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Evaluation of the Effects of Powder Coating Cure Temperatures on the Mechanical Properties of Aluminum Alloy Substrates

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The effects of curing temperature, based on new, low-temperature powder coating methods and traditional high-temperature powder coating methods, were studied. Heat-sensitive aluminum alloys (2024-T3, 6061-T6, and 7075-T6) were subjected to two different heat-treatment cycles, which were based on temperatures of 121 and 204 °C. Findings indicate that although both cure temperatures achieved powder coatings adhesion and thickness appropriate for industrial uses, the high-temperature cure treatment negatively affected the mechanical properties.

Keywords age hardenable aluminum alloys, degradation of mechanical properties, low-temperature cure powder (LTCP), solvent-borne paints

1. Introduction

Powder coatings are considered for replacing conventional solvent-borne paints in more applications as the performance of the powders is enhanced and as environmental restrictions become greater. Powder coatings are zero emission coatings that are durable and fulfill the performance requirements for most NAVAIR equipment (Ref 1, 2). The curing step is critical for the powder coating. Currently, a new powder coating process has been developed to apply coatings to heat-sensitive alloys at a considerably low curing temperature, 120 °C. Accordingly, typical cure temperatures range from 121 to 230 °C with a cure time of up to 30 min once parts reach temperature. When a part is cured and cooled to room temperature, it can continue to be processed or assembled. Powder coatings are an environmentally preferred option for the application of corrosion protective coatings. The production and maintenance facilities that apply coatings are the ones under pressure from environmental regulators to reduce their output of volatile and hazardous air pollutants; hence, they are likely to apply powder coatings to as much of their production as possible. The consequences of the loss of temper to the aluminum substrate due to heating during the powder coating cure process should be studied. Loss of temper, and the resulting loss of strength, of the components will have a negative effect on part performance, and strength is reduced below design requirements (Ref 2).

The aluminum alloy samples used for this study were 2024-T3, 6061-T6, and 7075-T6. Each of these aluminum alloys is widely used by the Navy, Marine Corps, Army, Air Force, and the commercial sector. These heat-sensitive alloys are used for, but not limited to, tow tractors, portable generators, and air conditioners that cool the cockpits of aircraft (Ref 2).

This article illustrates how much strength can be lost in the substrates even using newer coating technologies designed to do just that—protect the strength of the substrate. There are undoubtedly susceptible parts processed with the higher cure temperatures that are at risk for failure.

In this study, the objective was to perform the following:

1. Analyze the properties of each of the alloys with low-temperature cure powder (LTCP) at 121 °C for 30 min. Also, the properties of conventional powder coatings cured at 204 °C for 12 min and the properties of the uncoated substrate base metal will be analyzed.
2. Compare the effects of heating the aluminum alloys in a pre-heated furnace versus placing them in a room temperature furnace containing alloys that are gradually heated with the furnace to the desired temperature.
3. Study the effect of 1, 3, and 5 cycles of low (121 °C/30 min) and high (204 °C/12 min) temperature heat treatments on the mechanical and electrical properties of the three alloys.
4. Examine the interface between coating and substrate of alloys coated with LTCP and conventional powder.

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2. Feasibility Study on the 6061-T6 Alloy

Prior to fixing the limits of the LTCP and conventional powder temperatures, a feasibility study was carried out on the

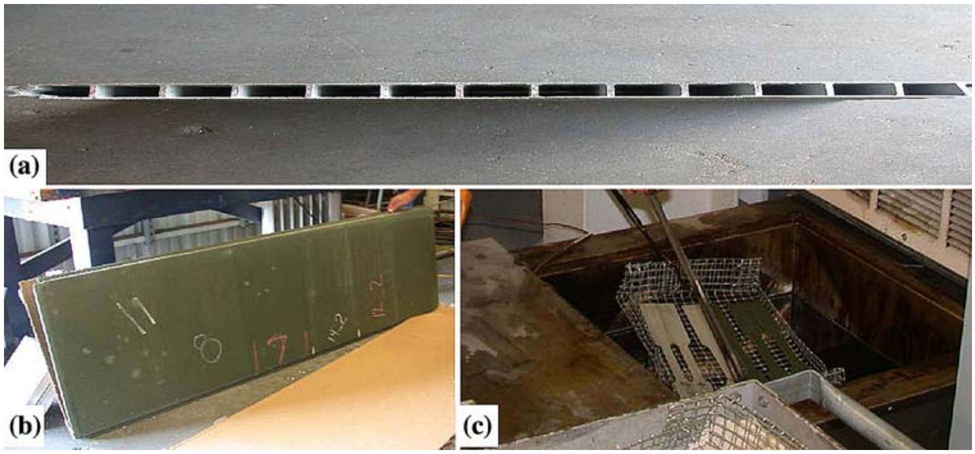

Fig. 1 (a) Cross-sectional view of Marine Corp AM2 mat, (b) as-received landing mat, and (c) tensile samples being removed from oil bath

weakest alloy (6061-T6) as compared to the 2024-T3 and 7075-T6. The purpose of this study was to generate a family of curves that would highlight the change or degradation of mechanical properties for the range of powder coating cure temperatures.

