Title of Publication *Edited by*
TMS (The Minerals, Metals & Materials Society), 2007

CHARACTERIZATION OF SURFACE DEFECTS ENCOUNTERED IN TWIN ROLL CAST ALUMINUM STRIPS

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Keywords: Twin roll casting, Automotive alloys, Surface segregations

Abstract

Solidification mechanism in twin roll casting (TRC) technique provides various advantages for the production of aluminum alloys having narrow solidification range. High production volume in casting, reduced cost of rolling due to the gauge of initial material to be rolled and elimination of some other intermediate processes are among those. However, alloys having wide solidification range is in tendency of creating serious surface defects.
They can readily deteriorate mechanical performance and results in severe complications not only in demanding applications, but also in ordinary engineering applications. If exposed to a surface treatment, they can be easily revealed by resulting in impairment of the aesthetic appearance. Present study aims microstructural characterization of surface defects created in TRC technique and their affects on some critical applications. 5000 and 3000 series aluminum alloys produced for demanding applications and 8000 series alloys for packaging industry form the subject of this study.

Introduction

Competitive environment in aluminum industry forces to investigate alternative solutions for existing technology in various ways. Recent studies on twin roll cast aluminum strips, including 5000 series alloys, provided promising results for applications necessitating major cost reductions in materials issue[(1-4)]. As compared to the traditional hot mill process, the relatively low capital cost of twin-roll casters, in combination with their lower energy and labor cost, have made twin-roll casting an increasingly popular method of producing a wide range of aluminum flat rolled products. The most attractive aspect of twin-roll casting is the ability to cast at thinner gauges allowing significant reductions in the cost of further down stream operations, along with higher productivity in the casting process itself.
The advantages inherent in the twin-roll casting process do not in itself ensure a competitive advantage in the production of strip if the strip is not of commensurable price and acceptable surface quality. Due to the nature of very high solidification rates achieved in thin strip casting, microstructural components of the as-cast strip exhibit unique features as compared to their DC cast and hot rolled counterparts. Much finer and uniformly distributed intermetallic constituents of twin roll cast strips enhance mechanical performance of the material for stringent applications. Topographical and microstructural constituent of the strip surface are determined by the characteristics of the solidification. Any effect distracting the solidification path of the metal, after the deployment from the ceramic caster nozzle, leads to local microstructural abnormality compared to its vicinity. Free surface of the strip, that is the interface between caster roll surface and the melt, is more prone for those defects to be observed. Since outermost skin of the strip is

not removed by any mechanical means, contrary to the scalping operation of DC cast and hot rolled ingots, through thickness uniformity in microstructural features is an important requirement for the performance of material in different applications, including aesthetic properties. The severity of surface segregations was found to depend critically on alloy composition [(5)].

Surface defects of twin roll cast strips originating from the casting phase of production were investigated in the present study. Twin roll cast aluminum alloys employed for general engineering applications, packaging and automotive applications were characterized for their surface defects encountered.

Experimental

Surface defects of various samples cast at 5-6 mm and samples gathered from rolled strips out of these coils were the subject of present study. 2200 mm wide strips were produced by employing industrial size twin roll casters having roll diameter between 1060-1100 mm. While some type of defects are readily detected at the as-cast surface of the strips, further rolling operations that decrease the surface roughness help others to be detected by visual inspection at thinner gauges. Optical microscope (Olympus PME3) and SEM (JEOL5600) equipped with EDS unit (Oxford 6587) were used for microstructural characterization of the defects. Surface roughness of as-cast strip and rolled material does not allow microstructural constituents to be detected unless any prior preparation technique is applied. Therefore, samples were slightly polished with 0,3 μm SiO_2 for those constituents to be revealed for analysis.

Severe surface segregations can have detrimental effects on mechanical performance of the material. If there exist any severe bending or deep drawing operation involved in the application, these defects lead to premature failure. Therefore, cross section of samples was polished by using metallographic sample preparation techniques to create very sharp corners between the plane of cast strip and thickness direction. The samples prepared with this method were bent parallel to the rolling direction to elucidate interaction between the tensile stress field at the convex side of the sheet and the constituents of surface segregations. Chemical content of intermetallic particles forming clusters were analyzed with the help of semi-quantitative EDS technique.

