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CORROSION RESISTANCE OF LASER-INTERFERENCE STRUCTURED ALUMINUM ALLOY 2024 COATED WITH MIL-PRF-85582 PRIMER

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ABSTRACT

The use of aluminum alloys in aerospace industry requires more effective and reliable joining techniques. The lubricant contaminants from prior rolling operations affect surface energies and the quality of coating adhesion and adhesive bonded joints. In this study, a new laser-based technique is investigated as a surface treatment for coating applications. The laser interference power profile was created by splitting the beam and guiding both beams towards the specimen and overlapping them on the specimen surface, creating a line-interference pattern on the specimen surface. The laser-interference structuring (LIS) is a much simpler surface preparation process as it can be employed without any chemical treatments, such as those in chemical conversion coating (CCC) and sulfuric acid anodizing (SAA). To assess the effect of LIS on the corrosion resistance of coating, Al 2024 panels prepared by LIS, CCC and SAA were coated with MIL-PRF-85582, Type I, Class N primer and exposed to salt spray environment according to ASTM B117. The exposure is currently in progress and the corrosion attack on the coated panels will be evaluated by the degree of blister formation and rust creepage.

INTRODUCTION

Pre-retreatment of Al2024 alloy surfaces is an essential step for the adequate adhesion of primer layer and corrosion resistance of the entire coating system. Chemical conversion coating (CCC) and sulfuric acid anodizing (SAA) are well-established pre-treatments for Al alloys and are widely used for initial application or repair of coatings (*1-9*). However, increasing concern on health and environmental hazards of CCC and SAA exists because these pre-treatments use toxic chemicals, such as Cd and hexavalent Cr, which increase the costs associated with safety and waste disposal. Therefore, non-chemical surface preparation techniques would be preferred. The sole use of mechanical surface preparation techniques, such as abrasion and grit blast, may leave abrasive particles and other contaminants which should be avoided for primer adhesion. Thus, mechanical-based surface preparation techniques offer sometimes inferior performance than those chemically based surface preparation techniques, which may include as an intermediate step the surface roughening through mechanical-based techniques. Recently, an increase in the shear lap strength for single-lap joints made with laser-interference surface preparation of Al and carbon-fiber polymer composites was reported (*10*). This increase was likely to be due to the periodic roughening resulting from the laser-interference structuring (*11*) and micro-alloying (12) that was recently reported for laser-interference structured Al5128 alloy.

Recently, the laser-interference structuring (LIS) technique, which utilizes the interference power profile of two separate laser beams originating from the same main laser beam, was successfully applied to modify Al surface. As a step to assess the use of LIS for field applications, the corrosion performance of coated Al panels with LIS needs be determined. While the corrosion data of coated Al2024 with CCC and SAA pretreatments was investigated previously (*1-9*), coated Al with LIS has not been tested in corrosive environment. To investigate the effect of pretreatments on the corrosion performance of coated Al, Al2024 test panels, prepared by CCC, SAA or LIS pretreatment and coated with MIL-PRF-85582 primer, were exposed to salt spray for up to 500h and then visually inspected to assess corrosion damage. The purpose of this study is to evaluate if the LIS surface treatment for MIL-PRF-85582 primer would exhibit corrosion performance at least as good as those surfaces prepared with the current state-of-the art CCC and SAA processes.

EXPERIMENTAL

In this study, surfaces of aluminum alloy Al 2024-T3 were treated using a Q-switched Nd:YAG laser that was setup for laser-interference (*10, 11, 13-15*). LIS-treated Al2024 panels were held on a LabView-moving platform controlled by two translational stages. Thus, the laser beam was rastered over the surface of Al2024 panels. The rastering speed of the laser was 6 mm/s and the laser beam size was 5 mm. After laser-structuring, the 2x3" panels were held in plastic cases to minimize surface contamination. The panels were held in plastic cases for several weeks. Prior to the actual coating, no additional cleaning and/or wiping was performed.

