

**A Corrosion Analysis
of
Aluminum Alloys and Coatings**

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An analysis of aluminum alloys and coatings to determine a reasonable resolution to aluminum die cast corrosion that is also cost efficient and environmentally friendly.

Abstract

As worldwide trade increases, a wide variety of aluminum castings and coatings have been introduced into the lighting industry. Often, inexpensive products have been installed with less than acceptable corrosion results. In response, some agencies/governments are trying to regulate the type of aluminum alloy that can be used. This type of alloy is generally extremely low in copper, and as such is much more resistant to corrosion than the more traditional alloys used. The low copper aluminum alloy standard most often referenced is the LM6 classification of the BS 1490 standard. Unfortunately, this type of alloy is often more expensive, more difficult to cast or machine, and may not provide the same structural strength (too ductile) as other available alloys. The premise of this paper is to show that it is not as advantageous to regulate the use of a specific alloy to control corrosion, as it is to regulate that the combination of alloy and coating meet specified corrosion test requirements. Therefore, this paper reviews the results of a 5,000 hour salt fog test performed on common die cast alloys that range in copper content, with various coatings applied. Based on this study, it is concluded that aluminum alloys with a higher copper content than what is permitted by LM6, can show a far superior corrosion resistance when the proper coatings are employed. These alloys also provide the greater structural integrity and tensile strength needed for many lighting applications.

Section 1: Introduction

Context of the paper.

In this paper, we are reviewing corrosion resistant attributes of three different aluminum alloys with two different coatings applied. A specific reference will be made to the LM6 classification of the BS 1490 standard concerning aluminum alloys with less than .1% copper. All six of the Alloy/Coating combinations were subjected to 5,000 hours of salt fog testing by an independent A2LA accredited lab that specializes in metals evaluations. The salt fog testing was performed in compliance with the ASTM B 117 standard, and the corrosion creep measurements were done in compliance with Procedure A of the ASTM D 1654 standard. ASTM B 117 defines the Standard Practice for Operating Salt Spray (Fog) Apparatus, and ASTM D 1654 defines the Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments. There were 15 samples for each of the 6 Alloy/Coating combinations, resulting in a total of 90 samples. The test surface for each of the round samples was approximately 7cm in diameter, and each sample had a single 5cm straight scribe line cut down the center. The average creepage from the scribe line of the 15 samples for each grouping was used to track the corrosion test results.

Problem Definition.

All aluminum alloys contain some copper. Alloys with what is considered a high degree of copper content (3-4%) have experienced an unacceptable rate of corrosion, especially in environments with a higher than average salt content. The proposal to resolve the unacceptable rate of corrosion is to limit aluminum alloys to those containing .1% of copper or less.

Limitations to the proposed solution.

Requiring a copper content of .1% or less in aluminum alloys disregards other solutions that may provide equivalent, or even better results. A simple decree of this sort does not take into consideration the additional costs and functional restrictions that are being forced upon the manufacturer. Structural integrity for weight bearing parts may also be jeopardized, with potentially less safe products as a result.

Goal of the paper.

It is the intent of this paper to provide significant evidence to challenge the simplistic .1% maximum copper content for aluminum alloys. This does not mean that .1% maximum copper content is not appropriate for use, but it should not be the absolute requirement to meet. Requirements need to be defined based on results. It is better to decree that aluminum alloys meet a specific corrosion standard than a specific copper content. To that effect, this paper will introduce the results of a 5,000 hour salt fog test so comparisons can be made between alloys with differing copper content and differing coatings applied.

Outline of the paper.

This paper is organized as follows:

Section 1: Introduction

Section 2: Test Preparations

Section 3: Test Results

Section 4: Conclusions

Section 5: Pictures

Section 2: Test Preparations

Sample Determinations

Historically, the typical lighting manufacturer using aluminum castings, uses a 380 alloy due to its ease of casting, structural qualities, and cost advantages. This would be coupled with a five-stage cleaning/preparation process that normally consists of two cleaning stages, two rinses and an iron phosphate conversion coating. A baked on powder paint would then be applied for color and protection from the environment. This industry standard process is represented by sample category A1.

