Corrosion behaviour of Tribaloy T400 coating prepared by laser cladding in molten aluminium alloys

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Abstract. Corrosion of molten Aluminium alloys is an important reason to lead the failure of moulds. The Tribaloy T400 coating was prepared on H13 steel by laser cladding to investigate corrosion behaviour in molten A356 Aluminium alloys at 993 K for different periods. The main phases in the Tribaloy T400 coating were primary Co-rich FCC phase and Laves phase (Co7Mo6 and Co3Mo2Si). The Tribaloy T400 coating maintain its surface integrity after immersion in molten Aluminium alloy for 7d. The corrosion resistance was improved significantly compared to H13 steel substrate. The Vickers hardness of the coating was increased from 686 to 727 HV0.3, which could be attributed to the obvious aging hardening effect in Tribaloy T400 coating.

Keywords: Tribaloy T400; molten aluminium corrosion; laser cladding.

1. Introduction

AISI H13 steel is widely used to manufacture forging dies, hot extrusion dies, as well as die-casting moulds for Aluminium alloys due to high thermal strength, hardness and good thermal fatigue resistance [1, 2]. The failure of the moulds in the molten aluminium starts from the aggregation of FeAl intermetallic compounds in the surface [3]. Multi methods had been used to improve the corrosion resistance of molten aluminium [3-5]. The traditional and economical nitriding process fails to be used in the high-temperature molten aluminium for long time service [3]. The thin thickness of TiN, Ti/CrN films through physical vapor deposition (PVD) limited their widely applications [4]. The poor thermal shock resistance ability of high velocity oxygen fuel (HVOF) WC-Co coatings restricted its application under frequently thermal cycles [5].

The Tribaloy intermetallic materials were developed to resist wear under extreme conditions in high temperatures, such as nuclear reactors, power generators, jet engines and other fields [6]. The In the commonly used Stellite and Tribaloy alloys, Tribaloy T400 has high Molybdenum content, which could improve high temperature strength. It has been reported that Tribaloy T400 coatings could be successfully deposited on the surface of substrate through laser cladding with high adhesion, good mechanical properties and high density [7-9].

Tribaloy T400 was selected as the coating material in this research to improve the corrosion resistance of the substrate. Laser cladding was applied to fabricate coating on the surface. The primary aim of this research is to observe and analyze the long-term corrosion behavior of Tribaloy T400 coatings in molten aluminium alloys.

2. Experiments

2.1 Materials

AISI H13 steel bar with a diameter of 80mm and length of 300 mm was used as the substrate in this study with a chemical composition listed in Table 1. Commercial Tribaloy T400 powders were purchased from Höganäs (Wallenberg, The Netherlands) with particle size of 45-106 um.

Table 1. The chemical composition of AISI H13 steel and Tribaloy T400 powder (wt%).

	C	Si	Mn	Cr	Mo	V	Ni	Co	Fe
H13	0.38	0.1	0.4	5	1.4	1	-	-	Bal.
Tribaloy T400	-	2.8	-	9.7	29.5	-	0.5	57.5	0.5

2.2 Fabrication of Tribaloy T400 coating

The H13 steel bar was mechanically ground with 400# SiC sandpaper, then was wiped with ethanol to remove pollutants before laser cladding. The feeding Tribaloy T400 powders were dried at 80 ℃ for 24 hours in a vacuum oven. The substrate was preheated to 523 K before laser cladding. A Sulzer Metco Twin-10C powder feeder with an off-axial nozzle was used to blow powder into the processing area. The laser cladding was operated with a 4kW continuous semiconductor laser in an argon atmosphere. Laser power was set 1.8kW with the working distance from the optics was 613 mm. The overlapping rate was 50%, and the diameter of defocus spot was 5mm.

2.3 Characterization of the coating

Samples for characterization were prepared according to standard metallographic process. The microstructure of the coating was observed by optical microscopy (OM, Leica DM4, Germany) and scanning electron microscopy (SEM, Thermo scientific Apreo 2S, US) equipped with EDS detector (Oxford Instrument, UK). The phase compositions were analysed with X-ray diffraction (XRD, Bruker D8) using Cu-K α radiation (λ =1.54 Å, 30 kV/40 mA).