Results

The Al-Mg alloys (5000 series) are extensively used in applications requiring a good combination of strength and formability. Typical example of this series is AA5754 based on Al-3wt%Mg, which is extensively used in automotive structures and engineering applications. Due to its wide solidification temperature range and high oxidation tendency in liquid form, transfer of metal from furnace to the caster and delivery through the ceramic nozzle bears some potential problems, if some critical rules are violated in casting practice of TRC technique. Physical solidification path of the molten metal prior to the contact with the caster rolls has strong influence on the solidification abnormalities. Disruption of the liquid or semi-solid metal by any physical mean results in formation of surface segregations. Surface characteristics of caster rolls can introduce supplementary effects on the formation mechanism of surface segregations. These are closely related to the “wetting” of the liquid metal on roll surface. Figure 1 shows heavy surface segregations on the as-cast surface of AA5754. Particles were revealed by slightly polishing the surface to be easily observed with optical microscope.

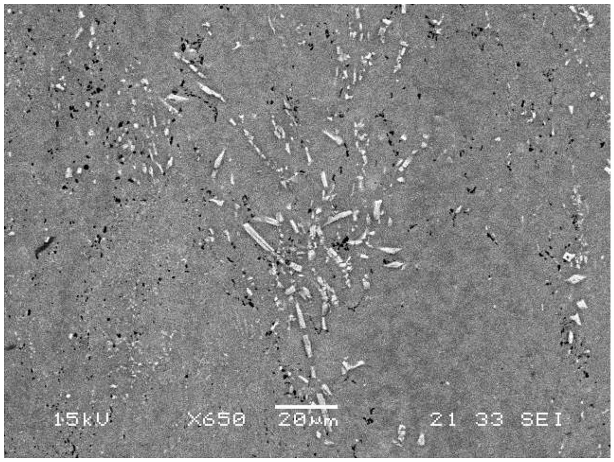


Figure 1. Surface segregations on the as-cast AA5754.

Wide solidification range of an alloy makes it more prone to form microstructural defects in the casting process, unless casting parameters are optimized. As the alloys that can be produced with TRC is listed in the descending order of their solidification range, while AA 5182 has the widest range, AA1050 has the narrowest solidification range with the lowest surface segregation tendency.
SEM and EDS studies carried out to determine chemical content of individual particles reveal that intermetallic particles are majorly composed of Al-Fe, Al-Fe-Si, Al-Fe-Mn and Al-Fe-Mg, depending on the alloy composition. They are relatively hard and non-deformable particles compared to the surrounding ductile matrix. While they can be formed within a narrow but continuous band along the casting direction, whole surface can also be covered with those if casting parameters are not appropriately controlled. Figure 2 shows one of these bands after slightly etching. Especially, in the latter case, the strain hardening and fracture mechanism of limited volume containing intermetallic particles are analogues to the mechanism operating in particulated reinforced aluminum alloys [(6,7)].

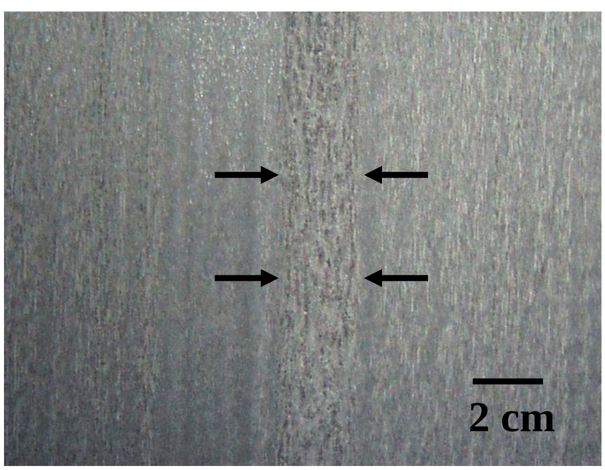
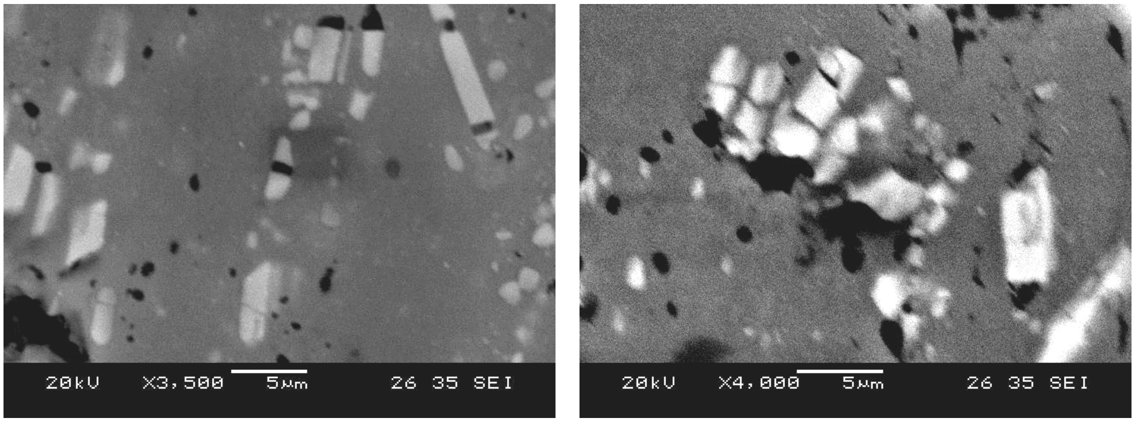