A1: A = 380 alloy with 3-4% copper

The same cleaning/conversion process and top coat was applied on two additional sample alloys:

B1: B = 360.2 alloy with less than .1% copper

C1: C = 413 alloy with .3-.4% copper

Test sample B1 meets the basic LM6 requirement of less than .1% copper, and as such will be used as reference when determining results.

For examples A2, B2 and C2, the conversion coating was changed from an iron phosphate, to an organic chromium-free surface treatment, and an epoxy base coat was added to the standard process above. The powder paint top coat is applied on top of the epoxy base coat. This process complies with the DeltaGuard™ coating system.

Sample Preparations

All cleaning and conversion coating was performed by the Henkel Corporation at their Madison Heights, Michigan facility. The Henkel Cleaning solution used for all x1 and x2 samples was Parco Cleaner 2039. The conversion coating applied for all x1 samples was Henkel B 1070. The conversion coating applied for all x2 samples was Henkel chromium-free Alodine 5200. **NOTE: In order to eliminate hazardous wastes and meet RoHS requirements, no chromium conversion coatings were applied to any of the samples.**

All samples had PPG Polyester Bronze Powder Paint (PCT 29101) applied by Delta Finishing. Delta Finishing also performed the Cathode Epoxy base coat applications for the x2 samples using PPG CF590-534 Epoxy Paint.

Test Preparations

Anderson Laboratories, Inc. of Greendale, Wisconsin, an independent A2LA accredited lab, prepared all of the coated samples for testing. All 90 samples had a single straight scribe line cut down the center as per Procedure A of ASTM D 1654. The scribe penetrated all organic coating layers on the samples, and was performed under low power magnification to verify its quality. The 90 samples were then installed in a salt fog chamber meeting ASTM B 117 requirements.

Following ASTM Standard D 1654, the test samples would be rated based on the corrosion creepage emanating from the scribe - Procedure A, and on prevalence of corrosion on areas removed from the scribe - Procedure B. (See table 1 below.) A Zero rating for Procedure A would mean that the corrosion creep from the scribe line measured greater than 16 millimeters. A Zero rating for Procedure B would mean that over 75% of the test sample has experienced corrosion or loss of paint/coating.

Table 1:

Creepage from Scribe in Millimeters (Procedure A)	Percent Area Failed (Procedure B)	Rating #
Zero	No Failure	10
Over 0 to 0.5	0 to 1	9
Over 0.5 to 1.0	2 to 3	8
Over 1.0 to 2.0	4 to 6	7
Over 2.0 to 3.0	7 to 10	6
Over 3.0 to 5.0	11 to 20	5
Over 5.0 to 7.0	21 to 30	4
Over 7.0 to 10.0	31 to 40	3
Over 10.0 to 13.0	41 to 55	2
Over 13.0 to 16.0	56 to 75	1
Over 16.0	Over 75	0

Section 3: Test Results (Data)

Letters A, B and C represent aluminum alloys:

A = 380 3-4% copper (Samples independently tested at 3.11% copper.)

B = 360.2 .1% copper (Samples independently tested at 0.06% copper.)

C = 413 .3-.4% copper (Samples independently tested at 0.38% copper.)

Numbers 1 and 2 represent coatings applied:

1 = Powder top coat, 2 = Epoxy base under Powder top coat

Only the A1 sample (industry standard) rated a zero (0) in either category after 5,000 hours.

