

## IMPROVEMENT OF CORROSION RESISTANCE IN MODIFIED 3003 ALUMINUM ALLOYS PRODUCED BY TWIN ROLL CASTING UNDER DIFFERENT CASTING PARAMETERS

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### Abstract

Finstock materials having different chemical compositions produced by TRC have been widely used in heat exchanger systems. Al-Mn alloys produced with TRC technique are also used as fin materials in various brazing applications. With the addition of zinc, these alloys are utilized as sacrificial materials to protect tube material. Alloy chemistry and casting parameters primarily dictate the stoichiometry and morphology of microstructural constituents in TRC strip.

Motivation of this study is to prolong the corrosion resistance of fin material by tailoring microstructure of as-cast strip during casting process. This was accomplished by decreasing the magnitude of centerline segregation instead of altering overall composition of the alloy.

Casting parameters were altered to gain better control over the microstructural constituents. Microstructure of as-cast strip and end product were characterized through entire thicknesses. Magnitude of CLS was correlated with variants of casting parameters. Results were supported by electro-chemical potential measurements and salt-spray tests.

### Introduction

Superior performance of aluminum alloys are the major motivation for their intensive use in wide range of industrial applications [1-2]. Aluminum have been replacing with traditional ferrous materials and copper alloys. New applications necessitating higher performance, light weight, aesthetical appearance and formability address aluminum alloys. Automotive applications are among those, heat extraction performance of aluminum alloys are exploited for heat management systems of the vehicles, including A/C, radiators, condensers etc.

Like all the components of automotive parts, cost of materials has always been an issue to be reduced. Along with the clad material, bare aluminum alloys are employed for thermal systems of the vehicles. Existing technology of Twin Roll Casting of aluminum alloys are not yet capable of providing clad finstock material for brazing applications. However the production technique, mechanical and microstructural characteristics of the products and related cost structure make TRC a promising candidate [3]. Very rapid solidification rate introduces some unique features to the microstructure and they provide advantages for the brazing process. Highly supersaturated aluminum matrix at the outer skin of the as-cast structure and its influence on recrystallization behavior and mechanical properties after post brazing application differentiate TRC materials from conventionally produced alloys [4-7].

Addition of Zn to 3003 alloy used as fin material changes its electrochemical behavior in favor of initiating corrosion on fin rather than the tube on which it was brazed. But not only the

parent material but some microstructural features, like center line segregation (CLS), may alter the initiation and development of corrosion. The effect of Zn content on the corrosion behavior of modified 3003 alloys and its effect on CLS were studied by Işıksaçan et. al [8].

### Experimental

Primary factors influencing the formation and magnitude of CLS are casting gauge and casting thickness. Three sets of coils were produced with variants of these parameters (Table 1).

Table 1. Casting parameters of the coils.

	Speed (cm /min)	Gauge (mm)
Standard production	106	5.65
Parameter set 1	80	5.65
Parameter set 2	80	6

Microstructural studies were conducted on the samples processed according to prescribed route in an industrial scale production. Samples at the as-cast thickness, after rolling, homogenization annealing and at the final thickness were prepared with metallographic techniques. Another set of samples in the final temper and thickness were also prepared to investigate the corrosion mechanism operating at the cross section in case of it is exposed to corrosive media.

6x5cm<sup>2</sup> samples were taken from the materials exposed to processes prescribed above and placed in salt spray test chamber for 14 days to observe the onset of corrosion visually. (Ascot S120S). 5% NaCl solution was used as corrosive media with a flow rate of 15 ml/min at 35°C (14 bars). Surfaces of these samples were observed with scanning electron microscope (SEM-JEOL 5600) along with energy-dispersive x-ray spectroscopy (EDS-OXFORD 6587).

From all the steps of production (down to 0.07 mm), samples were taken for metallographic inspection. Electro-chemical potentials (ECP) of 0.07 mm materials were measured by VersaSTAT 3 potentiostat according to ASTM G-69 standard. Test solution consisted of 58.5 g of NaCl and 9 mL of hydrogen peroxide reagent per 1 L of aqueous solution. Exposed surface area of test specimens was 430 mm<sup>2</sup>. Specimens were cleaned with acetone and distilled water in an ultrasonic cleaner for 5 minutes prior to test. Saturated calomel electrode was used as reference electrode.