Microhardness of the coating with different status was measured on polished cross sections using a micro-indenter (Hengyi MH-500D, Shanghai). Vickers hardness was measured by applying a load of 300 g, with dwelling time of 15 seconds. 10 indentations were tested on each sample.

2.4 Corrosion test of molten aluminium

A365 alloy was used for the molten aluminium corrosion tests, and the chemical composition was listed in Table 2. The cladded rod was cut to small pieces with a size of 12×6×8mm using a wire electro-discharge machine before the immersion. All samples were ultrasonic cleaned with ethanol and distilled water for 300s, respectively. The solid A356 aluminium alloy was placed in the alumina crucible and then heated to melt in muffle furnace. As shown in Figure 1, samples were immersed in molten aluminium (T=993K) for 1d, 3d and 7d and then cooled in air to room temperature. Samples with aluminium was cut perpendicularly for cross-sectional metallography.

Table 2. The chemical composition of A356 alloy (wt%)

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
A356	6.95	0.2	0.2	0.1	0.31	0.1	0.2	Bal.

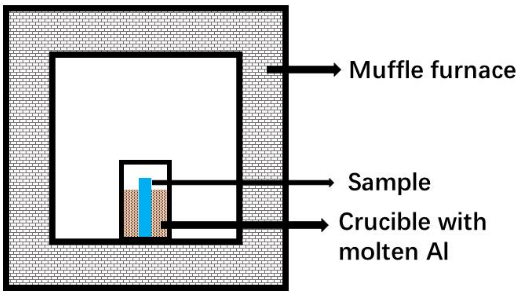

Figure 1 Schematic image of coating in molten Aluminium.

3. Results and Discussion

3.1 XRD analysis of the coating

The XRD pattern of Tribaloy T400 coating was presented as Figure 2. The strongest diffraction peaks was detected in the 2theta range 40°to 60°. The main phases in the coating were Co-rich FCC phase (JCPDS 15-806) and Laves phase (Co7Mo6 and Co3Mo2Si). The microstructure of the coating was presented as Figure 3. The Tribaloy T400 coating contained the primary white phase and eutectic phases. EDX was used to clarify the chemical compositions of the different phases (Table 3). The dark and eutectic phases contained higher Co-Rich solid solutions compared with the white phase [7]. It is obviously that the white phases consisted Co, Mo and Cr, which can be reasonably to conclude that the primary phase was the Laves phase. The peak for Co3Mo2Si intermetallic Laves phase was also identified in XRD pattern.

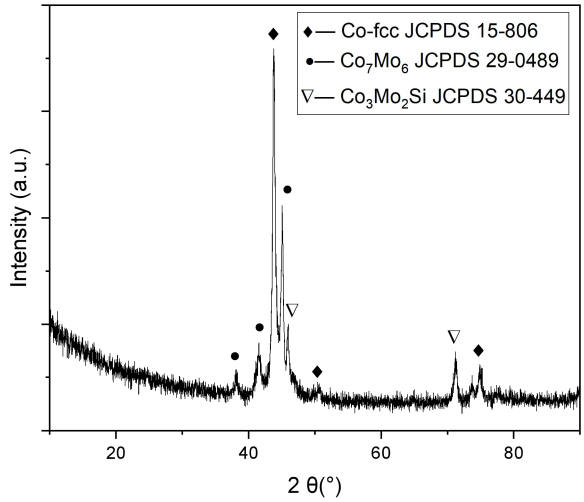

Figure 2 XRD pattern of Tribaloy T400 coating.

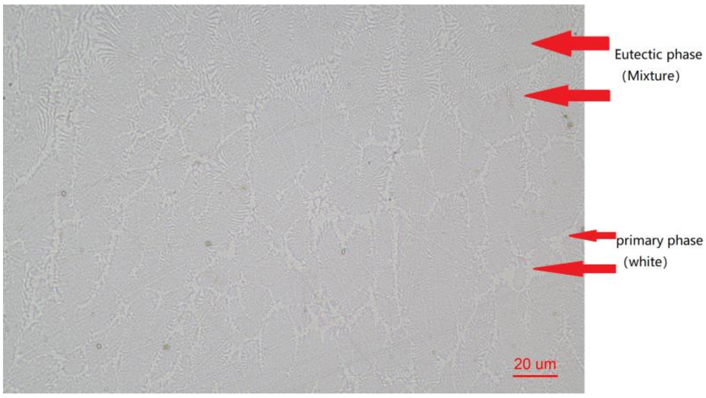

Figure 3 Metallography of Tribaloy T400 by SEM.