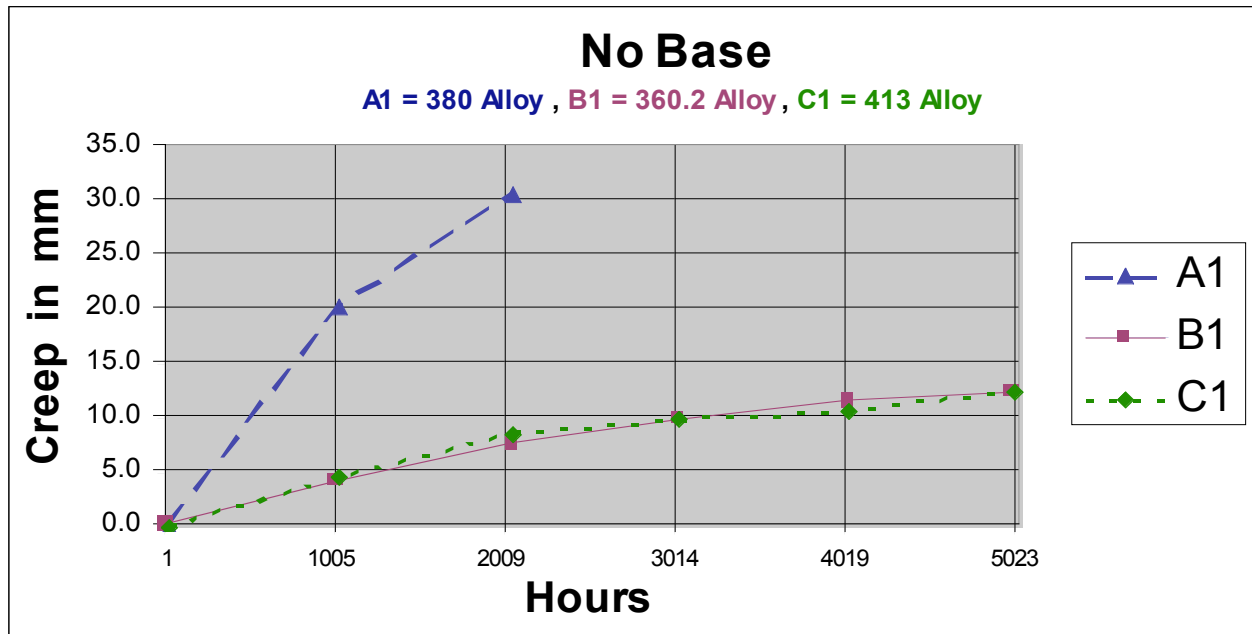
Table 2 below provides the statistical analysis for each type of alloy/coating combination, using data from all 90 samples, at the completion of 5,016 hours in a salt fog chamber.

Table 2:

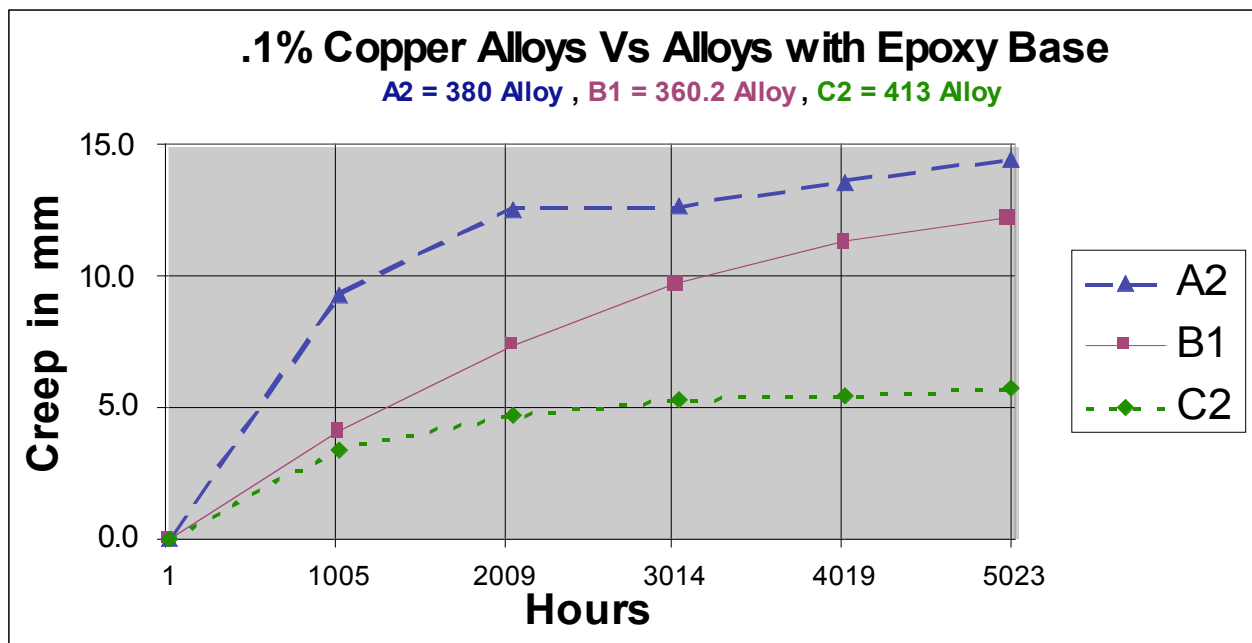
Creep	A1	B1	C1	A2	B2	C2
Average in MM	*	12.2	12.4	14.5	7.7	5.8
ASTM Rating	(0)	(2)	(2)	(1)	(3)	(4)
Range	*	25	22	22	20	4
Standard Deviation	*	6.94	6.91	6.06	5.09	1.32
95% Conf. Level	*	3.84	3.82	3.35	2.82	0.73