Figure 2. Segregation band, after etching, is marked with arrows.

Twin roll cast aluminum strips are cold rolled to the required thickness in their processing route. Due to the frictional forces at the interface between the work rolls of the mill and the sheet, very large shear stresses are generated [(8-10)]. On the other hand, deformation characteristics of rolling, that is plane strain, help alignment of these particles parallel to the rolling direction. These particles have relatively large aspect ratios. Corner profile of particle causes intense plastic straining in the nearby matrix and leads to void nucleation at the corners (Figure 3)[(11-12)]. This mechanism is more pronounced if there are clustered particles within a narrow domain. Overlapping strain fields around the corners of clustered particles result in coalescence of voids with induced more strain during rolling.



(a) **(b)**

Figure 3. Void nucleation at the corner of intermetallic particles (a) and expanded voids due to coalescence of strain fields (b).

Figure 4 shows the typical giant intermetallic particles formed during casting of AA5754. Al-Fe-Mg or Al-Fe are the major intermetallic phases. Dot mapping of a marked area is given in Figure 4. The chemical content of these phases are determined by the alloy composition.

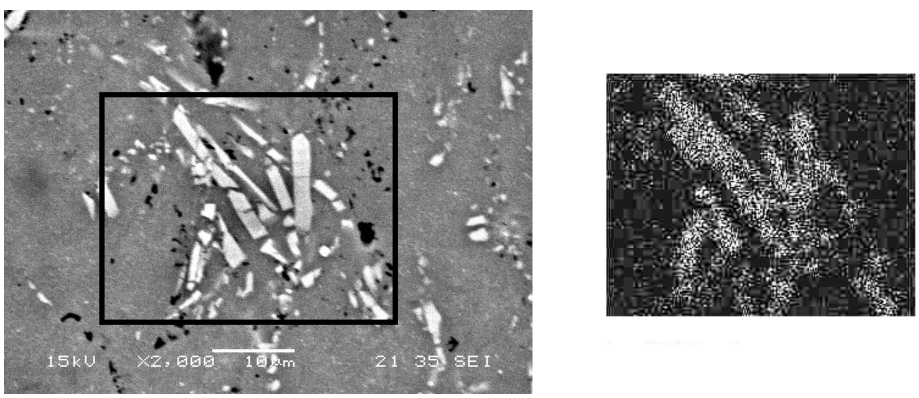


Figure 4. Dot mapping of intermetallic phases in AA5754.

AA8011was another alloy on which surface segregations were investigated. Major alloying elements of AA8011 are Fe and Si that form Al-Fe-Si and Al-Fe phases. They are typical intermetallic phases of Al-Fe-Si ternary alloys. Surface segregations are not unavoidable even in such a low alloyed materials. Unless casting related sources are eliminated, surface segregations can readily be generated at the sheet surface. Due to its lower solidification range, AA8011 is less prone to form surface segregations, compared to that of AA5754 involving more than 2,6% Mg and other alloying elements, like Fe and Si. However, contrary to the AA5754, morphology of the intermetallic phases are significantly different than that of AA5754. They are in equiaxed shape rather than whisker-like geometry. Their aspect ratios are close to one. Cold rolled samples have shown that equiaxed morphology of particles is not even sufficient enough to prevent void nucleation after applying several rolling passes (Figure 5). Severe void formation is again observed around the intermetallic clusters.