Table 3. EDS result for different phases (wt%)

Phase	Si	Cr	Co	Mo
Primary phase	3.92	6.95	45.78	43.35
Eutectic phase	0.6	14.21	72.8	12.39

3.2 Corrosion behaviour of the coating to molten aluminium

The overall corrosion morphologies of Tribaloy T400 coating after different corrosion time was presented as Figure 4. The loss of coating size was obviously less than the substrate in all 3 samples. Thus, Tribaloy T400 coating illustrated significantly improvement in resistance to molten aluminium from 1d to 7d.

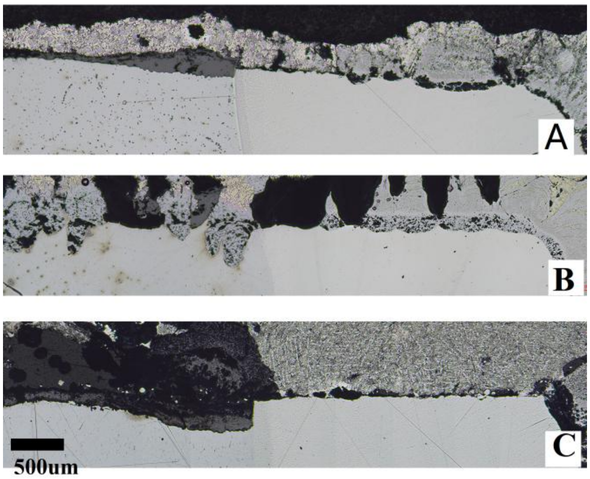

Figure 4 Overall morphology of Tribaloy T400 coating after corrosion for (A) 1d, (B) 3d and (C) 7d. The left parts of images were H13 substrates and right parts were Tribaloy T400 coatings.

The microstructure of H13 steel and Tribaloy T400 coating after corrosion for 7 days were presented in Figure 5. Figure 5 (A) illustrated the corrosion pits on the surface of H13 alloy due to aluminium attack. Multi FeAl intermetallic compounds could be also observed after long time corrosion of molten Aluminium [2]. To contrast, the surface of Tribaloy T400 coating remained intact even after 7 days corrosion.

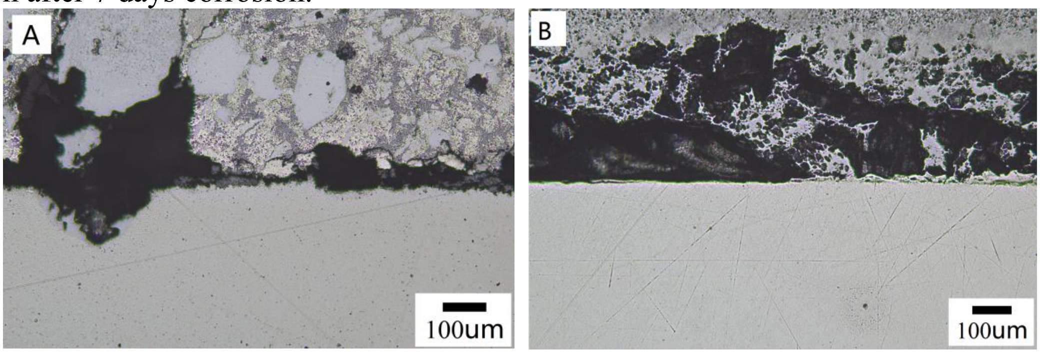

Figure 5 Microstructure of H13 (A) and Tribaloy T400 (B) after corrosion for 7d in molten Al.

