Bonding strength of annealed aluminum substrate deposited TiO_2 coating by cold spraying process

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ABSTRACT: It is well known that cold spraying ceramic materials can be difficult because cold spraying requires plastic deformation of the feedstock particles for adhesion to the substrate. The challenge lies in the difficulty of plastically deforming hard and brittle ceramic materials, such as titanium dioxide, TiO_2.It has generally been believed that to achieve bonding, the oxide covering the surface of metallic particles or metal substrates must be broken and removed by adiabatic shear instability (ASI), whether induced at the particle-substrate interface or at the particle-particle interface. The aim of this paper is to investigate the relationship between the oxide thickness and substrate deformation with the adhesion strength of cold-sprayed TiO_2 coating towards the bonding mechanism involved.

Keywords: *Cold Spray; Bonding Mechanism; Metallurgical bonding*

1. INTRODUCTION

Cold spraying, also referred to as kinetic spraying, represents a relatively the high-velocity acceleration of powder particles, typically in the 300–1200 m/s range, in a jet flow of supersonic velocity with the projection directed onto a substrate or a coating that has been pre-deposited at an absolutely solid state. Due to the impact at high velocity, intensive deformation of plastic manifests in the cold-sprayed particles or substrate, allowing the formation of a low oxidized cold-sprayed coating [1].It is interesting that cold spraying can also be used to deposited ceramic materials, although initially it appears impossible as cold spraying require plastic deformation to work. Previous studies have reported the possibility of cold spraying thick pure titanium dioxide, TiO_2 within range 300 μm [2] but the bonding mechanism of cold sprayed TiO_2 is not fully understood. Therefore, this study investigated the effect of annealed substrate properties of AA 1050 toward bonding mechanism of cold sprayed TiO_2.

2. METHODOLOGY

2.1 Materials

As a feedstock, we used agglomerated TiO_2 powder (WP0097, TAYCA Corporation, Tokyo, Japan) containing a pure anatase crystalline structure with an average particle size of about 7.55μm. Pure Aluminium (AA 1050) were used as the substrates. The substrates were first grit-blasted then annealed to four different temperatures (i.e. 100 °C, 200 °C, 300 °C and 400 °C, respectively) under atmospheric ambient. The substrate without annealing (room temperature substrate) were also used in this study.

2.2 Cold spray process

Cold spraying equipment with a De-Laval 24TC nozzle (CGT KINETIKS 4000; Cold Gas Technology, Ampfing, Germany) was utilized in all the coating experiments. Nitrogen was used as the process gas with a 500 °C operating temperature, and a 3 MPa pressure. The spray distance was 20 mm, with a process traverse speed of 10 mm/s.

2.3 Characterizations

In accordance with JIS H 8402, specimens measuring Ø25 mm × 10 mm were utilized to assess the coatings' adhesion strength, given as the fracture load value measured by a universal testing machine (Autograph AGS-J Series 10 kN, Shimadzu, Japan). An X-ray photoelectron spectroscopy (XPS: ULVAC-PHI, PHI Quantera SXM-CI,Japan) was used to measure chemical composition of the substrate oxides. In this study, XPS analysis using a monochromatic Al Kα source (15 mA, 10 kV) with narrow scans (0–1000 eV) of Al 2p and O1s for different annealed substrates were collected. The measured binding energies were then corrected with C 1s at 285.0 eV. The FEI Helios Dual Beam 650 field emission SEM (FESEM, FEI, Oregon, USA) and focused ion beam (FIB, FEI, Oregon, USA) microscope was used to investigate the single particle TiO_2 deposition on mirror polish annealed substrates.

3. RESULTS AND DISCUSSION

The adhesion strength of the cold-sprayed TiO_2 coating on annealed AA 1050 as shown in figure 1. The TiO_2 coating showed a decreased trend of adhesion strength from room temperature to 400 °C annealed, with values from 3.88 MPa to 2.05 MPa.

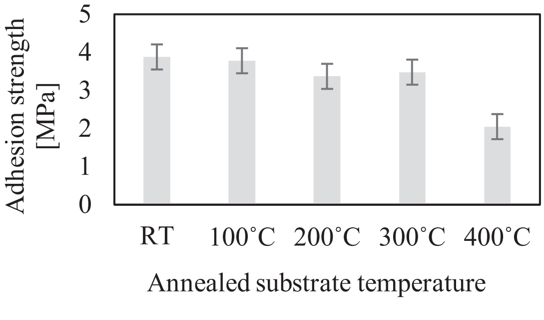

Figure 1 Adhesion strength of the TiO_2 coating on AA 1050 from room temperature to 400 °C annealed.