In order to reveal the impact of CLS on the corrosion mechanism, cross section of all the samples at the final gauge were also metallographically prepared and exposed to the same salt spray test.

Also as-cast samples of these coils were metallographically prepared and investigated with a light microscope in order to evaluate the effect of these parameters on magnitude of CLS

which is thought to have a detrimental effect on the corrosion properties of Twin-Roll Cast materials.

### Results and Discussion

3003 modified materials were produced in H14 temper and the processing route is given in Figure 1.

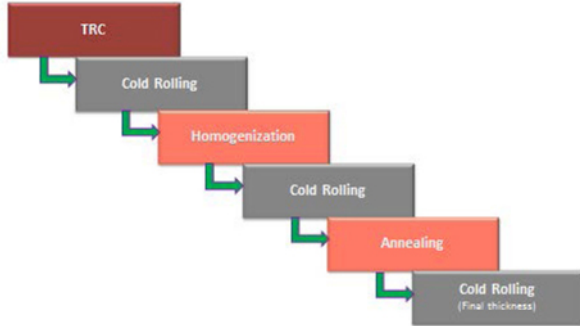


Figure 1. Processing route of modified 3003 alloy materials.

Light microscope view of cross section of the as cast samples was given in Figure 2. Clear difference in magnitude of CLS between the microstructure of two samples obtained from two casting parameters can be easily seen. In standard production parameters, CLS is distributed at the center plane of the cross section. Clusters of intermetallic particles forming the CLS are dispersed around the center plane (Fig. 2.a). Decreasing casting speed change its form into a thick line particularly concentrates at the center plane (Fig.2.b). Slightly shifted CLS is due to off-centered ceramic tip nozzle position. Further reduction in casting speed but increase in casting gauge stands for relatively lower solidification rate at the caster roll bite. Solidification mechanism is capable of dissolving more elements in the matrix and intermetallic phases are formed. Solidification initiates at the roll surface. Advancing solidification front toward the center plane of the strip enriches the solute element in the liquid. The metal at the center plane that is still liquid but rich in alloying elements leads to formation of CLS. Depending on the positioning of ceramic caster nozzle, size of particles may vary from one surface to the other (Fig. 2.c). It is seen that slow and thick gauge casting has a positive effect on CLS formation which is result of changes in cooling rate.

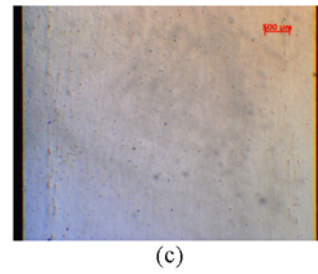
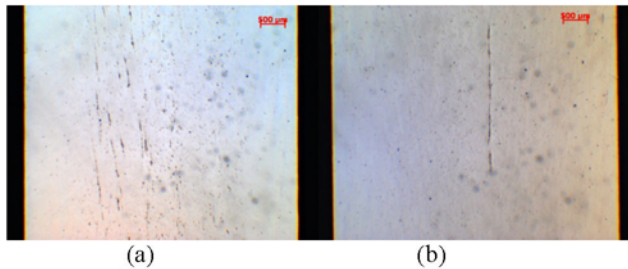


Figure 2. Light microscope image of (a) standard material (b) parameter 1 (c) parameter 2

SEM images of the as-cast samples were given in Figure 3. As was expected, Si, Fe, Mn and Zn are the primary elements existing in different stoichiometry in the eutectic phases of the CLS. Morphology of CLS varies depending on the casting parameters.