CCC and SAA pre-treatments on Al2024 were conducted by a company. A commercial conversion coating solution with hexa-chromate was used to achieve CCC. The size of Al panel used was 2" × 3" and the thickness was approximately 1 mm. After completing pre-treatment on Al panels, MIL-PRF-85582 primer was painted using a spray gun according to the instructions provided by the primer supplier. The painted panels were then held in a lab at room temperature for 24h and subsequently cured in a ventilated oven at 60°C for 24h. After finishing the 60°C curing, the coating thickness was measured using a commercial thickness meter. The thickness ranged from 22 to 34 μm (0.9-1.2 mil). The cured coating was then X-scribed using a box cutter, and the edges of the scribed panels were covered with beeswax. The scribes were made such that they fully penetrated the coating and exposed the Al surface underneath. These test panels were exposed to salt spray according to ASTM B117 procedure with an exception – to prepare the 5 wt% salt solution, tap water was used instead due to limited access to deionized water. The chemical analysis of the tap water is shown in Table 1. The test panels experienced several intermittent dry interruptions due to a scheduled power outage and malfunction of the salt spray chamber. Thus, the final chamber time was increased to account for these unexpected short dry exposures to reach a salt-spray exposure of 500h.

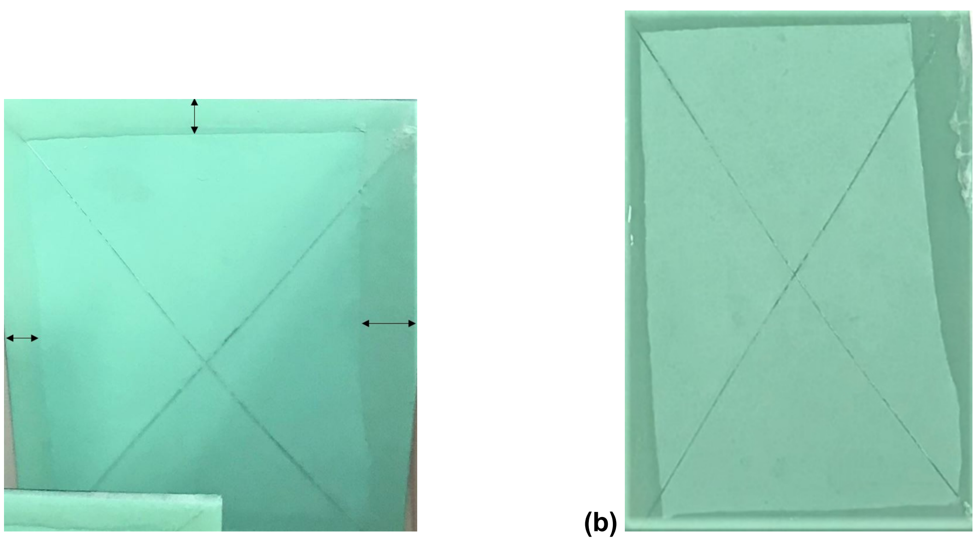
RESULT AND DISCUSSION

Pictures of a CCC-treated test panel after 208h and 500h salt spray exposure are shown in Figure 1, where no visible corrosion attack was observed. Similarly, a SAA-treated test panel did not show any corrosion attack after 208 and 500h exposure as shown in Figure 2. These results indicate that CCC and SAA pre-treatment with MIL-PRF-85582 primer is highly resistant to corrosion within the test duration used here (500h). However, a LIS-treated test panel after 500h salt spray exposure, shown in Figure 3 exhibited blisters in regions near the scribe line, blisters away from the scribe lines, and white corrosion product on the upper-left scribe. This corrosion susceptibility of the LIS-treated test panel could be attributed to the absence of a corrosion inhibitor that exists in CCC and the Al_2O_3 barrier layer formed by SAA. As unprotected Al surface was exposed along the scribes in LIS-treated test panels, it can be more susceptible to corrosion and blister formation near the scribe lines. Meanwhile, blisters that formed on sound coating areas cannot be attributed to the exposing of the Al substrate by the scribe lines. A possible explanation for this could be the presence of weak spots in the coating or surface contamination where chloride and water can easily permeate to the substrate or other surface contamination. In order to assess the variation in coating thickness for possible association of thin-coated or thick-coated areas with blister damage, the coating thickness was measured in areas without any corrosion damage and areas near the blister damage. The results for the coating thickness are shown in Table 2 for the SAA specimen (Figure 2) and the LIS specimen (Figure 3). The coating thickness measurements indicate that the coating thickness is quite uniform, aside from one measurement in the SAA specimen, in corrosion-free areas and areas prone to blister damage. The uniformity in the coating thickness could be controlled by optimizing the painting process. Ongoing surface chemistry analysis may be used to understand the formation of the blisters for the LIS specimens. Surface contamination could be reduced by considering a simple solvent wiping prior to the coating application. Moreover, specimens coated with the full coat system, including the top coat, are considered for corrosion evaluation.

