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Effect of Cold Rolling Reduction Rate on Corrosion Behaviour of Twin-roll Cast 8006 Aluminium Alloys

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Abstract: Utilization of aluminum alloys in the automotive industry takes a crucial role in recent years due to their excellent properties such as corrosion resistance and light weight. 3003 and 8006 aluminum alloys have been particularly used as a heat exchanger compartment due to their corrosion resistance feature which has a perfect match for a heat exchanger fin stocks and a destructive salty environment in this car's part. In the present work, an effect of cold rolling reduction (CRR) rate on the corrosion twin-roll cast 8006 aluminium alloys was investigated. Firstly, the aluminium alloy was submitted to twin-roll casting process to achieve 8.5 mm thickness sheet. Then, homogenization annealing was applied between 550 °C and 600 °C. Subsequently, two cold rolling routes were subjected at different CRR rates of 94% and 98%, respectively. Finally, the aluminium sheets were annealed between 400 °C and 450 °C for 60 min. in a furnace for electrochemical corrosion tests. Electrochemical corrosion tests were performed in 1 M NaCl and H_2O_2 solution, and open circuit potential and polarization curves were successfully achieved. The surface features of the specimens before and after corrosion tests were assessed using stereomicroscopy and 3D profilometer. Based on the results, an increase in the various CRR rates depending on cold rolling route applied decreases the corrosion resistance of the twin-roll cast 8006 aluminum alloys. Thus, they could be very versatile materials for heat exchanger fin stock materials.

Keywords**:** Twin-roll cast aluminium, 8006, corrosion, polarization curves, cold rolling reduction rate

İkiz Merdane Sürekli Döküm 8006 Alüminyum Alaşımlarının Korozyon Davranışına Soğuk Hadde Ezme Oranının Etkisi

Özet: Alüminyum malzemelerin, korozyon direnci ve hafiflik gibi harika özelliklerinden dolayı, otomotiv sektöründe kullanımı son yıllarda önemli bir yer tutmaktadır. Özellikle ısı eşanjörü (heat exchanger) elemanı olarak 3003, 8006 grubu hadde alüminyum alaşımlarının kullanımı, eşanjörlerin korozif bir sıvı ortamı içermesinden dolayı ve bu malzemelerin korozyon özelliklerinden dolayı tercih edilmektedir. Bu çalışmada, ikiz merdane sürekli döküm yöntemi ile elde edilen 8006 grubu alüminyum alaşımlarının korozyon özelliklerine soğuk haddeleme ezme oranının etkisi incelenmiştir. 8006 Alüminyum alaşımı, öncelikle soğuk deformasyon haddesi olan ikiz merdanelerin arasına 8.5 mm kalınlıkta levha olarak döküldü ve ardından 550 ila 600 ^{o}C arasında homojenleştirme tavlamasına tabi tutuldu. Hemen ardından ezme oranı farklı olan iki haddeleme işlemine tabi tutularak sırasıyla, %94 ve %98 oranında bir ezme işlemi uygulandı. Nihai olarak, 400 oC ila 450 oC arasında bir sıcaklıkta normalizasyon tavlamasına maruz bırakıldı. Elde edilen numunelerin yüzeyi, 1 M NaCI + H_2O_2 içeren çözeltide korozyon testleri (açık devre potansiyeli ölçümü ve polarizasyon eğrileri eldesi)

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öncesi ve sonrası, stereo mikroskop ile yüzey görünümü analizine tabi tutuldu ardından 3B yüzey pürüzlülük ölçümü yöntemi kullanılarak, yüzey pürüzlülüğü analizi gerçekleştirildi. Elde edilen sonuçlara göre, soğuk deformasyon işlemine bağlı olarak uygulanan farklı ezme oranındaki artışın ikiz merdane sürekli döküm yöntemi ile elde edilen 8006 alüminyum alaşımlarının korozyon davranışında azalmaya bağlı olarak, korozyon direncinin arttığını göstermiştir.