Two used AM2, Al 6061-T6, aircraft landing mats were supplied by the NAVY at Lakehurst, NJ. The mats are hollow extrusions with a top and bottom surface supported by stiffeners. Bars were cut from the provided panels, Fig. 1(a) and (b). These bars were then milled into tensile samples, Fig. 1(c). Samples were cut from the top and bottom surface between the stiffeners. The as-received mats included a green solvent-borne paint, Fig. 1(b), conventional coatings on the top and bottom surfaces. Samples were thermally exposed to a test matrix temperatures/times in an oil bath (Fig. 1c). Following immersion in the oil bath, samples were air-cooled at room temperature and cleaned in an alcohol bath. The coatings were then removed using a sanding belt.

Samples were machined from the top and the bottom of the panels for testing. Electrical conductivity measurements were preformed using Auto Sigma 3000 conductivity tester. The mechanical tensile properties were evaluated by using an Instron 4505 universal testing machine. The thermal processing test matrix is shown in Table 1. It covers the times and temperatures of interest for conventional cure powder coatings as well as the temperature range of interest for developmental low temperature, cure powder coatings (Ref 1, 2).

The as-received mats had different properties: a reduction of 16-20% in ultimate strength, a reduction of 18-20% in yield strength, and an increase of ~20% in conductivity (Table 2) as compared to the reference data, of 290 MPa (42 ksi), 241 MPa (35 ksi), and 30% IACS (Ref 3, 4). The reason for the reduction of properties is that the provided mats had been exposed to heavy Air Force and Navy transport aircraft since the mid-sixties in the Vietnam War (Ref 2). The mats used in this study were randomly selected.

Samples subjected to temperatures from 120 to 210 °C had values of ultimate strength and yield strength similar to the as-received specimens of 6061-T6 aluminum. At 210 °C at 30 min, the yield and ultimate strengths were slightly lower than the as-received values. At temperatures above 210 °C, degradation in the mechanical properties of the alloy was observed at time durations of 15 min or longer. The results for the increase in conductivity and decrease in tensile properties at the 230 °C heat treatment are shown in Fig. 2(a)-(c). The top surface exposed to the stress and exhaust gases display lower strength as compared to the bottom surface.

It is reasonable to cure powder coatings on the 6061 aluminum alloy with temperatures ranging from 120 to 210 °C and at any time frame less than or equal to 30 min, without degradation to the mechanical properties of the alloy. Accordingly in this study, the LTCP and conventional powder methods had the limits of 120 and 204 °C.

Table 1 Thermal processing of 6061 AM2 mats

	Time, min					
Temperature, °C	5	10	15	20	25	30
120					X	X
150		X	X	X	X	X
160		X	X	X	X	X
170		X	X	X	X	X
180	X	X	X	X	X	X
190	X	X	X	X	X	X
200	X	X	X	X	X	X
210	X	X	X	X	X	X
220	X	X	X	X	X	X
230	X	X	X	X	X	X

Table 2 Average data for as-received 6061

	Ultimate, MPa (ksi)	Yield, MPa (ksi)	Conductivity, %IACS
Top	246.7 (35.8)	221.2 (32.1)	47.5
Bottom	259.1 (37.6)	228.8 (33.2)	47.7

Note: Each data point is an average obtained for six samples tested

3. Materials, Processing, and Testing

The chemical compositions for the three aluminum allows are shown in Table 3 (Ref 3). Sheets of the three aluminum alloys—2024-T3, 6061-T6, and 7075-T6—were marked and