*The A1 reading for creep was 16.9 (0) after 792 hours, and it experienced paint/coating failure over 75% of its surface after 2,352 hours. A1 test readings were stopped after both measurements reached a Zero (0) rating.

Graph 1 – Compares all three aluminum alloys with powder paint top coat only.



Graph 2 – Compares the aluminum alloy that meets the LM6 .1% copper requirement (B1), to the higher copper content alloys with Epoxy Base coat added (A2 & C2).



Section 4: Conclusions

Based on the test data and the rating numbers provided by the ASTM D 1654 standard, the only sample that failed with a zero rating after 5,000 hours of salt fog was A1 (380 alloy with top coat only).

*Using the LM6 requirement of .1% copper content or less as the reference standard, sample B1 in table three will be used as the benchmark.

Table 3:

Rank	Sample	ASTM Rating	Creep In MM	Alloy Definition
1	C2	4	5.8	413 alloy with .3-.4% copper, Epoxy base under powder top
2	B2	3	7.7	360.2 alloy with .1% copper, Epoxy base under powder top
*3	B1	2	12.2	360.2 alloy with .1% copper, no base under powder top
4	C1	2	12.4	413 alloy with .3-.4% copper, no base under powder top
5	A2	1	14.5	380 alloy with 3-4% copper, Epoxy base under powder top
6	A1	0	**	380 alloy with 3-4% copper, no base under powder top

**A1 reading for creep was 16.9 MM after only 792 hours. By 5,000 hours nearly the entire surface of the sample was experiencing some level of corrosion.

Table 3 above ranks sample C2, an alloy having a copper content greater than .1%, significantly higher than the benchmark sample B1. In addition, sample C1 was statistically equal to the benchmark B1. Sample A2 did not fair as well as the benchmark B1, but it did survive the 5,016 hours of salt fog with an ASTM rating of 1.

While the .1% copper content alloys clearly outperform the 3-4% copper content alloy with no base coat applied, the results are just as clear that the copper content of an aluminum alloy should not be the only deciding factor concerning corrosion resistance. There is a high degree of confidence that using a low (.3-.4%) copper alloy, such as 413 or an equivalent 360, with an epoxy base coat applied under a powder top coat, will protect against corrosion as well or better than the minimum requirement of using an alloy with .1% copper. It is also very clear that the samples with the Epoxy base coat were more consistent in the extent of corrosion exhibited, especially sample C2. The least amount of consistency was seen on the .1% copper baseline example B1, as evidenced by the Range, Standard Deviation, and 95% Confidence Level numbers documented in table 2.

Recommendation

Based on the results of this test, it is recommended that when writing corrosion performance standards, it would be best to specify the degree of corrosion protection required, not the constituency requirements of the aluminum alloy used. The latter approach restricts the manufacturer's ability to provide equivalent, if not better corrosion protection, and it may actually increase the cost to the consumer.

Section 5: Pictures (After 5016 hours of salt fog testing)

A1



Magnification 3.4 Diameters

B1



Magnification 3.4 Diameters

C1



Magnification 3.4 Diameters

A2



Magnification 3.4 Diameters

B2



Magnification 3.4 Diameters

C2



Magnification 3.4 Diameters