**Investigation of blister formation on painted aluminium sheets**

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**Abstract**

The present work deals with painted aluminium alloy window frame structures, which exhibited premature coating failure during service. The results from the detailed microstructural investigations reveal that the coating failure was originated from the surface defects, which contained high amounts of intermetallic phases in the aluminium profile after metallurgical processing. In the hostile environment, the presence of this heterogeneous microstructure caused corrosion of the aluminium substrate below the painted layer. The mechanism of coating failure due to corrosion of the substrate is elucidated.
1 Introduction

Aluminium 5000 series alloys are one of the higher strength, non-heat-treatable alloys, which provide ease of workability and good corrosion resistance properties (1). The excellent corrosion resistance properties of these alloys make it particularly well suited for marine applications, such as marine components, fuel tanks, oil lines (1). The extruded components of these alloys are being used extensively in residential and commercial building industries. All these applications require painting of the aluminium structures. Premature failure of the coating cause product failures and financial loss (2). Coating failures are usually caused by the water penetration through the coating followed by interface failure due to corrosion. Although an intermediate layer of conversion coating is usually used prior to painting for increasing paint adhesion, microstructure of the aluminium substrate plays a big role in determining the interface behaviour especially in a hostile environment. Surface defects in a profile can arise due to various reasons such as related to chemical composition of the alloys in combination with the subsequent deformation process, and other post-processing corrective measures (3).

In aluminium alloys, one of the most common issues in relation with corrosion is the presence of undesired iron containing intermetallic particles formed during the casting and subsequent metallurgical processing (4). Recycled alloys typically contain higher amount of these particles due to the lower solubility limit of iron in aluminium (5). Presence of intermetallic particles has reported to act as local heterogeneities in alloy microstructure, which play an important role in the local distribution of anodic and cathodic areas within the alloy matrix (4). It has been reported that (4) the presence of higher amount of iron containing intermetallic particles in the alloy matrix triggers the formation of local cathodes during electrochemical process, which leads to localised corrosion attack at the surface. Further, several surface defects, which generally formed during deformation processing can also contribute to this phenomenon (6). It has been reported in the literature (3, 7-9) that presence of these surface defects can involve clustering of intermetallic particles during extrusion or hot deformation process due to the differences in densities of these particles and aluminium matrix during material flow, and results in formation of “pickups” or “shingles”. In the rolled sheets of aluminium alloys, shingles formation was reported (10), which is formed due to sticking effect drawbacks between the tool and rolled workpiece.

The present study deals with the failure analysis of AA 5006 aluminium alloys windows frame, which was powder coated. During the short time service, the windows frames showed the formation of blisters under the powder coating. This paper elaborates the failure analysis study of the failed aluminium painted profiles.

2 Experimental and Methods

2.1 Material

A series of samples (1.0 × 1.5 cm) were prepared by cutting 5.0 × 3.0 cm EN AW 5006 H49 aluminium alloy rolled and powder coated profile, which showed corrosion attacks.
The chemical composition of the alloy is presented in Table 1.

Table 1 Chemical composition of EN AW 5006 H49 alloy in wt. %, remaining is aluminium.

<table>
<thead>
<tr>
<th>Alloying elements [%]</th>
<th>Cr</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Mn</th>
<th>Si</th>
<th>Ti</th>
<th>Zn</th>
<th>Others, each</th>
<th>Others, total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW 5006</td>
<td>≤ 0.1</td>
<td>≤ 0.1</td>
<td>≤ 0.8</td>
<td>0.8-1.3</td>
<td>0.4-0.8</td>
<td>≤ 0.4</td>
<td>≤ 0.1</td>
<td>≤ 0.25</td>
<td>≤ 0.005</td>
<td>≤ 0.15</td>
</tr>
</tbody>
</table>

2.2 Visual appearance

The preliminary examination of the failed profiles was carried out with unaided visual inspection. The next step of preliminary examination was a general photography of the entire part and damaged or failed regions, which showed localized corrosion and blistering of paint.

2.3 Preparation of samples

Original rolled and powder coated profiles, with and without blistering, were manually saw cut to the desired size. Moreover, for the detailed investigations, the blisters were peeled off mechanically using sterilized tweezers.