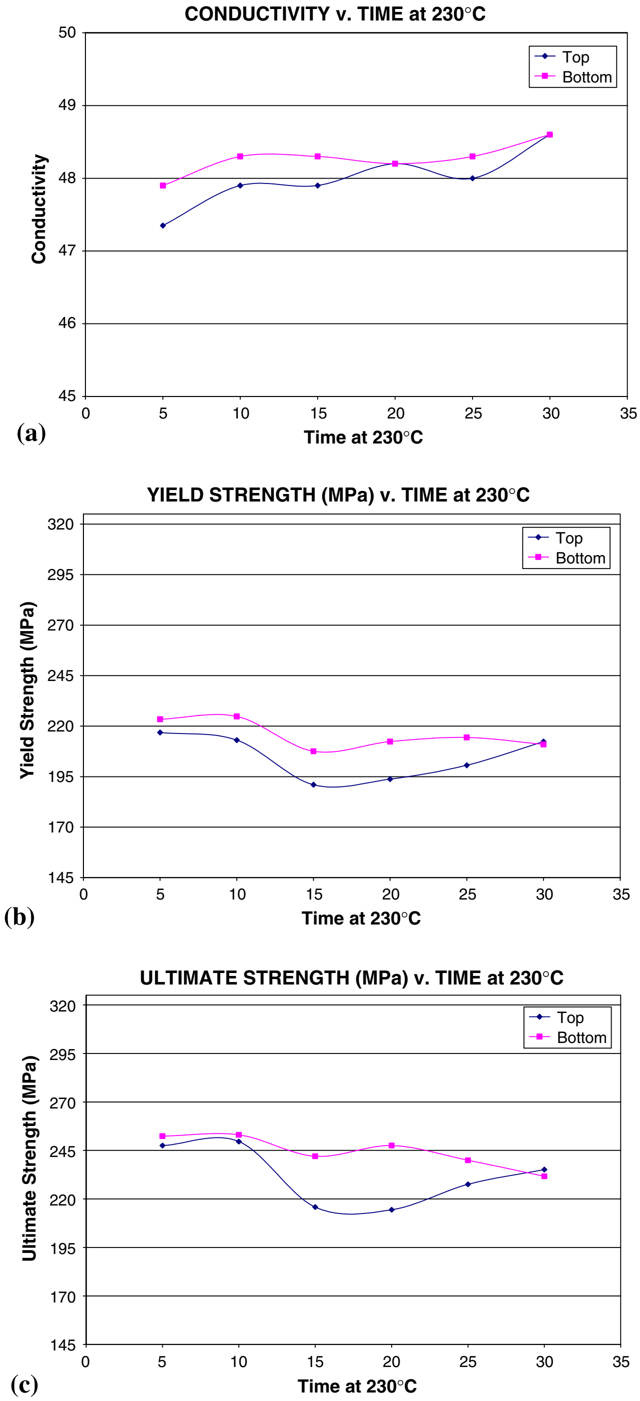

Fig. 2 (a) Conductivity (%IACS), (b) yield strength, and (c) ultimate strength for 6061 aluminum at 230 °C (time in minutes)

Table 3 Nominal chemical composition of alloys 2024-T3, 6061-T6, and 7075-T6 (Ref 2, 3)

Aluminum alloy	Alloying elements (typical percentages)
2024-T3	4.5 Cu, 1.5 Mg, 0.6 Mn
6061-T6	1 Mg, 0.6 Si, 0.25 Cu, 0.25 Cr
7075-T6	5.5 Zn, 2.5 Mg, 1.5 Cu, 0.3 Cr

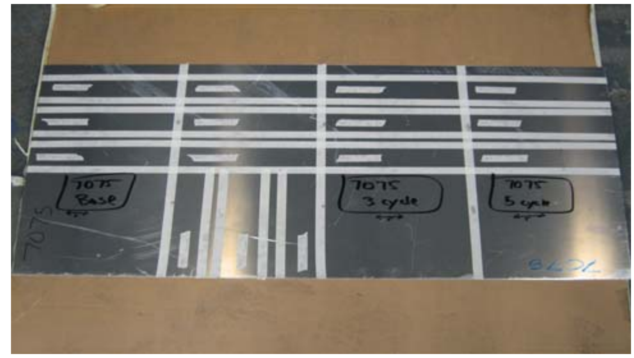

Fig. 3 Marked rectangular samples on uncoated sheet

sheared into 30×60 cm (1′×2′) sections and sprayed using a Corona gun with electrostatically charged powder coatings. Two of the coated sections of each alloy were then cured in the conventional fashion at 204 °C for 12 min. Two other coated sections were cured using the low-temperature method at 121 °C for 30 min (LTCP). These coated panels were received for testing.

A 60×120 cm uncoated section of each alloy was received and used in baseline property testing and for multiple exposure tests (objectives 2 and 3). Each of the uncoated samples was then cut into small rectangles (Fig. 3) and identified as one of the following cycles for each type of aluminum alloy: 1 cycle, 3 cycles, and 5 cycles for both the low-temperature and high-temperature heat treatments (Fig. 4).

The uncoated samples were heat treated at 121 °C for 30 min or 204 °C for 12 min for the different cycles.

Samples of each alloy were heat treated at 121 °C on a ceramic plate with thermocouples embedded under each sample. The samples were placed in an unheated oven and then heated with the oven until the alloys had reached 121 °C. The alloys were then baked for 30 min (Process A). Other samples were placed in a pre-heated furnace in the same arrangement on a ceramic plate as previously described. When the temperature of the alloy reached 121 °C, they were timed for 30 min and removed (Process B). All sets of samples were air-cooled. Samples of each alloy were also subjected to the same procedure outlined above but at 204 °C with a 12-min time bake period. Process A indicates that the sample is placed in the furnace at room temperature and experiences a gradual rise in temperature until the target 121 and 204 °C temperatures are reached. Process B, on the other hand, indicates that the sample is placed in the oven already maintained at the target temperature.

The high- and low-temperature cycles were repeated with sets of three samples for both 3 and 5 cycles for processes A and B.

The coated samples were not subjected to heat-treatment tests, as they were already heat treated by the manufacturer during the powder coating process. Conductivity was tested using a Hocking AutoSigma 3000 electrical conductivity tester. Hardness measurements were determined by using the Rockwell B scale. Tensile testing was performed using an Instron 4505 machine.

4. Results and Discussion

4.1 As-Received Alloys: Comparison Properties

A summary of the standard minimum mechanical and electrical properties of the three alloys is shown in Table 4, AMS-QQ-A-250 [4]. A summary of the mechanical and electrical properties of the uncoated as-received alloys, low-temperature cure coated alloys, and the high-temperature cure alloys is shown in Table 5-7 respectively.

