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MECHANICAL AND CORROSION PROPERTIES OF AA8011 SHEETS AND FOILS

MEHANSKO VEDENJE IN KOROZIJSKE LASTNOSTI TRAKOV IN FOLIJ AA8011

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The mechanical and corrosion properties of a twin-roll cast Al-Fe-Si aluminum alloy with 0.74 % Fe and 0.52 % Si (AA8011) were investigated. The influence of the thermo-mechanical processing route on the mechanical behavior of AA8011 sheets was determined. Comparisons were made with AA3003 and Al99.5 sheets. The restoration of the mechanical properties was used in the analysis of the recrystallization behavior of the twin-roll cast AA8011 alloy deformed under cold-working conditions and subsequently annealed. The effect of the cold rolling-annealing combination on the deep drawing properties is presented. The corrosion properties were determined using accelerated corrosion-testing methods and compared to the properties of the Al99.5 sheets.

Keywords: AA8011 sheets, processing mechanical properties, corrosion properties

Podan je opis mehanskih in korozijskih lastnosti neprekinjeno ulite zlitine aluminija z 0,74 % Fe in 0,52 % Si (AA8011) ter vpliv termomehanskega procesiranja na mehansko vedenje trakov AA8011 in primerjava s trakovi zlitine AA3003 in Al99,5. Sprememba mehanskih lastnosti je uporabljena pri analizi rekristalizacijskega vedenja neprekinjeno ulite zlitine AA8011, ki je bila hladno deformirana in žarjena. Predstavljen je vpliv kombinacije hladno valjanje–žarjenje na lastnosti pri globokem vleku. Korozijske lastnosti so bile določene z uporabo pospešenih metod preskušanja in primerjane z lastnostmi trakov Al99,5.

Ključne besede: trakovi AA8011, procesiranje, mehanske lastnosti, korozijske lastnosti

1 INTRODUCTION

Twin-roll casting has been accepted worldwide as a cost-effective method for producing a wide variety of flat rolling products. The twin-roll casting process converts molten aluminum alloys directly into a coiled sheet suitable for cold rolling, effectively eliminating the operations associated with traditional D.C. casting and the hot-mill method of coil production[1-3]. The AA8011 alloy is one of the most popular commercial alloys in the Al-Fe-Si ternary system and is often produced by the twin-roll casting process. In contrast to the other alloys in this system, AA8011 has certain characteristics that compensate for the impact of the high solidification rate encountered during twin-roll casting. Silicon, which is present in this alloy in quantities nearly as large as iron, limits the supersaturation of the matrix phase with Fe by causing a substantial level of Fe precipitation. Hence, the chemistry of this alloy makes it very attractive for a thin-gauge high-speed casting process that involves a very high solidification rate[4-6]. Some producers use the AA8011 alloy as a substitute for the AA3003 aluminum alloy in the production of semi-rigid containers and similar products for packaging in order to avoid some problems, such as the contamination of the melting and holding furnaces generated from the AA3003 and to obtain materials with better quality in terms of the consistency of the mechanical properties and a good grain size[7,8].

The present work is concerned with the mechanical and corrosion behavior of an AA8011 aluminum alloy with 0.74 % Fe and 0.52 % Si produced by the cold rolling of a twin-roll cast strip. The mechanical behavior during the thermo-mechanical processing of the twin-roll cast AA8011 alloy was investigated and, to some extent, compared to the behavior of AA3003 and Al99.5 sheets. The corrosion properties of the AA8011 sheets were investigated in fresh water and sodium chloride solution and compared with the properties of Al99.5.

2 EXPERIMENTAL

The present investigations were performed on samples of commercial AA8011 Al-Fe-Si alloy with 0.74 % Fe and 0.52 % Si. The alloy was continuously cast to a 7 mm thickness before being cold rolled to a final thickness of 0.07 mm, with intermediate annealing at gauges of 2 mm and 0.5 mm under industrial conditions, **Table 1**.

