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Gas Shielding and Stand-off–distance Effects in Ti-6Al-4V Protective Coatings Deposited by Electric Arc Thermal Spraying for Aluminum Die Casting Molds

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Mold manufacturers continue to use tool steel for molding parts with molten metals, such as Al. However, even with significant advancements in heat-treatable tool steels and the innovative use of inserts, a debate remains between the material characteristics desired for mold-making, and those needed for molding performance. One problem related to tool grade steel molds for aluminum die casting is the formation of Fe-Al intermetallics. To prevent this, industrial ceramic coatings are often applied by spraying or brush painting before each molten metal injection cycle, which should provide a thermal barrier, reduce wear, and facilitate part removal [1]. However, the usefulness of these coatings is very short due to their poor adhesion associated with the application methods. An alternative is to use materials that intrinsically present higher resistance to mold degradation due to the formation of aluminum-based intermetallics such as Ni- or Ti-based alloys [2].

Ti-6Al-4V is an alloy that has an excellent combination of strength and toughness along with excellent corrosion resistance. Its uses include aerospace parts, pressure vessels, aircraft gas turbine disks, cases and compressor blades, and surgical implants, among other applications. In addition, electric arc spray occupies an important niche in thermal spray technology and is suitable for the rapid prototyping process. Since wires are directly melted by the arc, the thermal efficiency of the electric arc spray process is considerably higher than that of any other thermal spray process [3].

However, a disadvantage of the arc spraying process is the poor control of in-flight particle oxidation phenomena, which naturally affects the quality of the coatings. To avoid such problems, oxidation control atmospheres can be used by the use of gas shielding, e.g. with high purity nitrogen.

In this work, Ti-6Al-4V coatings have been produced by twin wire electric arc thermal spraying (TWAS) on H13 tool steel substrates using factorial designs of experiments (DoE) in which the effect of nitrogen as a shielding gas as well as other spray parameters was evaluated. Specifically, three process parameters were chosen in a first DoE, considered as a comparison reference in which no shielding gas was used: spray current I [100 - 180 A], robot speed V [0.5 - 1.5 m/s], and stand-off distance SOD [150 – 600 mm]. This set of experiments will be identified as “air sprayed” coatings. A second DoE was optimized considering the substrate temperature T [25 - 300 °C], N_2 primary gas pressure PG_N_2 [35 – 60 psi], and SOD [50 – 150 mm] and will be identified as “gas shielded” coatings. The analyzed output variables were porosity percentage, hardness, deposition efficiency, and oxidation percentage.

The rest of the results were analyzed using Minitab and the following conclusions were reached:

- The most influential input parameter was SOD, which affects the oxidation level, the porosity of the coatings, and their hardness. From the “air sprayed” coatings, decreasing the SOD and increasing the current leads to an increase in deposition efficiency. From the “gas shielded” coatings, a lower oxide content was in general obtained. Furthermore, lower porosity and higher hardness were observed at a shorter (50 mm) working distance (Fig. 1a).

- Porosity from “gas shielded” coatings sprayed at the lowest SOD (50 mm) drops to about 5%. The lower the SOD, the closer the spray gun is to the substrate; therefore, particles tend to be more compacted resulting in lesser porosities. Current also influence the decrease in porosities. Higher currents yield more molten material which can then recrystallize more uniformly. As a result, there is less porosity and a more uniform metallic coating.

- Hardness, on the other hand, increased at lower SOD values in “gas shielded” coatings. At 50 mm, where the coating appeared to have less porosity and a more uniform microstructure a maximum in hardness (1000-1200 HV0.3) was obtained. These values are clearly much higher than bulk Ti6Al4V alloys (365-370 HV0.3) [4].

Optimal characteristics in terms of phase purity, low porosity, and high hardness were obtained in “gas shielded” coatings using the following deposition parameters: spraying voltage 30 V, I 220 A, V 0.1 m/s, T 100 °C, PG_N_2 35 psi, N_2 gas pressure of 60 psi and 50 mm SOD. SEM analysis of the cross section shows a coating of multilayered microstructure (Fig. 1b) with two contrasting shades corresponding to the α and β phases of the alloy (Fig. 1c). Fig. 1d) shows a dendritic microstructure formed during the solidification of the coating layers.

The XRD pattern of the raw material confirmed the Ti-6Al-4V alloy and showed a preferential orientation (texture) in the (002) plane of the HCP structure of the alpha phase, which is probably due to the fabrication method of the wire. However, once the wire is melted by the electric arc and sprayed onto the substrate, the coating solidifies in the α-Ti phase, where the texture is naturally attenuated (Fig. 1e).