***Anahtar Kelimeler*:** İkiz merdane sürekli döküm alüminyum, 8006, korozyon, polarizasyon eğrileri, soğuk hadde ezme oranı

1. INTRODUCTION

Metal alloy fabrication or structure manufacturing processes, including rolling, extrusion, mechanical grinding, and machining generally subjects high shear deformation to the surface region of aluminium products which brings about various surface roughness profiles on the surface features [1-5]. Each cold rolling reduction deformation (CRRD) technique such as conventional cold rolling, reversing cold rolling, and twin roll casting (TRC) results in significantly different depth mapping characteristics as well as surface roughness on the surface of cold-rolled aluminium alloys [6-10].

A one of the CRRD techniques, twin-roll casting (TRC), has a significant role in the determination of the surface features of aluminium alloys [8, 11]. The presence of the surface cold reduced region obtained by TRC may crucially affect the corrosion performance of aluminium alloys due to the presence of high dislocation density, residual stress, alloying element segregation at the grain boundaries and surface roughness [12, 13]. Le et al. [8] reported that with an increase in the cold rolling reduction rate, longer wavelengths of roughness could be crushed more easily which could improve the corrosion resistance of aluminium alloys.

8006 aluminium alloys are widely used for manufacturing the packaging foils and sheets for common heat exchanger applications [13, 14]. Increasing demands of the industry on corrosion resistance, mechanical properties and formability has evoked an intensive investigation of sheets and foils with an influence of cold rolling reduction rate [15-17]. Although TRC aluminium alloy sheets and foils are optimal candidates for further cold rolling reduction process, there is no available data on an influence of CRR rates on TRC 8006 aluminium alloy's corrosion properties. Also, corrosion characteristics of various aluminium alloys produced by TRC resulting surface roughness profiles has been subjected to attention for the past decades because of its importance in pitting corrosion resistance [2, 6, 13, 15]. The present work is aimed to study the effect of cold rolling reduction rate as that achieved during the twin-roll casting process, on corrosion behaviour of 8006 aluminium alloys in 1M NaCI aqueous solution environment.

2. EXPERIMENTAL PROCEDURES

2.1. Specimens and surface preparations

Twin-roll cast (TRC) 8006 aluminium alloys with two different thicknesses provided by Assan Aluminium Company was used as the base material. The composition (wt. %) of the TRC 8006 aluminium alloys are listed in **Hata! Başvuru kaynağı bulunamadı.**. At the end of production process, comprising the TRC casting with a thickness of 8.5 mm, homogenization annealing performed between 550 °C and 600 °C and, the two different final thicknesses (150 µm or 180 µm) of the TRC 8006 aluminium alloy sheets were obtained. Prior to experiments, the aluminium sheet samples were ultimately annealed between 400 °C and 450 °C for 60 min. in a furnace to gain a homogenous microstructure.

After twin-roll casting processing and homogenization annealing, the TRC 8006 aluminium sheets were cold deformed in one direction between working the rolls to gradually reduce their thickness after numerous successive passes. The plates were cold rolled to a 94%, and 98% reduction in its thickness. Then, the samples were cut into 5 cm x 5 cm, with surfaces parallel to the rolling direction. All samples were sequentially rinsed in acetone and 2-propanol with ultrasonic cleaner for 5 min. at room temperature and dried before the electrochemical measurements.

Table 1. Chemical composition of the Twin-roll cast 8006 aluminium alloy used (wt. %).

Sample	**Fe**	**Si**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
TRC 8006	1.50	1.130	0.020	0.80	0.0025	0.0037	0.020	0.15	Balance

2.2. Electrochemical analysis

Electrochemical measurements have been employed to assess corrosion susceptibility of TRC 8006 aluminium alloys in the heat exchanger environments. Tests were performed using a Gamry's conventional three-electrode cell system (model PC14/750 Potentiostat/ Galvanostat/ ZRA), in 1M NaCI solution of pH 5.5 according to ASTM G69-12, aerated for 60 min. by magnetic mixer, before start (Figure 1). The cell was assembled with the TRC 8006 aluminium sample as working electrode (WE), a saturated calomel electrode was used as a reference (RE) and a graphite rod was used as an auxiliary electrode (AE). Exposed areas for working and auxiliary electrode were 0.785 cm^2.