Some samples of twin-roll cast strip were cold-rolled on an experimental rolling mill with the aim to investigate the influence of cold-rolling deformation degree and the combination of rolling-annealing practice on the earing of the sheets. The changes in the tensile properties during the thermo-mechanical processing were determined for the rolling (RD), diagonal (DD) and transverse (TD) directions. The changes in the

Table 1: Thermo-mechanical processing of the investigated Al-Fe-Si alloy
Tabela 1: Termomehanska obdelava zlitin AlFe-Si

Equipment	Caster	Cold mill	Annealing furnace	Cold mill	Annealing furnace	Cold mill
Processing	Twin roll cast strip, gauge 7 mm	Rolling, 4 passes (sheet, 2 mm)	Annealing 450 °C 6 h	Rolling 3 passes (sheet 0.5 mm)	Annealing 450 °C 6 h	Rolling 4 passes (foil 0.07 mm)

mechanical behavior during cold rolling of the AA8011 twin-roll cast strip were compared with the behavior of AA3003 and Al99.5 aluminum strips (aluminum of commercial purity - CP). Some samples of thin AA8011 sheets/foils in three different gauges, previously deformed by different degrees of rolling, were annealed for 1 hour at temperatures between 150 °C and 350 °C in order to investigate the effect of the rolling deformation degree on the temperature range of the primary recrystallization. The recrystallization response curves were determined by tensile measurements on the specimens after annealing in a laboratory furnace. Tensile and deep-drawing tests were performed using Instron and Erichsen equipment. The accelerated corrosion testing methods were used to determine some of the corrosion characteristics: monitoring of the corrosion potential, E_{corr}; linear polarization with determination of the polarization resistance, R_{pol}; and corrosion current and corrosion rate, using the potentiodynamic method. The corrosion tests were performed with a PAR-332 system (potentiostat-galvanostat mod 273, MK-047 cell, software PAR SOFTCORR 352 II) in fresh water and 0.51 mol sodium chloride solution. The corrosion properties of the AA8011 sheet were compared with the properties of the CP Al sheet processed under similar conditions.

3 RESULTS

Samples of an AA8011 twin-roll cast strip were submitted to cold rolling, down to a 0.07 mm-thick foil with two inter-anneals. The process of fabrication is described in **Table 1**. **Figure 1** illustrates the influence of the selected scheme of downstream processing on the mechanical properties of the annealed sheets/foils. The tensile strength of the annealed sheets decreases by about 10 % and the yield stress decreases by about 20 % after each cold rolling-annealing part of the downstream processing scheme. The elongation of the annealed sheets is almost twice as much as the elongation of the twin-roll cast strip. **Figure 1** also shows the effect of downstream processing on the anisotropy of the mechanical properties in three directions in the plane of the sheets: the rolling (RD) transverse (TD) and diagonal (DD) directions. The twin-roll cast strip shows the lowest tensile strength and the highest yield stress and elongation in the diagonal direction. After the first part of the cold rolling and annealing, the material shows the highest strength in the rolling direction. Both the tensile strength and the yield stress decrease with an increase of the orientation angle from the rolling to the transverse direction. The elongation of the annealed 2 mm thick sheet is significantly higher, if compared to the twin-roll cast strip, and increases in the plane of the sheet from the rolling to the transverse direction. The anisotropy of the mechanical properties of the annealed 0.5 mm-thick sheet (foil stock gauge) is quite different. This sheet shows the highest tensile strength and elongation but the lowest yield stress in the diagonal direction.

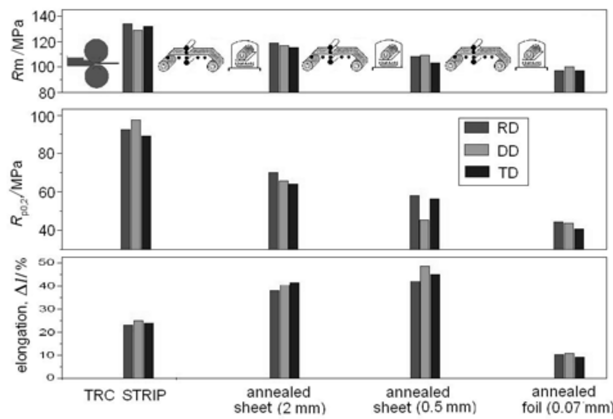


Figure 1: The dependence of the mechanical properties on the cold rolling and annealing of the AA8011 twin-roll cast strip
Slika 1: Odvisnost mehanskih lastnosti neprekinjeno ulitega traku AA8011od hladnega valjanja in žarjenja