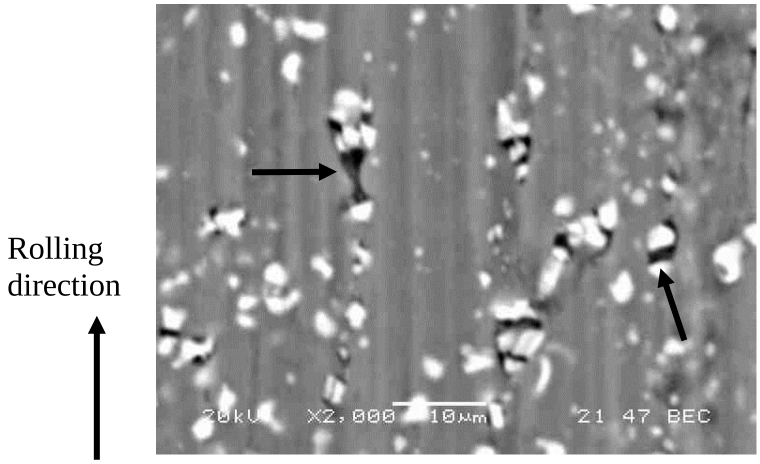


Figure 5. Void formation around the intermetallic phases after several passes. Note rolling direction.

Elemental analysis of the individual particles, formed in AA8011, was conducted with EDS technique. It revealed that they were Al-Fe-Si based phases (Figure 6). Although their chemical compositions are determined with semi-quantitative technique, their exact stochiometry, crystallographic nature and growth characteristics require further investigation.

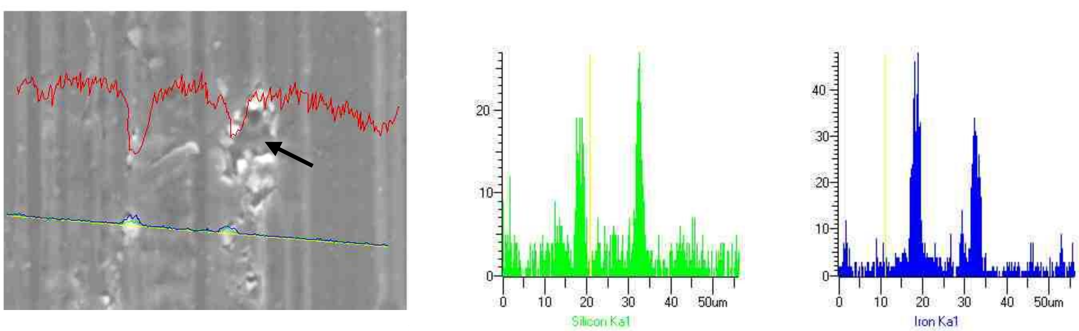
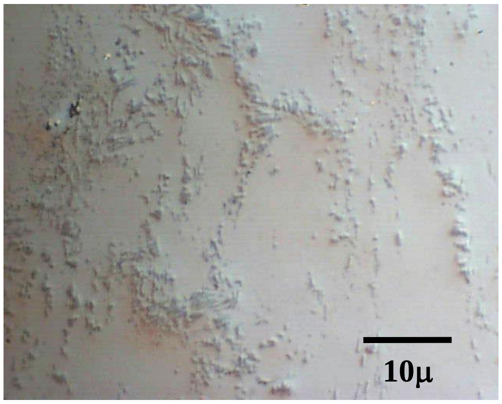
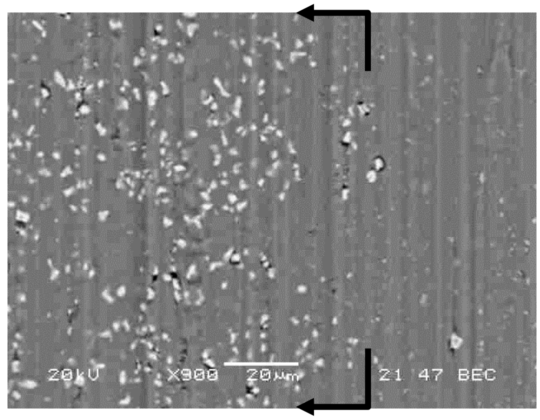


Figure 6. EDS analysis of intermetallic phases in AA8011, after rolling. An excessively opened void is marked with an arrow.

Initial form of these surface segregations was investigated on the as-cast strip surface. By employing metallographic techniques, as-cast strip was slightly polished. Clustered intermetallic phases were detected at the same position where segregation band was spotted on the rolled strip. As cast strip surface and rolled surface are shown in Figure 7 (a) and (b), respectively. Figure 7 (b) illustrates the noticeable border between segregated (left side) and segregation free areas.