For the 2024-T3, the uncoated and LTCP materials exceeded the standard for yield strength by 14 and 10%, respectively, while the material subjected to the conventional (high temperature) powder coating was identical to the standard. Tensile strength exceeded the standard value by 11% for the uncoated alloy, and approximately 7% for the coated material. Hardness, for the as-received material in the coated and uncoated states, was between 4 and 7% higher than the standard AMS value. The conductivity measurements for the as-received alloys were all within 3% of the standard. The

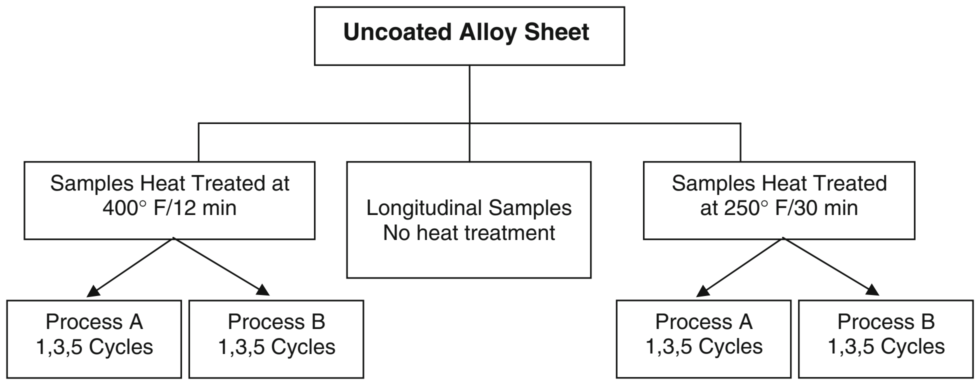

Fig. 4 Organization of uncoated samples for all three alloys heat treating and testing

Table 4 Summary of mechanical and electrical properties of alloys 2024-T3, 6061-T6, and 7075-T6 (Ref 4)

	Hardness, HRB	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Conductivity, %IACS	Percent elongation
2024-T3	70	434 (63)	290 (42)	30	15
6061-T6	55	290 (42)	241 (35)	43	10
7075-T6	81	538 (78)	469 (68)	33	8

Table 5 Summary of properties of as-received, uncoated material alloys 2024-T3, 6061-T6, and 7075-T6

	Hardness, HRB	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Conductivity, %IACS	Percent elongation
2024-T3	75	483 (70)	331 (48)	31	20
6061-T6	54	331 (48)	239 (34)	42	18
7075-T6	89	572 (83)	448 (65)	32	16

Table 6 Summary of properties of as-received, coated material alloys 2024-T3, 6061-T6, and 7075-T6 subjected to low-temperature cure

	Hardness, HRB	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Conductivity, %IACS	Percent elongation
2024-T3	75	469 (68)	317 (46)	31	20
6061-T6	54	331 (48)	255 (37)	41	18
7075-T6	89	572 (83)	503 (73)	31	15

Table 7 Summary of properties of as-received, coated material alloys 2024-T3, 6061-T6, and 7075-T6 subjected to high-temperature cure

	Hardness, HRB	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Conductivity, %IACS	Percent elongation
2024-T3	73	462 (67)	290 (42)	31	21
6061-T6	55	324 (77)	262 (38)	42	16
7075-T6	87	531 (77)	469 (68)	35	14

percent elongation for the as-received materials was approximately 33% higher than the standard AMS value regardless of the as-received condition (Table 4–7).

For the 6061-T6, the uncoated material was below the standard AMS yield strength value by less than 2%. Both the LTCP and conventionally coated materials exceeded the standard for yield strength by 6 and 9%, respectively. Hardness values for the as-received materials in all the states for 6061-T6 were within 2% of the standard AMS value. The properties of the material subjected to the traditional (high temperature) powder coating were equal to the standard AMS value for hardness. The conductivity measurements for the as-received alloys were all lower than the standard accepted values, though all were within 3%. The percent elongation for the as-received materials was higher than the standard AMS value regardless of the as-received condition. The percent elongation of the uncoated material and the LTCP condition material were 1.8 times the standard AMS value and the material subjected to the conventional (high temperature) powder cure was 1.6 times the standard AMS value (Table 4–7).

For the 7075-T6, the yield strength of the as-received uncoated material was below the standard AMS value by approximately 5%. The LTCP material exceeded the standard value by 7%. The as-received, conventionally (high temperature) coated materials had a yield strength value equal to that of the standard. Hardness values for the as-received materials in the uncoated and LTCP states for 7075 T-6 were 10% higher than the standard AMS value. The mechanical properties of the material subjected to the traditional (high temperature) powder coating were higher than the standard AMS value, but within 3%. The conductivity measurement for the as-received, uncoated alloy was 3% lower than the standard AMS value. The LTCP material showed a value 6% lower than the standard AMS value. The conventionally (high temperature) coated material had a conductivity 13% higher than the standard accepted value. The percent elongation for the as-received materials was higher than the standard AMS value regardless of the as-received condition. The value for percent elongation of the uncoated material was twice the standard AMS value and the LTCP condition material was 1.9 times the standard AMS value. The percent elongation of the material subjected to the conventional (high temperature) powder cure was 1.8 times the standard AMS value (Table 4–7).

4.2 Pre-Heated Furnace Versus Gradually Heated Furnace Effects

Pre-heated furnace versus gradually heated furnace effects on the resulting mechanical and electrical properties of the three alloys were similar. Distinctions were not made between samples treated in the pre-heated ovens versus those treated by heating simultaneously with the ovens, since they differed by less than 4%, Table 8. The results for the 6061-T6 alloy are shown as an example of the level of similarity in the mechanical and electrical properties between the A and B heat-treatment methods.