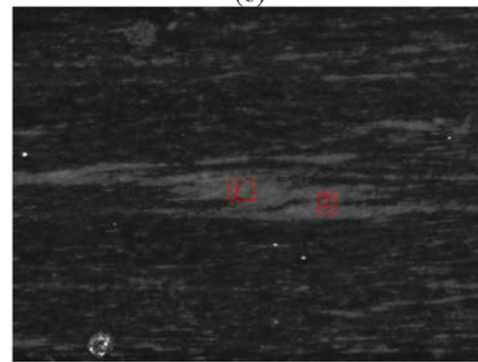
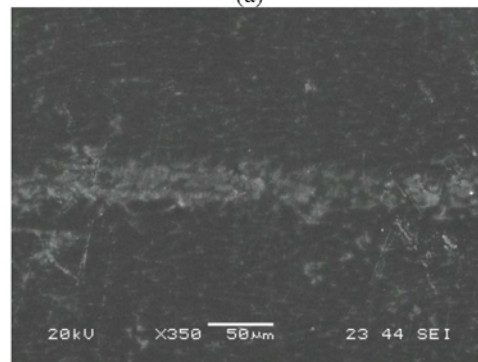
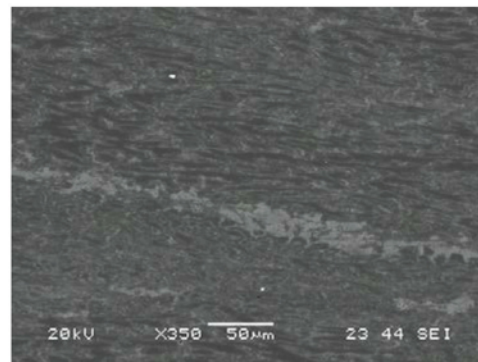


Figure3. 350X SEM images of (a) standard sample, (b) parameter set 1, (c) parameter set 2

Grain structures of all three materials were investigated in three stages of the production route. Figure 4, 5 and 6 show the grain structure of the materials produced with standard, parameter set 1 and parameter set 2, respectively.

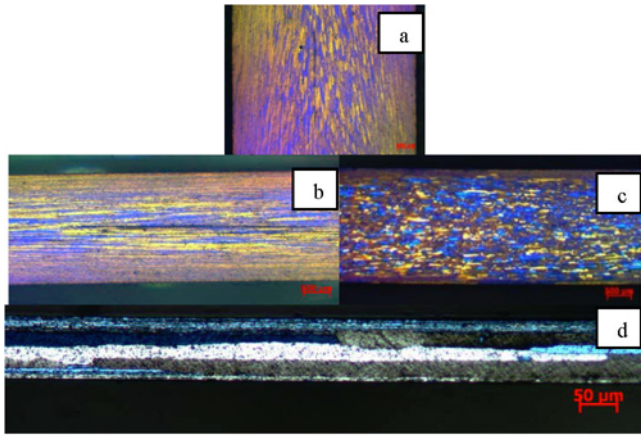


Figure 4. Microstructures of standard production (a) as cast (b) cold rolled (c) homogenized (d) final thickness

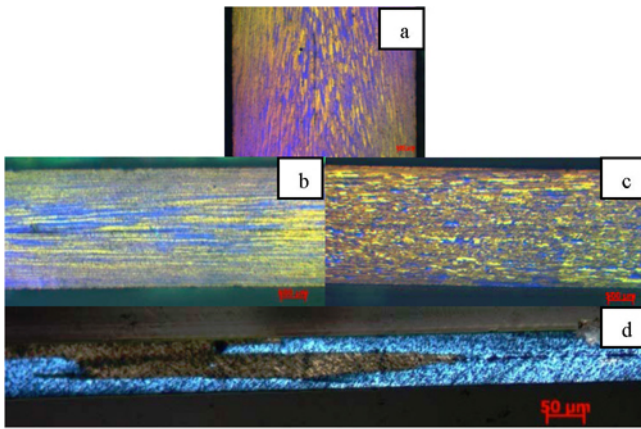


Figure 5. Microstructures of parameter 1 production (a) as cast (b) cold rolled (c) homogenized (d) final thickness