Figure 6 presented the interface between Tribaloy T400 coating and Al after corrosion for 7d, and the EDS analysis result was also presented. It could be seen clearly that the concentration of Al dropped sharply in the interface, which means the diffusion of Al element was hindered due to the integrity of Co coating interface [9]. It was worth mention that there were small peaks which represented Molybdenum in the Al matrix, which suggested that the primary phase contained higher Mo elements was might have weaker corrosion resistance ability than laves phases.

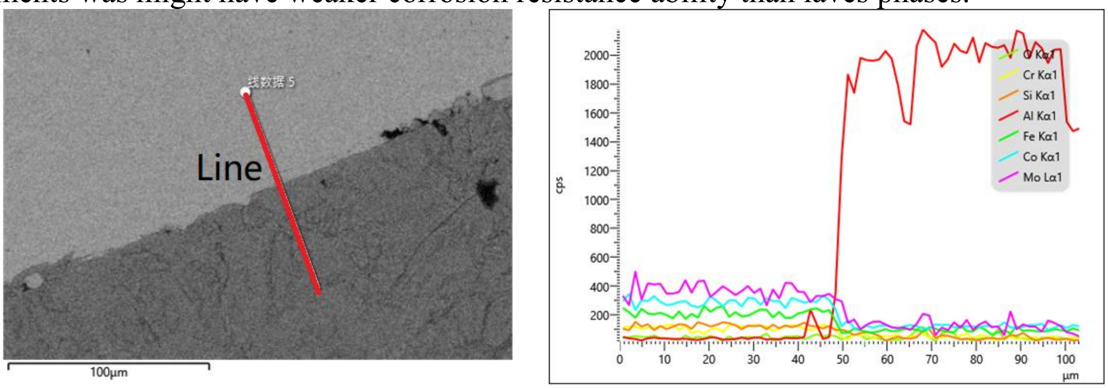

Figure 6 Interface of Tribaloy T400 coating and Al analysed by EDS line scan.

3.3 Vickers hardness of the coating

The Vickers hardness of the coating was measured about 300 um below the surface to avoid the influence of Aluminium corrosion. The data was shown in Figure 4. It can be seen that the hardness increased from 686 to 711 HV0.3 after corrosion by molten aluminium for 1 day, and then further increased to 727 HV0.3 after 3d. The hardness had no significant increase after 7 days corrosion at 998K. Aging heat treatment was carried out for the interior coating in the bath of molten aluminium for long time. The Vickers hardness increases significantly with aging time. The possible reason for this increase might that the Mo and Si diffuse from the primary phase to secondary laves phase in the aging process. The coating gained and maintained higher Vickers hardness after homogenization compared with coating before aging [8].

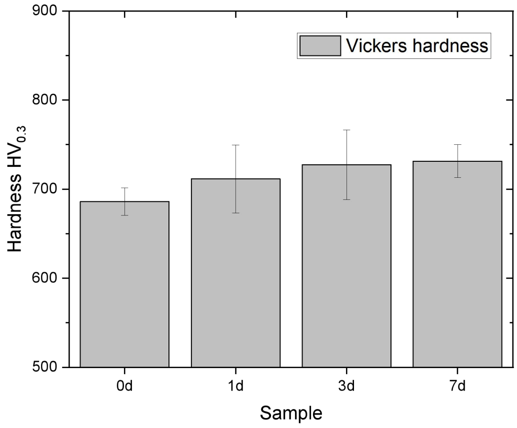

Figure 7 Vickers hardness of the Tribaloy T400 coatings after aging.

4. Conclusion

In this study, Tribaloy T400 coating was successfully deposited on the surface of H13 steel substrate with metallurgical bonding. The coating consisted Co-rich FCC phase and Laves phase (Co7Mo6 and Co3Mo2Si). H13 steel was corroded severely in the molten Al alloy. Tribaloy T400 coating illustrated superior corrosion resistance to molten Aluminium alloy. The surface of the coating was still intact and dense after molten Al corrosion for 7d. Mo-rich Laves phase might be corroded preferably due to slightly higher concentration of Mo than Co was observed Al matrix after solidification, which further and more investigation were still needed. A significant aging hardening effect was observed in the coating. The Vickers hardness of internal coating was increased 6% after 3 days heat treatment in molten Aluminium bath.

Acknowledgments

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