4.3 Effect of Heat-Treatment Cycles

For the 2024 T-3, the as-received uncoated samples showed a slight decrease in yield strength for the 1 cycle low-temperature heat treatments (approximately 1%). The 3 cycle heat treatment resulted in a reduction of 7% from the as-received yield strength. The 5 cycle low-temperature treatment had an increase over the 3 cycle treatment, but it was still 2% below the as-received value. The high-temperature heat treatment showed a 16% decrease after 1 cycle, but the 3 and 5 cycle treatments gave results higher than the as-received material by 6 and 20%. Overall, all samples except the 1 cycle high-temperature treatment met or exceeded the minimum specifications (Fig. 5 and 6). The ultimate strength for each of the samples of 2024-T3 was consistently within 3% of the as-received material. The ultimate strength obtained from each of the samples was above the standard AMS value regardless of the heat treatment applied (Fig. 7 and 8). Hardness was constant for the uncoated samples that were treated for 1 cycle at the low temperature. It decreased slightly with subsequent heat treatments at the low temperature (2% for 3 cycles and 5% for 5 cycles) and increased moderately (approximately 4%) after 3 cycles at the high temperature (Fig. 9 and 10). Hardness values were above the standard AMS minimum values for both temperature treatments. The 2024-T3 was the only substrate to increase hardness (Fig. 10) during the high-temperature heat treatment. It should be noted that the yield strength, ultimate strength, and hardness values all increased, which is probably due to age hardening of the material which is in the T3 temper (Ref 5). The conductivity for the 2024-T3 alloy in the as-received samples exceeded the maximum standard level of 30% IACS. The material subjected to the low-temperature heat treatment showed a differential of less than 1% from the as-received value. The material subjected to the high-temperature heat treatment demonstrated an increase in conductivity from 5% above the as-received level for 1 cycle, up to 29% above the as-received level for 5 cycles. After all heat treatments at both the high and low temperatures, the conductivity was above the standard AMS value (Fig. 11 and 12). Percent elongation for 2024-T3 increased by 1% for the 3 cycle low-temperature heat treatment, then fell to 4% below the as-received level. For high-temperature heat treatment, there was an initial increase of 2% above the as-received value for percent elongation for the 1 cycle heat treatment. The 3 and 5 cycle heat treatments showed a dramatic decrease (5 and 9%

Table 8 Properties of alloy 6061-T6 for pre-heated versus concurrent oven heating

Number of cycles	Oven heating method	Hardness, HRB	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Conductivity, %ACS	Percent elongation
1	Pre-heated	55	331 (48)	276 (40)	44	19
	Concurrent	54	331 (48)	269 (39)	44	18
3	Pre-heated	54	324 (47)	276 (40)	44	17
	Concurrent	53	331 (48)	269 (39)	44	17
5	Pre-heated	52	324 (47)	276 (40)	45	17
	Concurrent	54	324 (47)	269 (39)	45	17