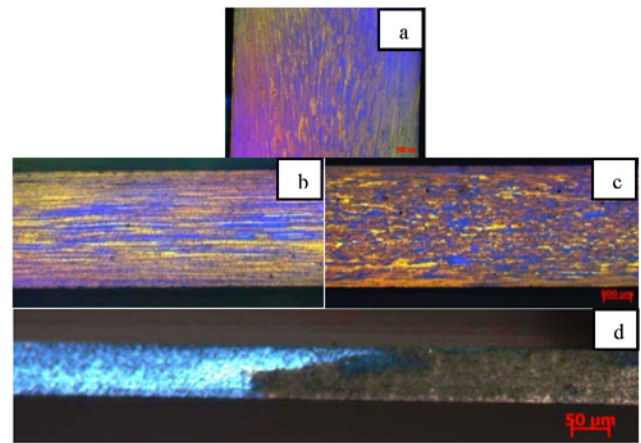


Figure 6. Microstructures of parameter 2 production (a) as cast (b) cold rolled (c) homogenized (d) final thickness

Grain structure of as-cast materials in three cases reveals similar features. Outermost surfaces are decorated with very fine grains in as-cast state. Rolling prior to the homogenization anneal does not change initial grain structure of all three materials. Homogenization annealing leads surface grains to coarsen. But their sizes are larger in the samples produced with parameter set 2 than those of standard and parameter set 1. While the whole thickness is composed of more than two grains in standard and parameter set 1 sample, whole thickness the sample is formed by a single grain in the sample produced with parameter set 2 samples (Fig. 4.d).

Contrary to the different grain structure of all three samples, mechanical properties at the final thickness did not exhibit remarkable difference. Almost similar values were obtained for the elongation. The results were given in Table 2.

Table 2. Mechanical properties of materials

	Yield MPa	Tensile MPa	Elongation %
Standard	190	195	1.1
Parameter 1	190	197	1.2
Parameter 2	193	200	1.2

Electrochemical potential (ECP) measurements conducted on the surface of samples by employing calomel electrode revealed that all the materials have ECP between 0.87 – 0.88 mV. Although the samples show some significant differences in the microstructural constituents, no distinctive measurements were observed between the materials produced with different set of casting parameters. ECP results were shown in Figure 7.

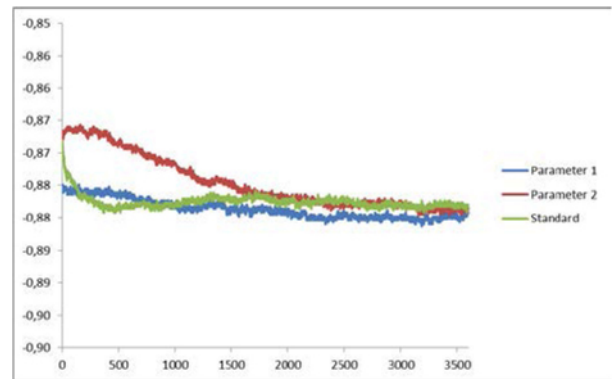


Figure 7. ECP measurement results of three samples

Macro images and surface appearances of the samples taken with stereo microscope after salt spray test are given in Figure 8 and 9. From macro images, it is clearly seen that there is a deformation on the surfaces of Parameter 1 and Parameter 2. Standard sample seems to be more stable compared to the other two samples.

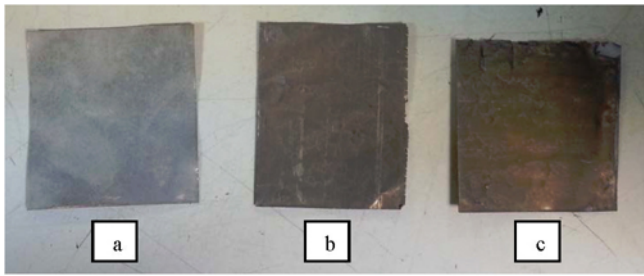


Figure 8. Macro images of samples after salt spray test (a) standard sample (b) parameter 1 (c) parameter 2