Table 1. Chemical analysis of the tap water used to prepare the NaCl solution.

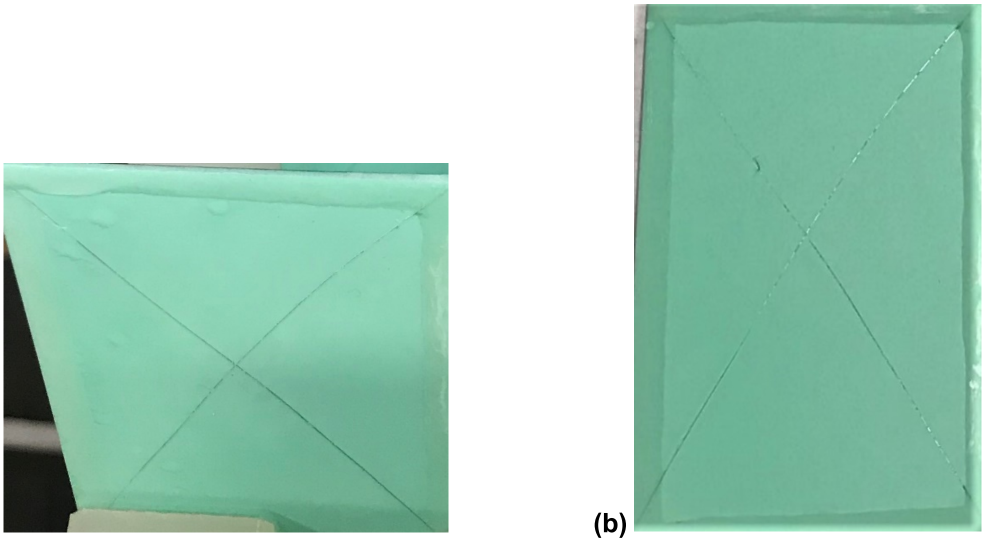
Property	Values
pH	7.93
Conductivity, µmho	267
Chemical Species	**Concentration [mg/L]**
Calcium Hardness, as $CaCO_3$	79
Iron, as Fe	0.06
Copper, as Cu	0.01
Zinc, as Zn	0.03
Sodium, as Na	5.8
Potassium, as K	1.6
Chloride, as Cl	8.6
Sulfate, as SO_4	16
Nitrate, as NO_3	2.4
Phosphate, as PO_4	<0.1
Silica, as SiO_2	5.6

The growth and formation of blisters on a LIS-treated test panel is shown in Figure 4 with increasing time of salt spray exposure. After 24h, a visible blister was noticed near the scribe on upper-right side (Fig. 4a). While this initial blister did not grow significantly at 96h exposure, three newly-formed blisters, one near the lower-left scribe and two on an area in the left-half of panel away from the scribe line, were observed (Fig. 4b). At 208h exposure, no additional blisters were found, and the size of blisters did not increase except for one blister that was on the scribe-free coating area (Fig. 4c). This result suggests that Al2024 with LIS + MIL-PRF-85582 primer is susceptible to blister formation and growth not only on damaged areas but also on seemingly-sound areas of the coating. Based on this preliminary analysis, other laser-structuring parameters and additional solvent wiping after laser-structuring are being considered to decrease the susceptibility to blister formation for MIL-PRF-85582 primer coating.