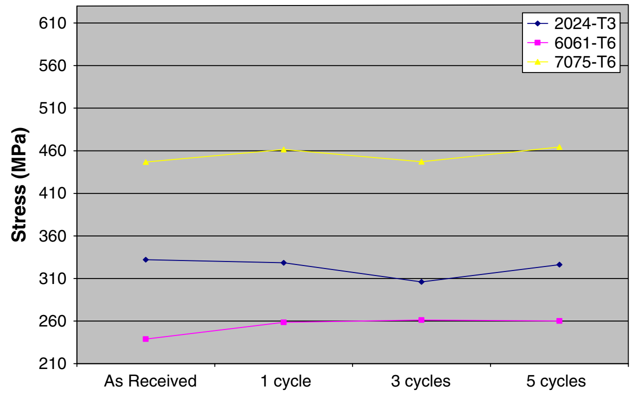

Fig. 5 Yield strength for all alloys after low heat treatments, at 120 °C

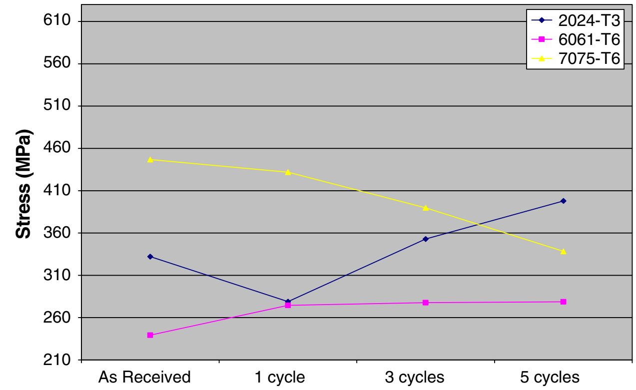

Fig. 6 Yield strength for all alloys after high heat treatments, at 205 °C

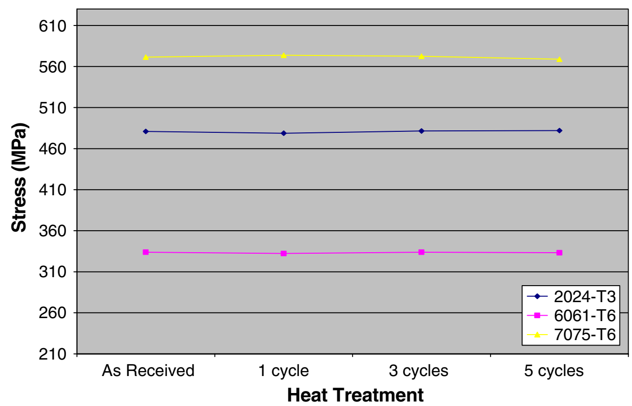

Fig. 7 Ultimate strength for all alloys after high heat treatments, at 120 °C

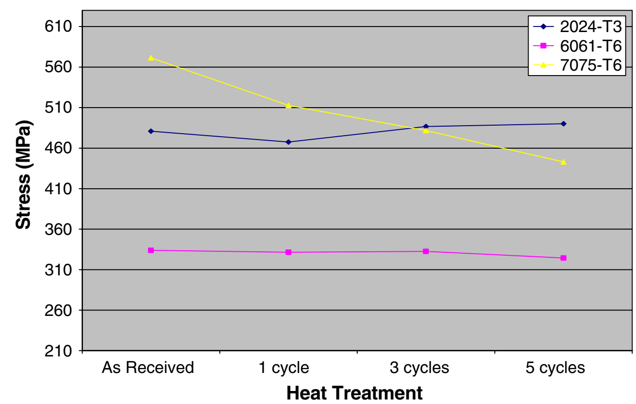

Fig. 8 Ultimate strength for all alloys after high heat treatments, at 205 °C

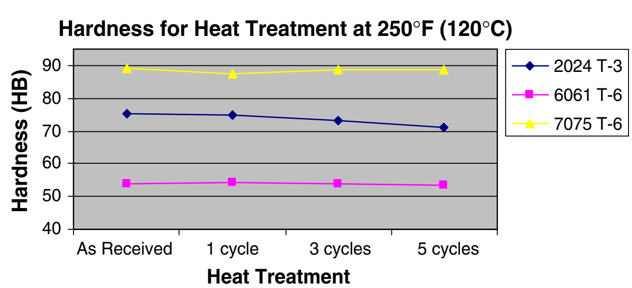

Fig. 9 Hardness for all alloys after low heat treatments

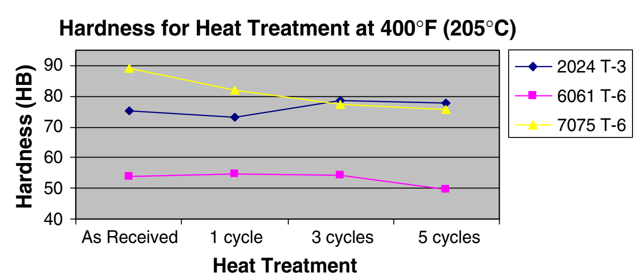

Fig. 10 Hardness for all alloys after high heat treatments

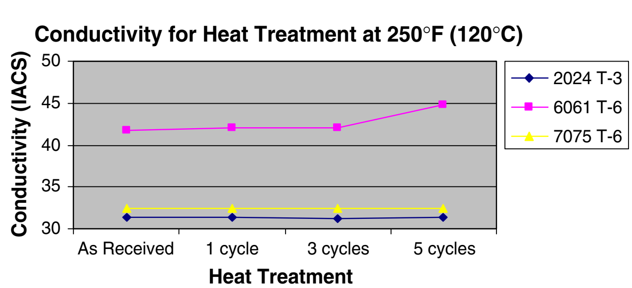

Fig. 11 Conductivity for all alloys after low heat treatments

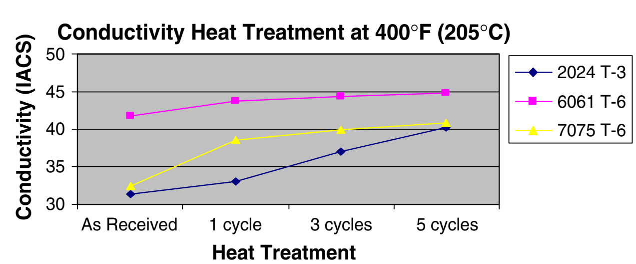

Fig. 12 Conductivity for all alloys after high heat treatments

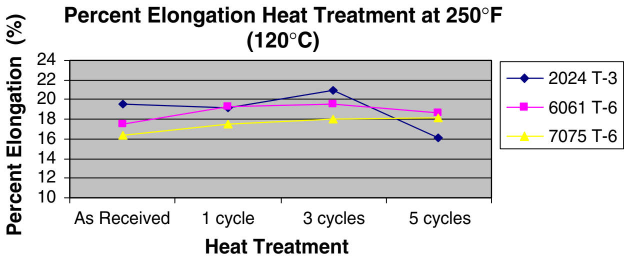

Fig. 13 Percent elongation for all alloys after low heat treatments

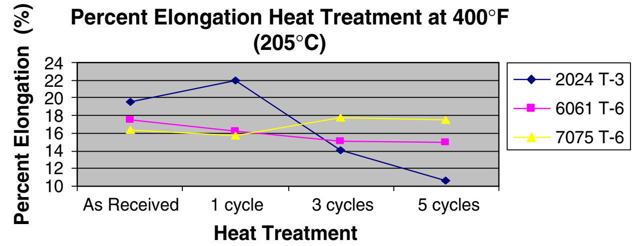

Fig. 14 Percent elongation for all alloys after high heat treatments

respectively). The 2024-T3 was the only substrate to experience a significant decrease in percent elongation such that the values fell below the standard AMS value (Fig. 13 and 14).