Figure 2 presents the mechanical properties of the alloys and their anisotropy in the plane of the sheet/foil, depending on the degree of cold-rolling deformation. The behavior of three different, but competitive, Al-foil materials (AA8011, AA3003 and Al99.5) was simultaneously monitored during the cold rolling from 0.5 mm to 0.070 mm. The strength of the AA8011 hardened sheets lies between the strength of CP Al and AA3003. The hardened AA8011 sheets also show tighter ranges of tensile strength and yield stress in the three investigated directions in the plane of the sheet/foil. The differences in the tensile strength and the yield stress of the other two alloys in the three directions are greater, especially in the case of the CP Al sheets/foils. All three Al alloys show the highest strength in the transverse direction. The deformed AA8011 sheets/foils show a slightly better plasticity than the AA3003 sheets/foils.

The as-cast microstructures of the longitudinal and transverse sections for the 7 mm roll-cast strip are shown in **Figure 3**. The centre segregation, which is a typical feature in conventional 7 mm twin-roll cast strip, is observed (longitudinal sections in figure 3) and can be

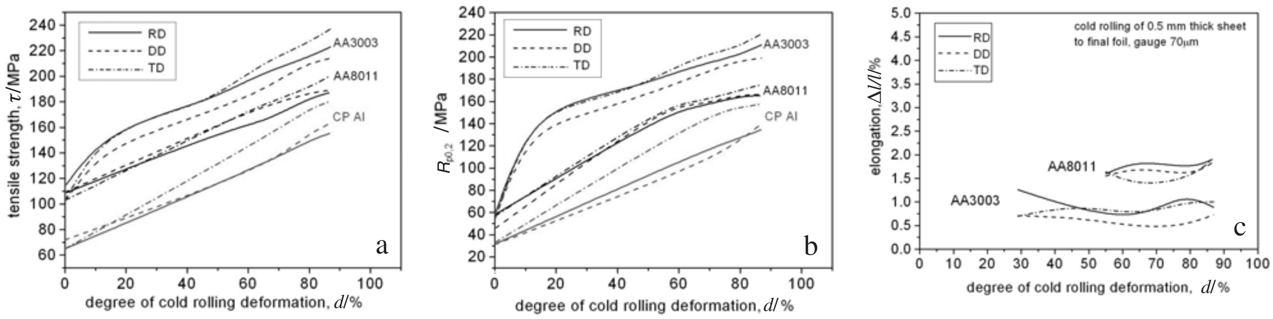


Figure 2: Dependence of (a) yield stress, (b) tensile strength and (c) elongation on the degree of cold-rolling deformation. Alloys: AA8011, CP Al, AA3003. RD – rolling direction, DD – diagonal direction, TD – transverse direction

Slika 2: Odvisnost (a) meje plastičnosti, (b) raztržna trdnost in (c) raztezek od stopnje hladnega valjanja zlitine: AA8011, CP Al, AA3003. RD – smer valjanja, DD – smer diagonale, TD – prečna smer