The results of the depth analysis of room temperature substrate and 400˚C annealed for AA 1050 substrates is shown accordingly in figure 2 (a) and (b). The composition as a function of depth can be analyzed by in-situ argon ion beam sputtering, found on most surface analytical equipment. Oxygen in deepest part also indicate increases from RT to 400˚C. This indicate that the oxide layer of AA 1050 grows thicker as the annealing substrate temperature is increased. The increasing of oxide film thickness, it will need more kinetic energy to break up and extrude the oxide film, thus a higher particle velocity is needed for bonding. In other words, the effective bonding area is decreased under the same particle impact conditions [3]. It could explain the decreasing trend of adhesion strength TiO_2 coating on annealed substrate of AA 1050 from room temperature to 400°C because the particle velocity was constant in all condition in this experiment.

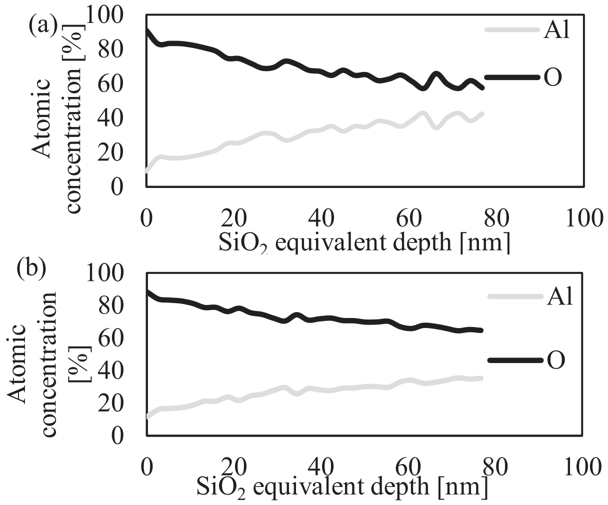

Figure 2 Depth profile analysis of AA 1050 (a) room temperature and (b) 400 °C annealed.

Figure 3 (a) and (b) shown FIB result of the cross-section images of the TiO_2 particle impacting on RT and 400˚C annealed AA 1050. Both undergo substrate deformation after been impacting by high velocity of cold sprayed TiO_2 particle as shown by red-dotted line in figure below 3. This indicates that substrate deformation is not the factors that influence the adhesion bonding of the 400˚C annealed AA 1050 with TiO_2 coating. The oxide film thickness had a strong effect on the deposition process because a thick oxide film inhibits formation of a new surface and oxide films full fills a role of deposition inhibitor for cold-sprayed CoNiCrAIY on the Inconel 625 substrate [4].

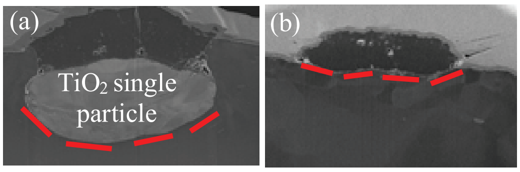

Figure 3 Cross-sectional view of TiO_2 single particle on AA 1050 (a) room temperature (b) 400 °C annealed.

Softer substrate like pure aluminium, AA 1050, large deformation of substrate even without annealing was observed by particles collision, indicating breakage of thinner oxide layer occurred on its surface. Bonding mechanism of sprayed TiO_2 onto pure AA 1050 may be metallurgical one [5], where atomic reaction occurred between TiO_2 particle and newly-formed pure AA 1050 appeared after breakage of thin oxide as shown by figure 4 below.

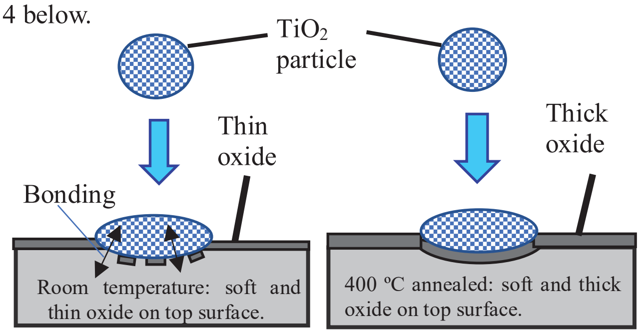

Figure 4 Schematic image of cold-sprayed TiO_2 deposition onto AA 1050 at (a) room temperature and (b) 400 °C annealed.

4. CONCLUSION

Oxide thickness play a role toward adhesion strength of TiO_2 coating on annealed AA 1050. Thicker oxide indicate more inactive area to form a bonding between TiO_2-AA1050 and contribute to decreasing of coating adhesion strength. The main bonding mechanism is metallurgical bonding which is newly form substrate surface of AA 1050 that oxide free to TiO_2 particle.

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