As discussed, higher SOD yields higher porosities, mostly due to the in-flight particles interacting with oxidizing agents, such as compressed air, which was used for the initial experiments. To eliminate these oxidizing agents that affect phase purity, porosity, and hardness, the “gas shielded coatings” were fabricated. The results after using only nitrogen as our propellant and shielding gas were favorable. The desired properties: high phase purity, low porosity, and high hardness, all improved in the “gas shielded coatings”.

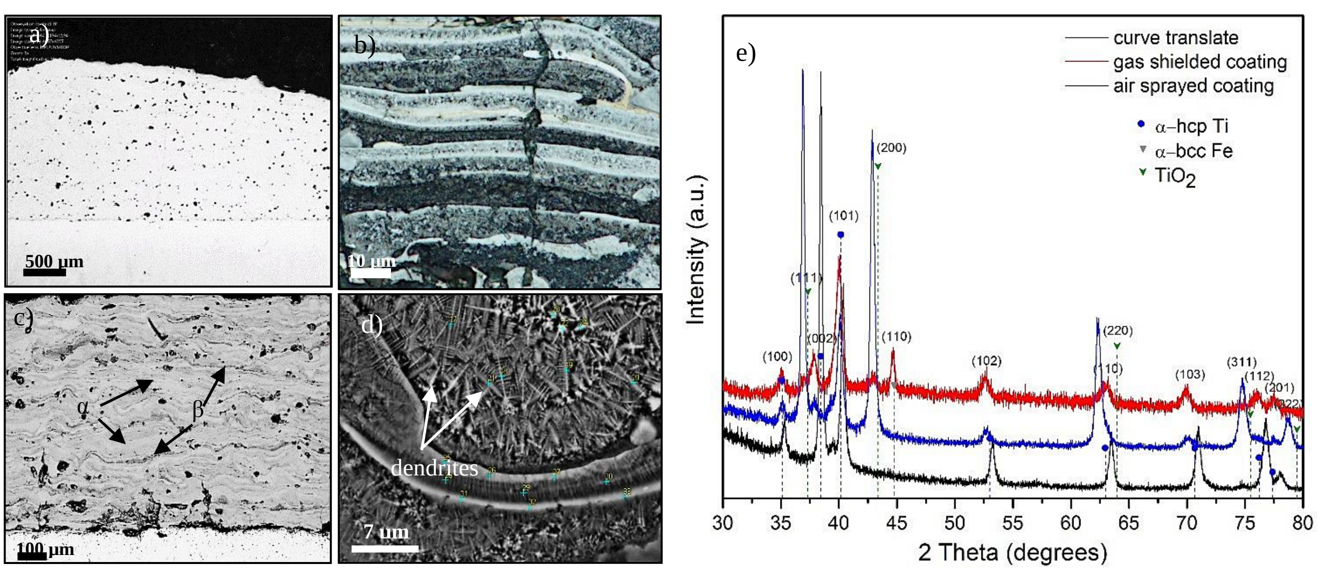

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Figure 1. Cross section of the “gas shielded” Ti-6Al-4V coatings. a) Optical micrograph of coatings processed at 300 °C, PG_N_2 60 psi, and SOD of 50 mm. b) Optical micrograph showing the multilayered microstructure of the “gas shielded” coating. c) Two contrasts corresponding to the alpha (light) and beta (dark) phases of the alloy are observed. d) Dendritic growth due to solidification processes from the melt. e) Finally, a comparison of α-hcp Ti-6Al-4V phase by X-ray diffraction of the wire and “air sprayed” and the optimized “gas-shielded” coatings is presented.

References:

[1] Peter, et al. “Study of protective coatings for aluminum die casting molds,” *Appl. Surf. Sci.*, vol. 358, pp. 563–571, 2015.

[2] Brizuela-Colmenares N, Muñoz-Saldaña J. “Ni-5wt% Al Coatings Deposited by Twin Wire Arc Spraying for Molten Aluminum Attack Protection”. *Therm Spray* 2021.

[3] J. R. Davis, *Handbook of Thermal Spray Technology*. ASM International, 2004.

[4] Tan AWY, Sun W, Bhowmik A, et al. “Effect of coating thickness on microstructure, mechanical properties and fracture behaviour of cold sprayed Ti6Al4V coatings on Ti6Al4V substrates”. *Surf Coatings Technol*. 2018.

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