The yield strength value for the as-received (uncoated) samples for 6061-T6 was below the acceptable standard AMS value of 241.2 MPa (35 ksi) for this alloy (Fig. 5 and 6). For the temperature treatments of 6061-T6, there was very little change in yield strength, less than 7 MPa (<1 ksi), but the treatment did bring the value above the standard AMS values. Similar results were obtained at the higher temperature (Fig. 6). Testing of the 6061-T6 alloy after low-temperature treatments indicated very little change in ultimate strength, less than 7 MPa (<1 ksi) (Fig. 5). The ultimate strength for 6061-T6 decreased minimally at 5 cycles of high heat (Fig. 8). Ultimate strengths were above the minimum standard AMS specifications for both treatment cycles. Hardness values of the as-received samples (both coated and uncoated) exceeded standard hardness values. Testing of the 6061-T6 alloy after low-temperature treatments indicated very little change in hardness (<1 HRB) (Fig. 9).

A similar trend was present for the 1 and 3 cycle high-temperature treatments, but after 5 cycles at the high temperature the hardness of the uncoated samples of 6061-T6 fell below the minimum standard AMS value of 55 HRB (Fig. 10). Conductivity of the 6061-T6 samples increased after 5 cycles of low-temperature heat treatments (up 7% from the as-received value) and showed a mild increase as the number of high-temperature heat treatments increased (from 4% for 1 cycle to 7% at 5 cycles). Conductivity exceeded the standard AMS value of 43% IACS after 5 cycles of the low-temperature treatment and for all cycles of high-temperature heat treatments (Fig. 12). Testing of the 6061-T6 alloy after low-temperature treatments indicated very little change in elongation (<1%), where results of high-temperature testing indicated a higher drop (approximately 3%) (Fig. 13 and 14). The drop in percent elongation, hardness, and ultimate strength values are consistent with slight overaging.

For 7075-T6, as with 6061-T6, the yield strength of the as-received, uncoated samples did not meet the standard AMS value. Treating with high temperatures decreased the yield strength significantly for the 3 (13%) and 5 cycle treatments (24%) (Fig. 6). There was no decrease in yield strength for the low-temperature treatments (Fig. 5).

Ultimate strength did not decrease significantly with heat treatments during the low-temperature cure (<1%) (Fig. 7), but the ultimate strength was compromised and fell below the standard AMS value at the high-temperature heat treatments (Fig. 8). Hardness did not decrease significantly (<2%) with curing treatment at the low temperature (Fig. 9). The hardness was compromised most prevalently after numerous high-temperature heat treatments, where it fell below the minimum standard AMS value after both 3 and 5 cycles (Fig. 10). Samples subjected to low-temperature treatments during the experimental process were within 1% of the conductivity standards (Fig. 11). Like the as-received coated samples, which had been subjected to a previous high-temperature cure, the uncoated samples, which were subjected to the high-temperature cure during experimentation, exceeded the conductivity standards for 7075-T6 by up to 8% (Fig. 12). Percent elongation of all as-received samples exceeded the 8% standard AMS value. Elongation increased from 16% to about 18% for both low and high heat treatments for the 7075-T6 (Fig. 13 and 14). Similar to the 6061-T6 alloy, the drop in strength and hardness indicates overaging since both alloys were in the T-6 temper.

4.4 The Interface Between Coating and Substrate of Alloys Coated with LTCP and Conventional Powder

In examining the microstructure of the coated samples, all were found to have uniform adhesion of the powder coating. The thickness of the coating on each substrate varied, with the 7075-T6 coating at approximately 150 μm and the 6061-T6 coating at approximately 200 μm for both conventional and low-temperature cures as illustrated in Fig. 15.

Thickness of the powder coating on the 2024-T3 substrate varied from 100 μm for the sample cured using the experimental low temperature to approximately 300 μm for the sample prepared using the traditional cure process (Fig. 16).

Closer examination with the naked eye and the metallurgical microscope showed a variation of thickness on each side of each sample. This may have been caused by a difference in temperature when the coating was applied or the wattage used in operating the corona gun. A uniform adhesion of the powder coating was observed for all three alloys.

5. Conclusions

1. The mechanical and electrical properties of 2024-T3, 6061-T6, and 7075-T6 were within the acceptable standard AMS values for both low-temperature cure and high-temperature cure as-received coated plates.
2. For the uncoated samples heated in a pre-heated furnace versus a non-preheated furnace, the mechanical and electrical properties were similar (<4% difference) for all three alloys.