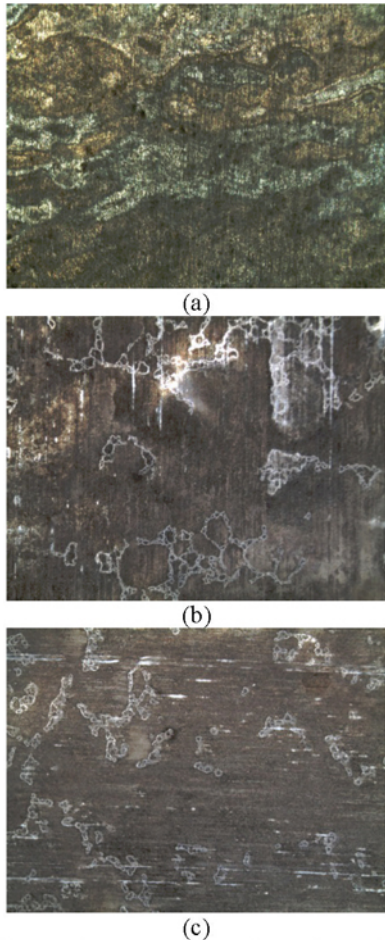


Figure 9. Stereo images of samples after salt spray test (a) standard sample (b) parameter 1 (c) parameter 2

SEM images of the surfaces after salt spray test were given in Figure 10. While attack of corrosive media to the surface of standard sample localized at certain areas, corrosion is in the form of evenly distributed smaller pits on the surface of both Parameter set 1 and Parameter set 2 samples. Corrosion initiates at the interface between the intermetallic particles and the surrounding matrix. Due to the difference in chemical potential of the particle and matrix, matrix begins to corrode at the interface and particle loses its contact with the matrix.

In the fin manufacturing process, each cut to produce individual fins generates a free surface of cross section having CLS. But corrosion mechanism does not operate in the same manner for the center line segregation. Not only the wide free surface but the

cross section of the material is also exposed to the corrosive media. Since the microstructural constituents in the CLS are rich in Fe, Si, Mn and Zn, corrosion initiates and propagates from the CLS. Figure 11 a and b show the cross section of the samples produced with Standard and Parameter set 1. Cross sections were exposed to the same salt spray test and SEM studies were carried out. It is very clear that corrosive media preferentially attacked to the interface between intermetallic phases at the center plane, i.e CLS and in the further stages of the corrosion they were dislodged from their original positions in the standard samples. However, samples from the Parameter set 2 show pitting corrosion like the one observed on their surface (Figure 10 b and c) but possible segregations on the upper surface also heavily affected with the corrosive media. But the absence of CLS through the cross section and pitting corrosion to be dominant mechanism confirm the proposed mechanism of contribution of CLS. This observation is in accord with the segregation features of as-cast material produced with Parameter set 2 (Figure 2 c).