2.4 Metallographic cross-section

Cross-sectioned samples were prepared by metallographic preparation methods. The metallographic samples were taken perpendicular to the corrosion defects and mounted in Struers Clarofast thermoset resin and cured. The moulded samples were subjected to mechanical grinding using silicon carbide papers to 4000 grit followed by polishing using 3 μm and 1 μm diamond paste.

2.5 Microstructural analysis

Scanning electron microscopy was used primarily to investigate the topographic and morphological characteristics of rolled powder coated and non-powder coated profiles on both fresh and corroded sites. Energy-dispersive X-ray analysis was performed for the elemental analysis. A scanning electron microscope model FEI Quanta 200™ ESEM FEG equipped with an energy dispersive spectrometer (EDS) (Oxford Instruments 80 mm² X-Max™) was used for the analysis.
3 Results

3.1 Visual appearance

Figure 1 Digital photograph of powder coated aluminium profile showing blisters

Figure 1 shows the powder coated aluminium profile where the presence of blisters was visible. The size of these blisters varied from 1 to 4 mm. Further, it appeared that the presence of these blisters were concentrated at the edge of the profile. The edge of the profile was containing a rubber, which is clearly visible in the cross-section image of the profile in Figure 1.

3.2 Surface morphology

3.2.1 Powder coated profile containing blisters

Figure 2 Back scattered images of surface blistering sites (topographic view) without paint peeling off (a) and with paint peeled off (b).

Figure 2 shows the morphology of the blister, which was present on the powder-coated profile. The EDS analysis of the blistered area showed the presence of the chloride at the surface indicating the corrosion attack, whereas the presence of Fluorine and Sulphur was attributed due to powder coating. Moreover, blisters of different sizes showed similar chemical composition. After the blister was mechanically removed, analysis results using EDS is presented in Table 2. The EDS analysis revealed the presence of chlorides; these analyses confirmed that the formation of blisters took place due to the corrosion attack at the powder coating and aluminium alloy interface.
Table 2 EDS analysis in wt. % of the blister area, before and after the removal of the blister mechanically.

<table>
<thead>
<tr>
<th>Area</th>
<th>O</th>
<th>F</th>
<th>Na</th>
<th>Al</th>
<th>Si</th>
<th>S</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blister surface</td>
<td>63.5</td>
<td>13.2</td>
<td>0.7</td>
<td>17.7</td>
<td>1.0</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>After removal of blister</td>
<td>63.7</td>
<td>-</td>
<td>-</td>
<td>33.5</td>
<td>-</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

3.2.2 Profile prior to powder coating

![Image](image.jpg)

Figure 3 Back scattered images of non-powder coated aluminium sheet surface (topographic view) at different sites: surface overview (a), intermetallics agglomerate in the vicinity of a shingle (b); secondary electron image of shingle (d).

In order to find the root cause of the formation of the blisters, the aluminium profile microstructure, prior to the application of powder coating, was analysed and presented in Figure 3. The analysis revealed the presence of rolling streaks, which appeared due to the mechanical processing of the alloy. Further, the presence of particles of various sizes (which appear bright in the SEM images), in the range of 2 µm to 10 µm, was observed. Moreover, the high magnification image of the profile showed the preferential clustering of intermetallic particles in certain areas as presented in the Figure 3 (b). The EDS analysis presented in Table 3 of these areas revealed that these bright particles were Al-Mg-Mn-Fe and Al-Mg-Si-Mn-Fe type of intermetallic particles.

Table 3 EDS analysis in wt. % of the two different type of intermetallic present in AA 5006.

<table>
<thead>
<tr>
<th>Area</th>
<th>O</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermetallic particles 1</td>
<td>0.8</td>
<td>1.1</td>
<td>83.3</td>
<td>-</td>
<td>4.7</td>
<td>10.1</td>
</tr>
<tr>
<td>Intermetallic particle 2</td>
<td>1.1</td>
<td>2.1</td>
<td>85.3</td>
<td>2.5</td>
<td>3.4</td>
<td>5.6</td>
</tr>
</tbody>
</table>

3.3 Cross section analysis

3.3.1 Failed profile

Figure 4 shows the typical cross section of the blister area, which composed of two different layers: namely top layer, which is powder coating and bottom layer, which is formed due to the corrosion of aluminium profile. Further, Figure 4 (b) revealed that the corrosion attack is deep down into the alloy and spread in the lateral direction. Moreover, the progression of the corrosion appears to follow the areas where high amount of intermetallic particles was present. Further, the analysis of
areas where the blister formation was not evident also showed the presence of corrosion attack as revealed by EDS analyses presented in Table 4. This corrosion attack appears to initiate at the top surface (Figure 4 (c)) where relatively higher amount of intermetallic particles was present at the surface.