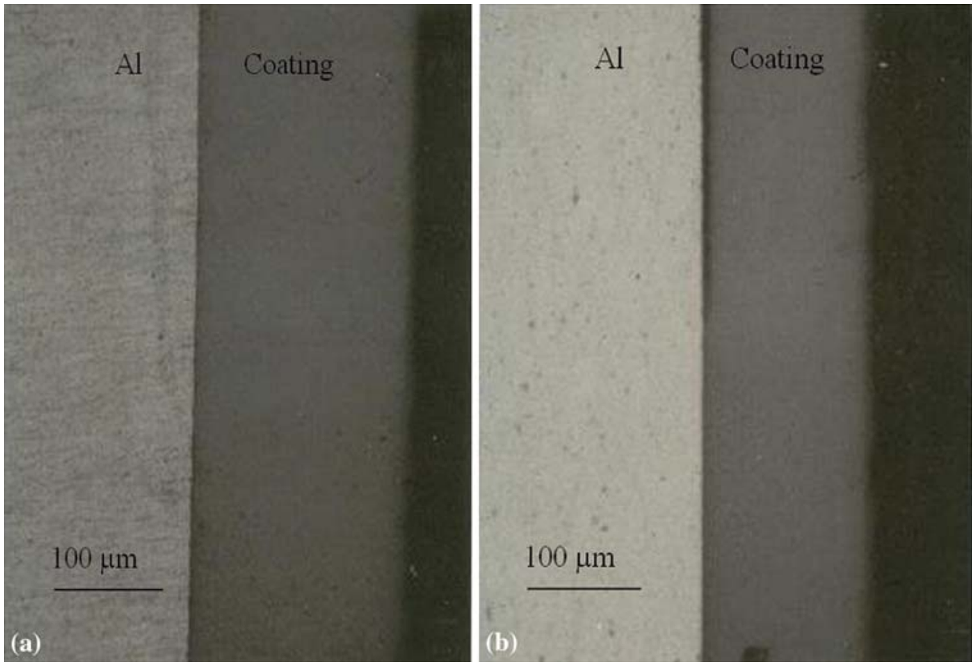

Fig. 15 Coating thickness of 7075-T6 and 6061-T6: (a) 6061-T6, high-temperature cure, and (b) 7075-T6, high-temperature cure

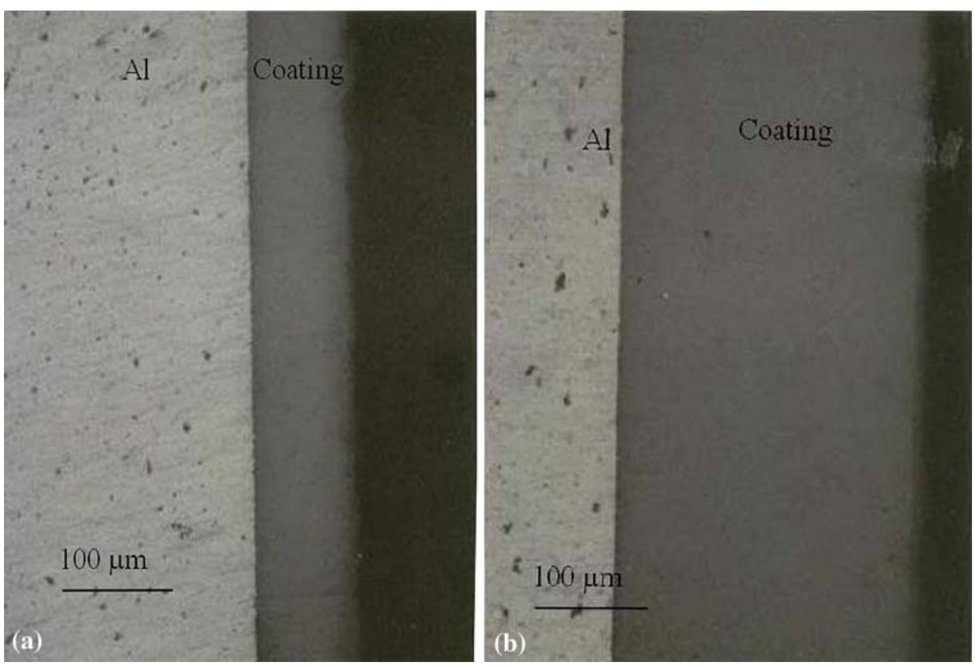

Fig. 16 Varied coating thicknesses of 2024-T3: (a) low-temperature cure and (b) high-temperature cure

3. The effect of 1, 3, and 5 cycles of low-temperature (121 °C for 30 min) heat treatment was almost negligible on the mechanical and electrical properties of 6061-T6, 2024-T3, and 7075-T6 alloys.
4. The effect of 1, 3, and 5 cycles of high temperature 204 °C for 12 min was significant: 6061-T6 and 7075-T6 showed overaging trends (7075-T6 showed more pronounced overaging) while 2024-T3 showed age hardening trends.
5. The interface between coating and substrate of alloys coated with LTCP and conventional powder was found to have uniform adhesion of the powder coating for all samples, regardless of the alloy.

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References

1. G. Merfeld, *120 °C Cure, Durable, Corrosion Protection Powder Coatings for Temperature Sensitive Substrates*, General Electric Global Research, 2005
2. Program Progress Report #6 For Phase I Option, *Advanced Nonskid Coating System*, Unpublished, 2006
3. Metals Handbook Eighth Edition, vol. 1. *Properties and Selection of Metals*, American Society for Metals, Ohio, 1977, p 865
4. AMS-QQ-A-250, *Aerospace Material Specifications*, SAE, Warrendale, PA, 1998
5. E.W. Lee and T. Oppenheim, et al., The Effect of Thermal Exposure on the Electrical Conductivity and Static Mechanical Behavior of Several Age Hardenable Aluminum Alloys, *Eng. Fail. Anal. J.*, 2007, **14**, p 1538–1549