (97 $HV_{0.1}$). Microhardness value thus depends on the position in the coating.

However, the average coating microhardness value obtained at different combinations of laser coating conditions was 176 ± 12 $HV_{0.1}$, which represented an 82 % higher microhardness value than that of the uncoated aluminium alloy. Further, the microhardness values in the case of 40/40/20 are higher then 60/20/20 as shown in figure 3. We can concluded and agree with Vallauri et al [9] study, that higher content of TiC increases the hardness of TiB_2-TiC coating.

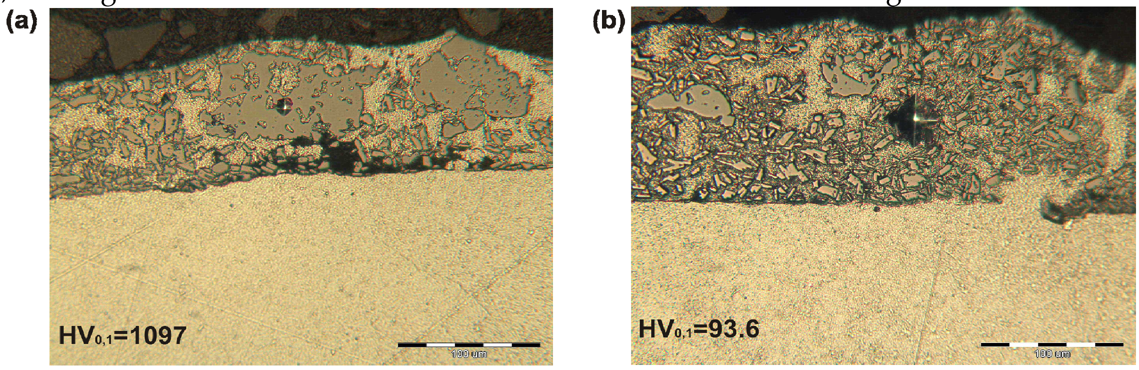

Figure 2. Due to unevenly distributed carbides and borides in the coating, the microhardness value depends on the measuring position. (a) The microhardness in the big carbide was 1097 $HV_{0.1}$ (b) The microhardness in the region without the presence of TiC and TiB_2 particles was 93.6 $HV_{0.1}$.

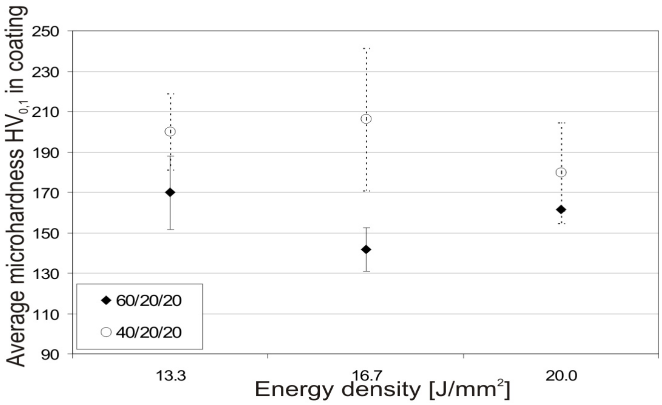

Figure 3. The average microhardness value in the coating at both radios of clad material.

3.3 Wear resistance analysis

Wear test was performed on the polished laser-clad surface and compared with the base material EN AW-6082-T651. The wear behaviours for all coated samples are similar. The wear volume results after the 30 min test are presented in Figure 4a. It is clearly observed that the coating experienced a much lower wear volume loss compared with the substrate. Average 8-times improvement was recorded with the coated samples compared with Al 6082-T651 alloy.

MMCs offer considerable potential for enhanced wear resistance, because the hard ceramic reinforcements impede the removal of material from abrading surfaces. Their effect is closely dependent on type and shape of reinforcement [17]. In the present study, however, no significant variation in the amount and shape of reinforcement as function of laser coating parameters was observed. Therefore, no differences in wear behaviours for coated samples by different laser coating parameter were observed.

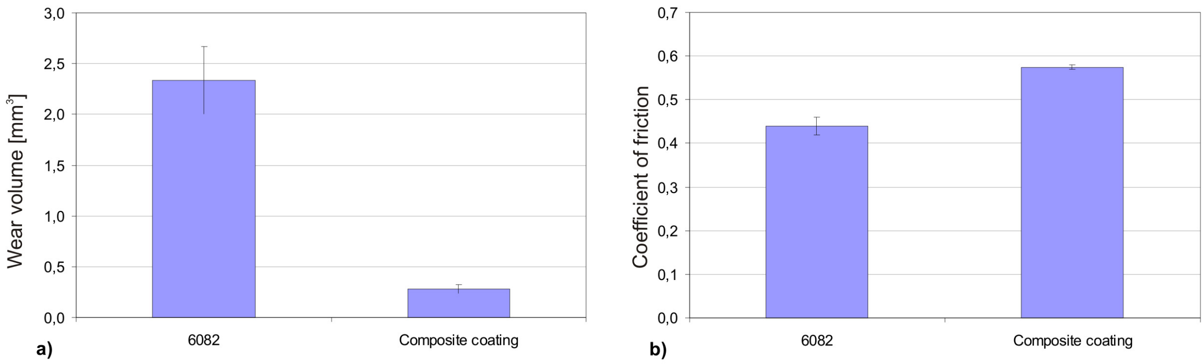

Figure 4. a) Wear volume and b) coefficient of friction of the substrate EN AW6082 and composite coating after 30 min wear test

The measurement of the coefficient of friction provides direct information about the work done to deform the surface of the material. It is not necessarily a direct indication of material loss or separation of loose debris from the surface [7]. The coefficient of friction in contacts with hard ceramic coatings is generally fairly high. The high coefficient of friction made the hard ceramic coating unsuitable for sliding component applications like bearings or piston ring vs. cylinder wall contacts [18]. The coefficient of friction results after the 30 min test are present in figure 4b. The energy density and different ratios of clad materials do not appreciably affect on coefficient of friction. The average coefficient of friction of TiB_2/TiC/Al composite coating was computed to be approximately 0.57 and it is 23% higher when compared to the uncoated alloy.

4. CONCLUSIONS

- The coating was sound and free of cracks. The average coating thickness was 100 μm with an average porosity lower than 2 %. A coating is obtained with TiC and TiB_2 particles of various shapes and sizes embedded in Al matrix. TiB_2 and TiC particles occupy around 60-65 % of the total volume in the coating.
- The average coating microhardness value obtained at different combinations of laser coating conditions was 176 ± 12 $HV_{0.1}$, which represented a 82 % higher microhardness value than that of the uncoated aluminium alloy.
- The coating shows exceptional wear resistance. After 30 min wear test coating shows about eight times less wear volume than the substrate. The coefficient of friction was computed to be approximately 0.57.

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