Figure 4 Back scattered images of corrosion sites cross sections in correspondence with the blistering (a) (b) and of corrosion initiation sites not corresponding to the blistering points (c).

Table 4 The EDS analysis in wt. % of the two different type of intermetallic present in corroded and non-corroded area in Figure 4 (c).

<table>
<thead>
<tr>
<th>Area</th>
<th>O</th>
<th>Mg</th>
<th>Al</th>
<th>Cl</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermetallic particles in corroded area (1)</td>
<td>15.4</td>
<td>68.8</td>
<td>0.5</td>
<td>5.6</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>Intermetallic particle in non-corroded area (2)</td>
<td>1.0</td>
<td>-</td>
<td>71.2</td>
<td>-</td>
<td>8.9</td>
<td>19.0</td>
</tr>
</tbody>
</table>

3.3.2 Profile prior to powder coating

Figure 5 Secondary electron images of non-powder coated aluminium sheet cross section showing surface defects (shingles) where intermetallics were agglomerated.

Figure 5 shows the typical cross section of alloy surface prior to powder coating. The surface of the alloy showed the high roughness areas where the value of roughness was tens of microns higher than the rest of the areas. Further, these high roughness areas were analysed by SEM analysis and presented in Figure 5 (b). These high areas correspond to the intermetallic particles enriched regions, which were present at the surface of the alloy as shown in Figure 3 (b).
4 Discussion

The failure case study presented in this paper reveals the connection between the defects originated on the rolled profiles carried over to the powder painted frames causing localised corrosion during use. The blister formation of the painted profile corresponds to the presence of high levels of intermetallic particles in the alloy.

Similar surface defects have been reported in the literature (10), and are referred to as shingles, however no prior information was found on the relationship between the shingle defect on subsequent painted profile, microstructure, and corrosion aspects. In particular, the presence of shingles is considered as undesirable. Shingles which are observed as “tongues on top of the surface” (11) and end up as severe roughness peaks and valleys seen in the present study. The reported mechanisms, being responsible for the formation of shingles defects, consist of local adhesion or sticking, followed by deformation into unconstrained regions and finally rupture of the contact as the sheet moves away from the rolls (12, 13).

In addition, considering the alloy’s microstructure, due to the low solubility limit of alloying elements and use of recycled aluminium a dramatically high content of intermetallic particles can be obtained (5). Local heterogeneities in alloy microstructure can yield to local cathodes formation and lead to localised corrosion attack at the surface, which propagates in the preferential corrosion paths constituted by the same intermetallic particles, ultimately causing enormous corrosion attack in the material.

In present failure case analysis, an interplay between the two above mentioned factors was assumed to be the reason for the blister formation. A dramatically high content of Al-Mg-Mn-Fe and Al-Mg-Si-Mn-Fe intermetallic particles was found in the substrate microstructure of the alloy. Shingles are formed due to the differences in densities of intermetallic particles and aluminium matrix during material flow. Moreover, these areas are heavily deformed, therefore generating fine intermetallic particles increasing the number of cathodes for localized corrosion to occur. The intermetallic particles preferentially concentrated in the shingles has caused corrosion underneath the paint when it was exposed aggressive atmospheric conditions.

5 Conclusions

This case study reveals that the formation of surface defects resulting from manufacturing process, together with a high content of intermetallic compounds resulting from metallurgical process and alloy recycling, were the root cause of randomly occurring corrosion on the studied aluminium windows profiles. The presence of high levels of intermetallic particles in the shingled site, at the interface between aluminium surface and coating, resulted in severe localized corrosion attack in the presence of chloride. The corrosion mechanisms revealed pitting corrosion attack around the intermetallics regions.
6 References