The open-circuit potential (OCP) was recorded for 6000 seconds waiting, in any case, to investigate how long the OCP value of the samples reaches a steady state. Polarization curves were recorded in a single sweep starting from -0.5 V versus OCP going as high as 0.5 V versus OCP. The scan rate was 0.20 mV/s. The measurements were conducted at room temperature (25 °C). From this experiment, I_{corr} and E_{corr} values were measured using Tafel plot and the corrosion rate in milli-inches per year (mpy) was determined. All trials were repeated three times to ensure reproducibility and accuracy of the measurements.

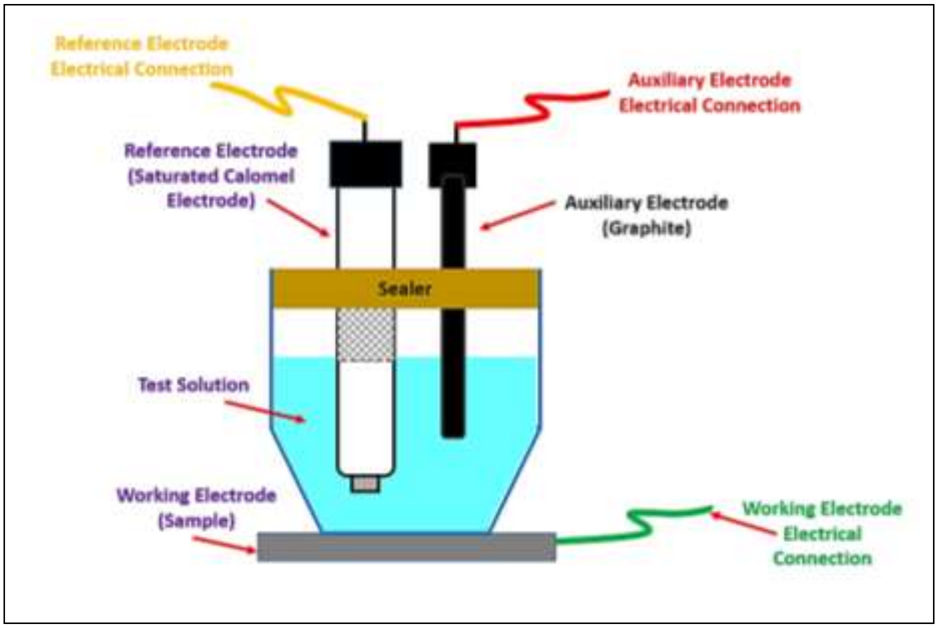

Figure 1. A typical three electrodes paint-cell used for electrochemical testing

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2.3. Microstructure and surface observations

The surface morphology evolution was analysed using stereomicroscopy (Nikon SMZ

1500, Tokyo, Japan) and 3D optical microscopy (Bruker Contour GT-I, Germany). 3D optical microscope was applied to determine 3D surface profiles of the TRC 8006 aluminium alloys with the different cold rolling reduction rates. For stereomicroscope examination of the samples before and after corrosion tests, specimens were rinsed with distilled water.

3. RESULTS and DISCUSSION

3.1. Surface morphology investigation

A characteristic rolling topography and contained a number of defects in the form of transverse cracks, shingles and holes were observed throughout the surfaces of the cold rolling reduced TRC 8006 aluminium alloys before exposure to the solution, shown in Figure 2. Moreover, surface profiles were qualitatively characterized by 3D optical microscopy images. The depth mapping images through the specimen' surface were depicted in Figure 3(a) and (b) showed an influence of cold rolling reduction (CRR) rate on the surface topography. Figure 3(a) depicted the surface topographical changes of the TRC 8006 aluminium alloy with a CRR of 94%. In Figure 3(a), small hills were presented on the surface of the specimen and surface roughness (R_a) value was 0.554 µm. Figure 3(b) showed the surface morphology of the TRC 8006 aluminium alloy with a CRR of 98% which has more cold rolling reduction rate compared to the one with a CRR of 94%. Compared to the TRC 8006 with a CRR of 94% sample, smaller hills were captured on the surface topography and a lower surface roughness value which is about 0.344 µm (Figure 3(b)).

(a) (b)

Figure 2. Stereo microscopy images of TRC 8006 aluminium alloys before corrosion tests applied: thickness of a) 150 µm and b) 180 µm.