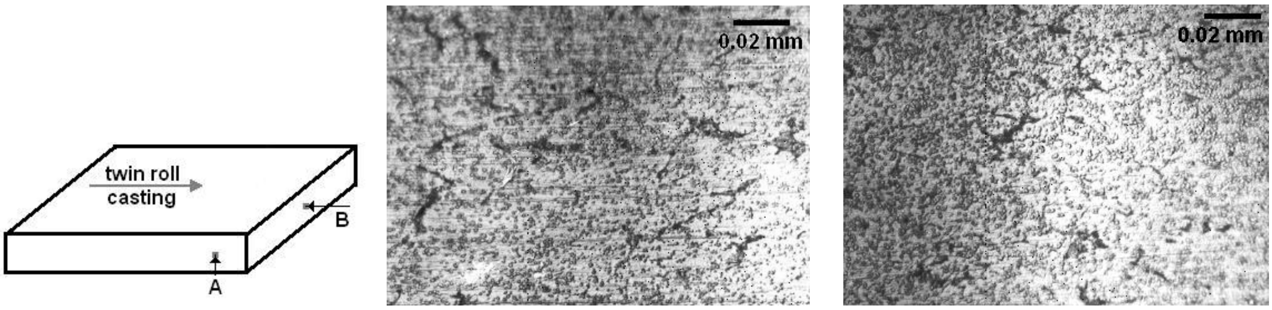


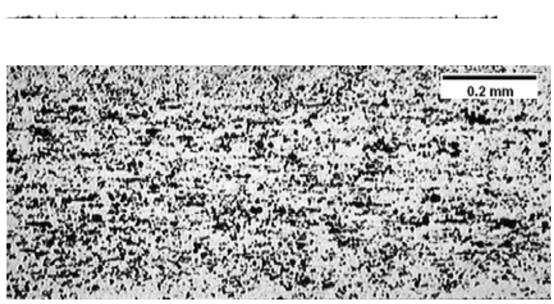
Figure 3: Longitudinal and transverse sections showing a typical distributed segregation of as-cast AA8011, 7 mm thick strip

Slika 3: Vzdolžni in prečni prerez, ki prikazujeta značilno porazdeljeno segregacijo v neprekinjeno ulitem 7milimetrskem traku zlitine AA8011

classified as a "distributed segregation pattern". The microstructures of the longitudinal sections of the sheets with 2 mm and 0.5 mm thicknesses after cold rolling and inter-annealing are similar, showing the small effect of the thermo-mechanical processing on the distribution of the micro-constituents inside the twin-roll cast strip, **Figure 4**. The segregation in the twin-roll cast aluminum alloys is most intensive on the center plane, and coarse particles are encountered in these places. The areas near the surfaces of the twin-roll cast sheets consist of significantly finer micro-constituents.

The effect of the thermo-mechanical processing scheme on the earring of the AA8011 sheets was analyzed for two cases. **Figure 5** illustrates the effect of cold rolling before and after the first inter-annealing on the earing of the finally annealed sheets. The processing of the twin-roll cast strip with an equal degree of cold-rolling deformation before and after the inter-annealing produces a sheet with 5 % of earing. The decreasing of the earing, for chosen processing conditions, is obtained by increasing the deformation degree during the first part of the rolling (before inter-annealing). **Figure 6** shows the effect of rolling deformation on the earing during the cold rolling of a sheet with a relatively high initial earing ($z = 5.2$ %). The level of earing slightly increases during the first 17 % of rolling degree, but further increasing of the deformation degree causes a decrease in the anisotropy. The acceptable earing level of 3 %, in this condition, can be achieved by cold rolling with a more than 30 % deformation degree.

a)



b)

Figure 4: Longitudinal sections showing the microstructure of inter-annealed 2 mm-thick sheet (a) and 0.5 mm-thick sheet (b)

Slika 4: Vzdolžni presek z mikrostrukturo vmesno žarjenega 2-milimetrskega traka (a) in 0,5-milimetrskega traka (b)

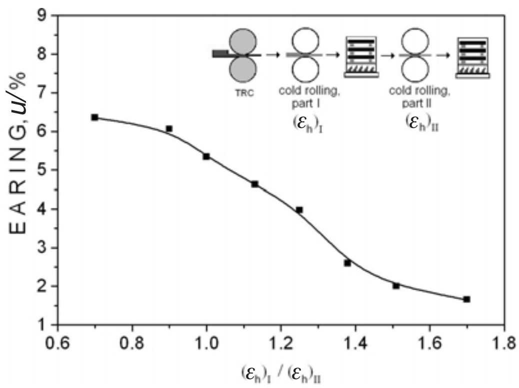


Figure 5: Earing of the annealed AA8011 sheets vs. the ratio of cold-rolling degree before and after the inter-annealing

Slika 5: Ušesenje žarjenega traka AA8011 v odvisnosti od razmerja stopnje hladnega valjanja pred vmesnim žarjenjem in po njem

Recrystallization response curves were determined with tensile measurements for three AA8011 foils, previously cold rolled with different deformation degrees, **Figure 7**. Changes in the strength and elongation after the annealing for 1 hour at different temperatures illustrate the effect of the previous cold-rolling deformation degree on the mechanical properties. The increase in the degree of the previous rolling deformation causes the moving of the primary recrystallization curve segments to a lower temperature, **Figure 8**.