(a) **(b)**

Figure 7. Clustered segregations on the as-cast strip surface (a) and after rolling (b).

Surface segregations can be very detrimental for many end-use of aluminum sheet and foils products. As the gauge of the strip decreases with rolling passes, their volume fraction increases through thickness. Some applications, in which plane strain deformation is operative at particular areas of their geometry, such as deep drawing, these non-deformable particles may lead to premature failure. Analogues to the Marciniack-Kuczinsky principle[13], any physical defects, either in the form of local thinning through the thickness or microstructural discontinuity compared to the rest of the volume or plane, create a sensitivity to mechanical loading and leads to premature failure.

Hemming and clinching are two important mechanical joining techniques in automotive applications of aluminum alloys. In the presence of surface defects, even with the application of large bending radius, very minor cracks can easily propagate to the inner side of the thickness with the help of above mentioned surface segregates and associated voids. Crack propagation pattern preferentially follow the existing voids and cracked particles. Figure 8 illustrates crack propagation pattern at the outer fibers of an AA5754 sheet that involve segregates. The sheet thickness is 1 mm and bent parallel to the rolling direction, that comply the rules specified in the standards, Shear stress generated at sheet-work roll interface is the primary factor resulting in fragmentation of these non-deformable particles, having large aspect ratio. As, these intrinsically existing defects are exposed to the tensile stresses at the convex side of the bending radius, they form an easy path for the propagating crack.

Detrimental effects of these defects are not limited with the mechanical performance of the material. Surface segregates encountered in the sheet of AA8011, aimed to be employed for production of lid foil, easily alter surface roughness that also leads to pronounced effect on the lacquering performance of the surface. The bands that bear surface segregations develop different surface roughness compared to the adjacent areas, due to voids around individual or clustered segregates. Since wetting characteristics of these areas are significantly different than that of adjacent segregate-free sites, they hold more lacquer and these are visually recognized as dark lacquered areas or shades.

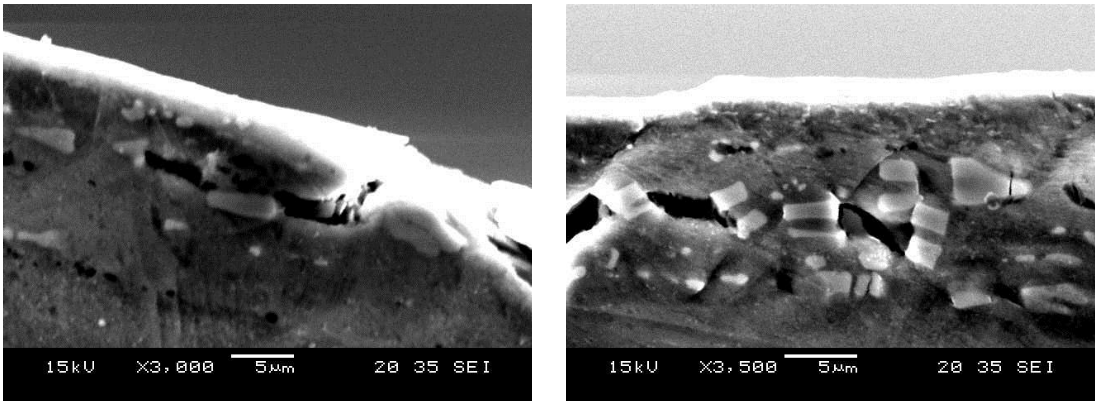


Figure 8. Crack propagation pattern at the outer fibers of AA5754. Free surface is exposed to the tensile stress in bending.

Conclusions

1. Aluminum alloys having wide solidification range is prone to develop surface segregations during Twin roll casting.
2. Casting parameters have significant influences on the formation mechanism of surface segregations, size and distribution on the as-cast strip surface. Surface segregations can be controlled and eliminated with optimized casting parameters.
3. They can not be dissolved or eliminated by any means of post metallurgical process.
4. Excessive shear stresses generated at the outer fibers of sheet during cold rolling cause these hard and non-deformable particles to be broken into small fragments.
5. Fracture mechanics and crack propagation mechanism is dictated by those particles and mechanical performance of the strip is significantly deteriorated due to the presence of these particles. They allow limited bending, hemming and forming applications.
6. Presence of surface segregations has adverse affect if the strip is exposed to an electrochemical process or coating.

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