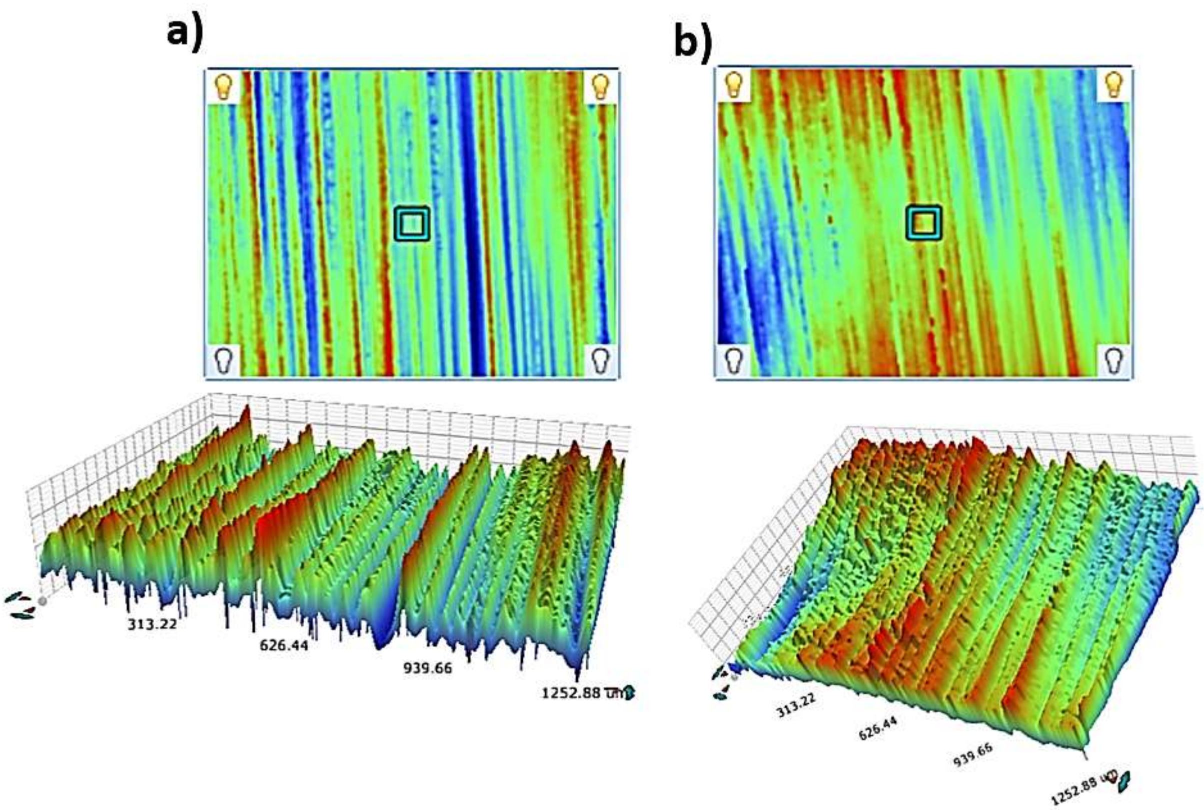


Figure 3. 3D topography images of the TRC 8006 aluminium alloys used: a CRR of 94% (a) and 98% (b).

3.2. Open-circuit potential results

Corrosion potential data given in Figure 4 show that the TRC 8006 aluminium alloys with two different cold rolling reduction rates, the TRC 8006 aluminium alloy exhibited a relatively stable potential around -780 mV_{SCE}, close to the reported critical pitting potential values of aluminium [18]. Cold rolling reduction at increasing reduction rates up to 98% caused the formation of much deeper transients of increased longevity in the corrosion potential, starting from an increasingly negative potential and lasting for approximately half an hour before the potential stabilised at a rest potential similar to that of the TRC 8006 aluminium alloy with a CRR of 94 %. The initial potentials of the high cold rolled samples were close to -980 mV_{SCE} and increased slowly towards a rest potential near that of the TRC 8006 aluminium alloy with a CRR of 94 % sample over nearly an hour. Both samples had a monotonically characteristic increase towards the rest potential.