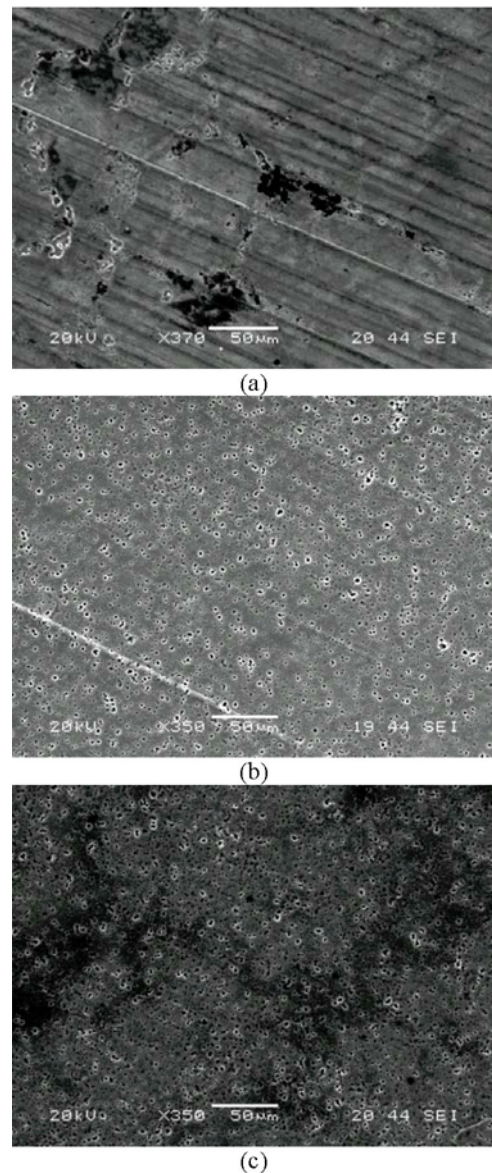
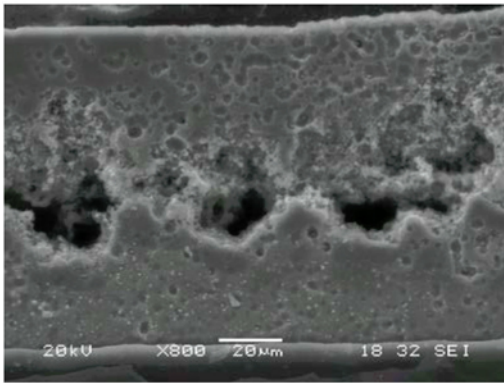
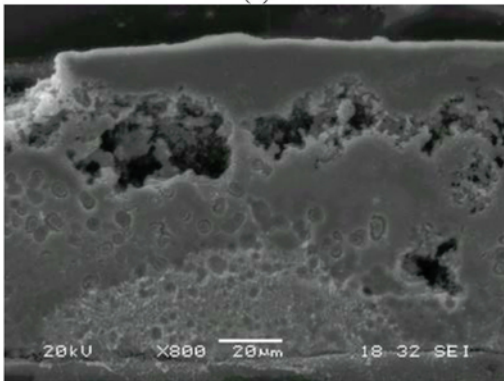


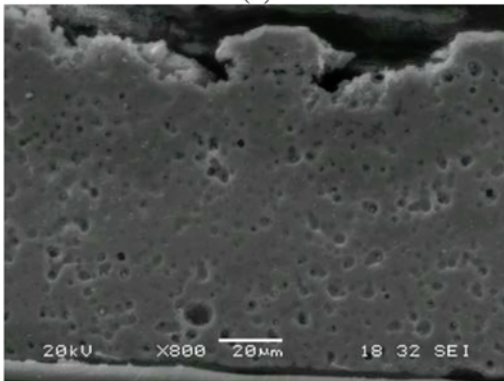
Figure 10. SEM images of the samples after salt spray test (a) standard sample (b) Parameter 1 (c) Parameter 2.



(a)



(b)



(c)

Figure 11. SEM images of the cross sections after salt spray test (a) standard sample (b) Parameter 1 (c) Parameter 2

### Conclusion

- Formation of CLS, its morphological features and magnitude can be controlled with the casting parameters. Combination of appropriate casting parameters resulting in relatively slower solidification is the solution for manipulating the segregation behavior at the center plane.
- CLS is composed of Fe, Mn, Si and Zn rich particles and/or eutectics.
- Presence of CLS does not have any adverse effect on the mechanical properties of the end product.
- The ECP results reveal that changing casting parameters does not affect corrosion potential that was measured from the surface of the materials regardless of the

overall microstructure, including the grains. Since the material is thick enough to conceal the CLS and being exposed to the corrosive media, the measured ECP is the one belonging to the surface of the material. However, corrosion mechanism changes with the exposure of CLS to the corrosive media. Electrochemical interaction between the CLS and surrounding matrix initiate the corrosion at the interface and matrix begins to be corroded and propagate along the microstructure.

- Presence of CLS accelerates the corrosion if and only if new cross sectional surfaces are generated by any cutting action. Because, each new cross sectional surface may intercept with CLS. If this surface is exposed to the corrosive media, corrosion preferentially initiates and propagates faster than that of surface of parent metal. However this mechanism can be stopped by minimizing the CLS in the microstructure. The intensity and morphology of CLS can be controlled with better manipulation of casting parameters.

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