The restoration of tensile strength for the AA8011 and Al99.5 sheets of 0.1-mm thickness deformed under equal cold-working conditions and subsequently annealed for one hour at temperatures between 150–350 °C is illustrated in **Figure 9**. The range of recrystallization temperatures of the AA8011 foil lies between 200 °C and 320 °C and for the Al99.5 foil it is between 170 and 250 °C. The Al99.5 annealed foil shows a tensile strength lower by almost 30 %. The microstructure of the annealed 100-μm-thick foil is presented in **Figure 10**.

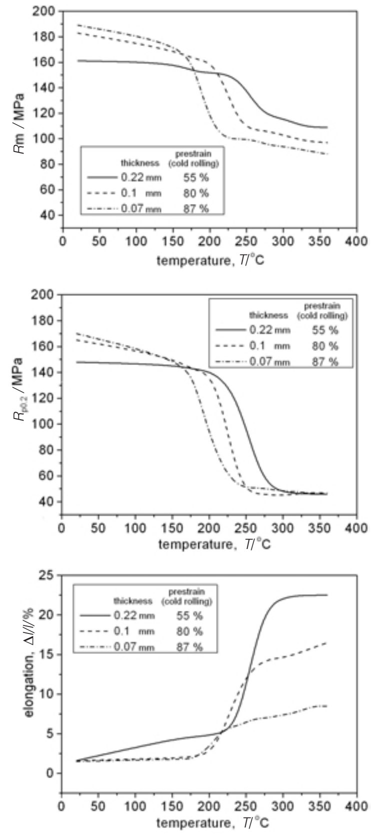


Figure 7: Dependence of tensile strength (a) yield stress (b) and elongation (c) on the annealing temperature and previous deformation

Slika 7: Odvisnost raztržne trdnosti (a), meje plastičnosti (b) in raztezka (c) od temperature žarjenja in predhodne deformacije

The performance of the packaging foils depends not only on the mechanical but also on the corrosion properties. Our investigations of the corrosion properties consisted of monitoring the corrosion potential changes in fresh water and in 0.51 mol sodium chloride solution, and then determining the polarization resistance, the corrosion current and the corrosion rate in both

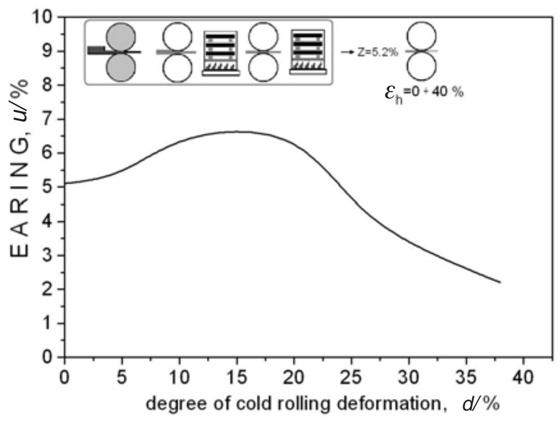


Figure 6: Earing of the deformed AA8011 sheets vs. the degree of cold-rolling deformation

Slika 6: Ušesenje deformiranega traka AA8011 v odvisnosti od stopnje deformacije s hladnim valjanjem

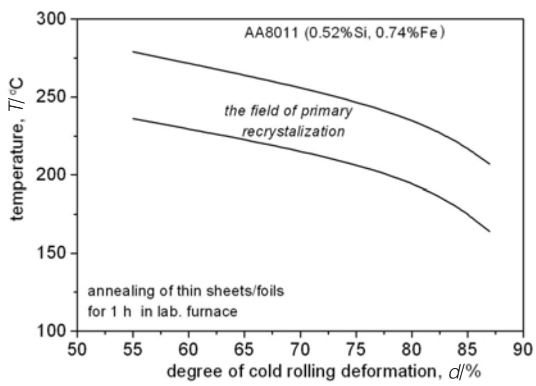


Figure 8: Influence of the cold-rolling deformation degree on the primary recrystallization temperature field of the AA8011 thin sheet/foil