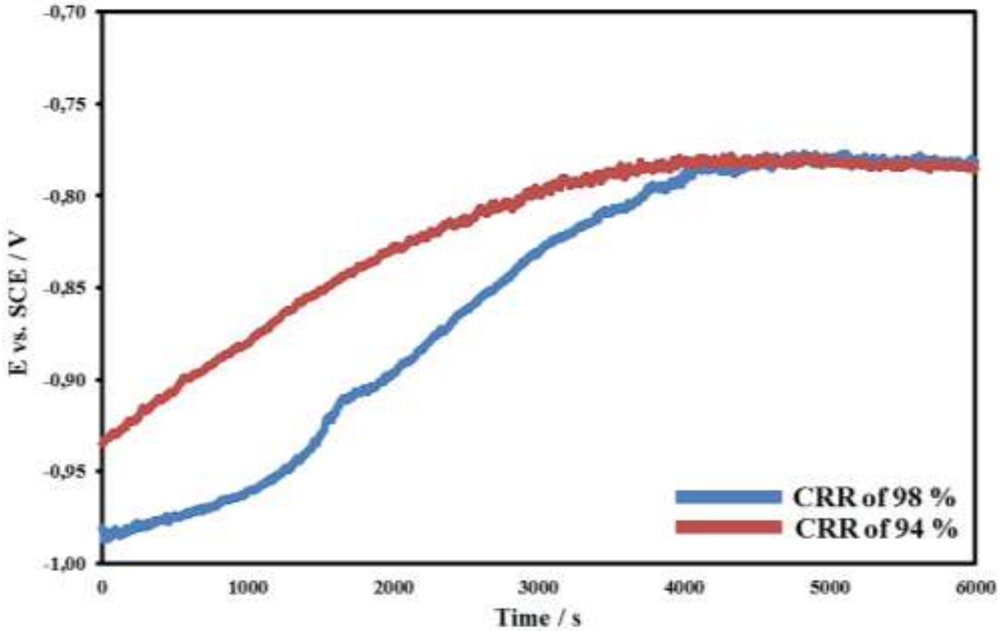


Figure 4. Corrosion potential vs. exposure time in 1M NaCI solution for the TRC 8006 aluminium alloys with different cold rolling reduction (CRR) rates.

3.3. Polarization curve measurements

A comparison of polarization curves for different cold rolling reduction (CRR) rates done is shown in Figure 5. With the increase of cold rolling reduction (CRR) value, the corrosion potential of the specimen decreased and anodic dissolution current density increased. Cathodic current density increased as the CRR value reached 98% (Figure 5). It can be seen that an increase in CRR rate for TRC 8006 aluminium alloys used improved the corrosion resistance of the specimens. Moreover, TRC 8006 aluminium alloys would not be passivated in the 1M NaCI aqueous solution containing H_2O_2.

The electrochemical parameters, including corrosion current density, corrosion potential, anodic and cathodic Tafel slopes are fitted and listed in **Hata! Başvuru kaynağı bulunamadı.**. The corrosion rate in mpy was determined from the E_{corr} and I_{corr} values measured from the Tafel plots as per the ASTM Standard G69-12 [19]. The results obtained clearly indicated that an improvement in corrosion resistance can be explained by the help of surface roughness. There may be the presence of shorter wavelength of highly cold rolled TRC 8006 aluminium alloys which provides initial corrosive attack regions on Al-rich phases forming a protective layer.

Table 2. Fitted electrochemical parameters at different cold rolling reduction CRR rate.

CRR (%)	E_{corr} vs. SCE (mV)	i_{corr} (μA.cm^{-2})	b_a vs. SCE (x10^{-3} V/decade)	b_c vs. SCE (x10^{-3} V/decade)
94	-796	1450	781.3	665.8
98	-714	126	67.50	174.2