(a) (b)

Figure 1. Pictures of 2" × 3" test panels with CCC pre-treatment after: (a) 208h and (b) 500h of salt-spray exposure. The two-way arrows indicate the edge area covered with beeswax. The test panel in (a) was wet while the test panel in (b) was water-rinsed and dried.



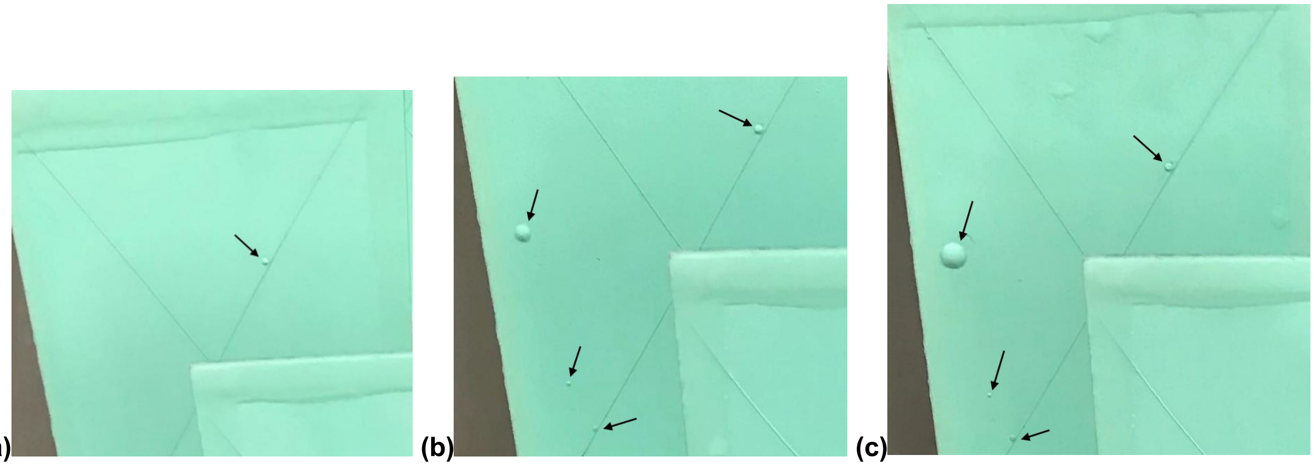
(a) (b)

Figure 2. Pictures of 2” × 3” the same test panel with SAA pre-treatment after: (a) 208h and (b) 500h of salt-spray exposure. The test panel in (a) was wet while the test panel in (b) was water-rinsed and dried.

Figure 3. Pictures of a 2” × 3” test panel with LIS pre-treatment after 500h salt spray exposure.

Table 2. Coating thickness [um] in corrosion-free areas and near blister corrosion damage areas.

					Average	**Area type**
SAA (Fig. 2)	28	25	23.5	40	*30*	*corrosion-free*
	30	26.5	22	28.5	*27*	*near corrosion damage*
LIS (Fig. 3)	17	19	18	14	17	*corrosion-free*
	17	16.5	18	17	17	*near corrosion damage*



(a) (b) (c)

Figure 4. Pictures of the same 2" × 3" test panel with LIS pre-treatment after (a) 24h, (b) 96h and (c) 208h salt spray exposure. The arrows indicate the location of visible blisters.

CONCLUSION

The corrosion performance of Al2024-T3 panels treated with CCC, SAA and laser-interference and then coated with MIL-PRF-85582 was compared using salt spray exposure for up to 500h. CCC- and SAA-treated test panels exhibited no apparent damage after 500h exposures, while LIS-treated panels exhibited blister formation and corrosion along the scribe after only 24 h of exposure. The susceptibility to blister formation is likely associated with the unprotected Al substrate and possible weak spots of coated primer that could enable easier permeation of corrosive species. To mitigate the blister damage in LIS specimens, additional cleaning steps and/or testing with the entire coating system, which include the top-coat, are being considered. Additional solvent wiping, which was not used in the current study, after the laser-structuring step and right before coating application may decrease the susceptibility to blister formation with the MIL-PRF-85582 primer coating.

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