Slika 8: Vpliv deformacije s hladnim valjanjem na polje primarne temperature rekristalizacije za trak in folijo zlitine AA8011

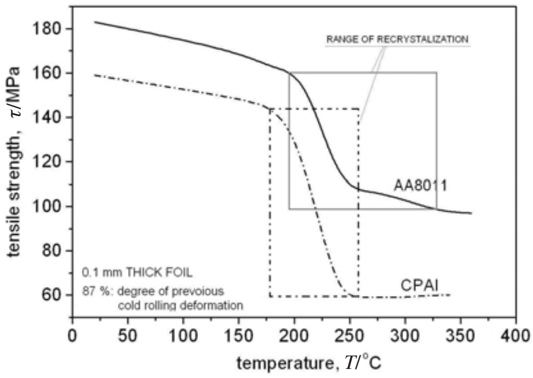


Figure 9: Restoration of the tensile strength of AA8011 and Al99.5 sheets of 0.1-mm of thickness (produced under equal cold-working conditions)

Slika 9: Obnova raztržne trdnosti trakov zlitin AA8011 in Al99,5 z debelino 0,1 mm (izdelano pri enakih pogojih hladne predelave)

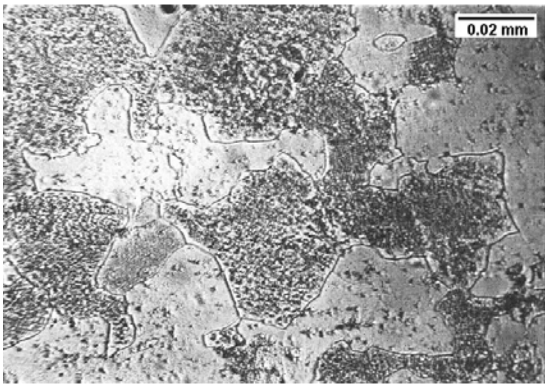


Figure 10: Longitudinal section showing the microstructure after annealing of 100-µm-thick foil produced from AA8011 twin-roll cast strip

Slika 10: Vzdolžni prerez z mikrostrukturo 100 µm debele folije, izdelane iz neprekinjeno ulitega traka zlitine AA8011

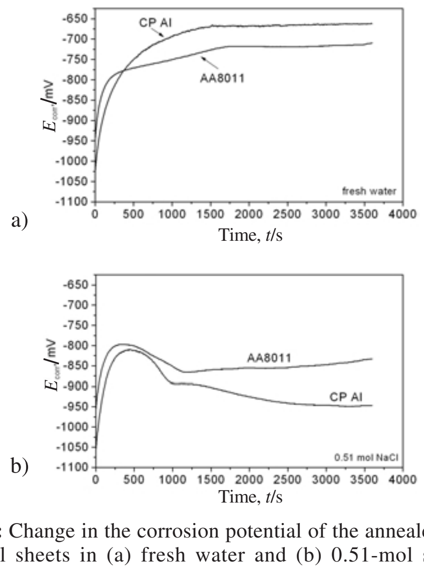


Figure 11: Change in the corrosion potential of the annealed AA8011 and CP Al sheets in (a) fresh water and (b) 0.51-mol solution of sodium chloride

Slika 11: Sprememba korozijskega potenciala žarjenih trakov AA8011 in CP Al v sveži vodi (a) in v 0,5 L molarni raztopini natrijevega klorida (b)

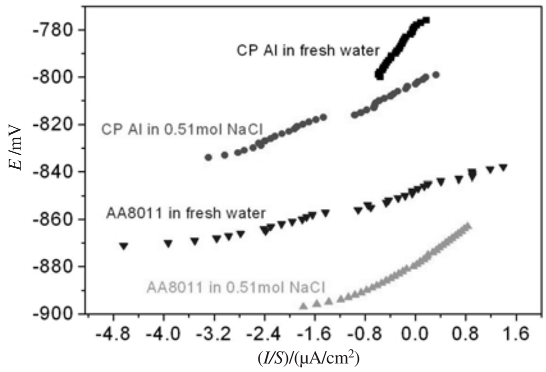


Figure 12: Dependence of the potential on the current density of the tested Al alloys under conditions of linear polarization testing.