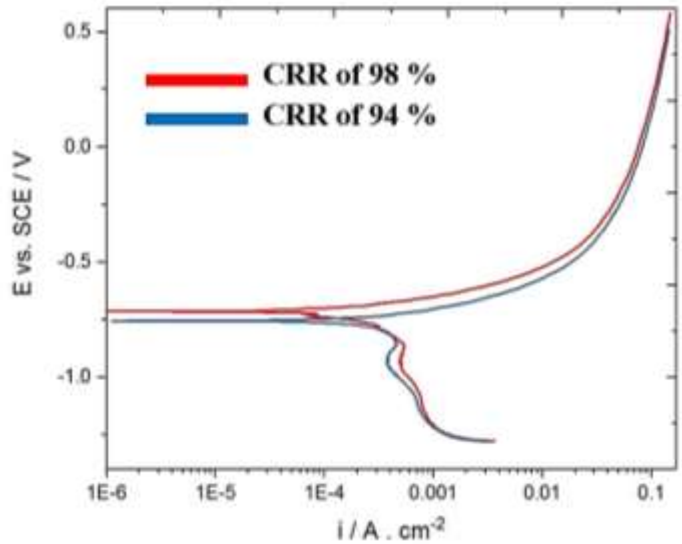
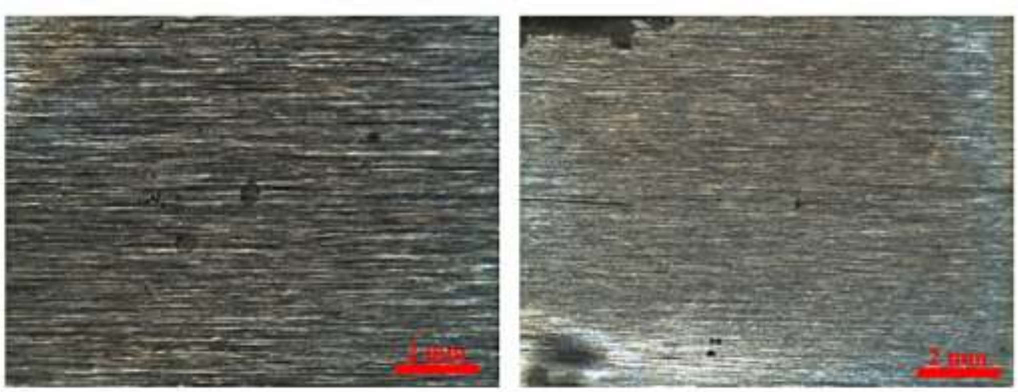


Figure 5. Effect of cold rolling reduction rate on the polarization behaviour of TRC 8006 aluminium alloys in 1M NaCI solution containing 5 wt. % NaCI and 2.52 ml H_2O_2 at room temperature.

3.4. Surface characterization after corrosion tests

An effect of cold rolling reduction rate on the corrosion morphology of the cold rolling reduced samples was investigated in the 1M NaCI aqueous solution. Figure 6 shows the stereomicroscope images of the surface morphology for the TRC 8006 aluminium alloys with different CRR values after polarization curve measurements in the test environment, 1M NaCI aqueous solution. In general the mode of corrosion was that of localised crystallographic attacks extending mostly in the rolling direction. The pits observed were in rounded or elliptic shape (Figure 6). Figure 6(a) presents the surface morphology of the TRC 8006 aluminium alloy with a CRR of 94%. It is clearly seen that several pits appeared with large pit mouth. Figure 6(b) shows the surface view of the TRC 8006 aluminium alloy with a CRR of 98%. In Figure 66b, many pits with smaller pit mouth compared to the other one can be clearly seen. With CRR value rising, pit sizes tended to decrease, while the pit number and pit size distribution was increased.



(a) **(b)**

Figure 6. Stereo microscopy images of TRC 8006 aluminium alloys after corrosion tests applied: CRR of a) 94% and b) 98%.

4. CONCLUSIONS

Twin-roll cast 8006 aluminium alloy with different cold rolling reduction rates of 94% and 98% has been studied. Major conclusions drawn from the work are summarised below:

- Shorter wavelength of roughness, less surface defects like cracks, shingles and holes were noticed on the surface of the TRC 8006 aluminium alloy with a CRR rate of 98% compared to that of 94%. This may improve the surface corrosion resistance and thus benefit in handling of good heat exchanger aluminium foils.
- The TRC 8006 with 98% showed better corrosion resistance than the other with 94% in 1M NaCI aqueous solution.
- Pitting size and distribution on the surface of the TRC 8006 with 98% in 1 M NaCI aqueous solution was appreciably less than that of the TRC 8006 with 94% and thereby the improvement in cold rolling reduction rate may result in higher corrosion resistance.

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