Slika 12: Odvisnost med potencialom in gostoto toka za preskušene Al-zlitine pri linearni polarizaciji

solutions. The corrosion characteristics of the Al99.5 sample, that was used as a reference material and produced in the same way, were simultaneously monitored. **Figure 11** presents the change in the corrosion potential of the annealed thin sheets in both corrosion media. The AA8011 sheet exhibits the lower corrosion potential in fresh natural water, by 7 % (47 mV), compared to CP Al sheet. After the initial period of

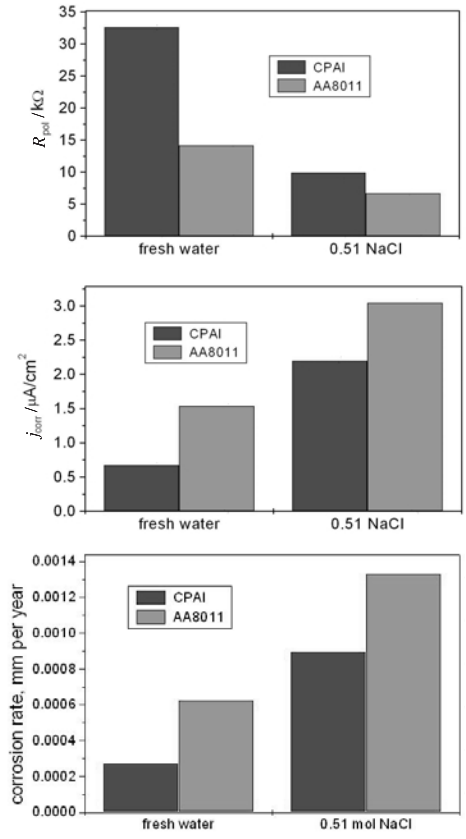


Figure 13: Polarization resistance, corrosion current and corrosion rates of the annealed AA8011 and Al99.5 sheets.

Slika 13: Polarizacijska upornost, korozijski tok in hitrost korozije za žarjene trakove AA8011 in Al99,5 passivation, both materials show constant values of E_{corr}. The tested sheets show similar changes of corrosion potential in the 0.51 mol sodium chloride solution. They exhibit the same shape of peak during the initial passivation, but the AA8011 sheet shows a higher corrosion potential than the CP Al sheet, by 12 % (114 mV).

Figure 12 presents the dependence of the potential on the current density of the tested Al alloys under conditions of linear polarization testing. The 8011 alloy has lower potentials than the CP aluminum in both corrosion media. The polarization resistance of the CP aluminum sheet in fresh water is higher, almost twice, and in sodium chloride by one third, if compared to the AA8011 values (**Figure 13**). The values of the corrosion current and the corrosion rates are analogous and correspond to the polarization resistance relations. The 8011 aluminum alloy shows a higher corrosion rate in both corrosion media, almost twice as high in fresh water, and by one third in 0.51 mol sodium chloride solution, compared to the CP aluminum annealed sheet.

4 CONCLUSION

The tensile strength of the annealed sheets decreases by about 10 %, and the yield stress decreases by about 20 % after each cold rolling-annealing part of the down-stream processing scheme. The elongation of the annealed sheets is almost twice as high as the elongation of the twin-roll cast strip. The strength of the AA8011 hardened sheets lies between the strength of the CP Al and AA3003, but hardened AA8011 sheets also show tighter ranges of tensile strength and a yield stress in the plane of the sheet/foil. Centre segregation, which is a typical feature in conventional 7 mm twin-roll cast strip, is observed and can be classified as a "distributed segregation pattern". Reducing the earing, for selected processing conditions, is possible with an increase in the deformation degree during the first part of the rolling (before inter-annealing). The polarization resistance of the AA8011 sheet in fresh water is lower, almost twice as low, and in sodium chloride by one third, if compared to the AA99.5 values. The AA8011 sheet shows higher corrosion rates in both corrosion media, almost twice as high in fresh water, and by one third in a 0.51 mol sodium chloride solution, compared to the CP aluminum annealed sheet.

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