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STRAIN-RATE-DEPENDENT TENSILE CHARACTERISTICS OF AA2139-T351 ALUMINUM ALLOY

NATEZNA TRDNOST ALUMINIJEVE ZLITINE AA2139-T351 V ODVISNOSTI OD HITROSTI OBREMENJEVANJA

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Mechanical properties of sheet materials are affected by the strain conditions. In this study, the influence of the strain rate on the mechanical properties of AA2139-T351 aluminium-alloy sheet materials was studied, by applying uniaxial tensile tests on these materials at four different strain rates (0.03, 0.003, 0.0003, 0.00003) s^{-1}. Upon analysing the obtained results, it was seen that the elongation, anisotropy value and the load-carrying ability during the necking were reduced, while the AA2139-T351 yield strength, tensile strength, work-hardening coefficient and work-hardening rate were not significantly affected by the increasing strain rate.

Keywords: strain rate, tensile strength, aluminium alloys, AA2139-T351

Na mehanske lastnosti pločevin vplivajo pogoji obremenjevanja. V študiji je proučevan vpliv hitrosti obremenjevanja na mehanske lastnosti pločevine iz aluminijeve zlitine AA2139-T351, z uporabo enoosnega nateznega preizkusa tega materiala pri štirih različnih hitrostih obremenjevanja (0,03, 0,003, 0,0003, 0,00003) s^{-1}. Iz analize dobljenih rezultatov sledi; raztezek, vrednost anizotropije in nosilna sposobnost na kontrakcijo so se zmanjšali, medtem ko se meja tečenja AA2139-T351, natezna trdnost, koeficient utrjevanja in hitrost utrjevanja niso spreminjale pri povečani hitrosti obremenjevanja.

Ključne besede: hitrost obremenjevanja, nateznost, aluminijeve zlitine, AA2139-T351

1 INTRODUCTION

The main purpose of the current studies conducted on the materials used in vehicles, is to observe the fuel consumption when using light materials such as aluminium and magnesium alloys and, as a result, the reduction of the CO_2 fingerprint.[1] Aluminium alloys are widely preferred in the automotive and aerospace industries because these materials have superior characteristics such as low density, high strength and formability capabilities, resource availability, high corrosion resistance, good thermal and electrical conductivity.[1–2]

Tensile testing is a widely used method in order to determine a number of mechanical properties of materials and their deformation behaviours. Many parameters obtained from a tensile test may differ depending on the deformation conditions of the material.[3] The strain rate is known to affect the mechanical properties of many metallic materials by affecting the stress/strain relationship.[2] When the studies on the effect of the strain rate on the mechanical properties of aluminium alloys were examined, T. Ohwue et al.[4] determined, by examining the mechanical properties depending on the temperature and strain rate of aluminium/magnesium alloys, that the tensile strength is not affected by an increase in the strain rate at room temperature and that the amount of elongation shows very little tendency to decrease.[4] In the study of Y. Chen et al.[5] it was seen that the strain rate had no significant effect on the tensile behaviour of the AA6xxx and AA7xxx aluminium alloy series, that a strain-rate increase had no significant effect on the yield strength and that this increase only slightly improved the tensile strength.[5] In the study of O. – G. Lodema et al.[6] they determined, by examining the strain rate sensitivity of the AA1200 and 3103 aluminium alloys, that a slight increase in the tensile strength and elongation amount occurred depending on the increase of the strain rate although the yield strength was not affected. M. J. Hadianfard et al.[7] determined, at different strain rates of the AA5182 and AA5754 alloys, that the tensile strength and the elongation amount decreased with an increase in the strain rate while the yield strength was not affected due to the increase in the strain rate. F. Ozturk et al.[8] determined in their study that there is a decrease in the increase in the strain rate, the elongation amount and the work-hardening coefficient of the 5052 aluminium alloy at room temperature. A. L. Noradila et al.[9] studied the tensile properties and work-hardening behaviour of aluminium/magnesium alloys. F. Ozturk et al.[10] also studied the work-hardening and strain-sensitivity behaviour of the high-strength steel sheet in their other study.

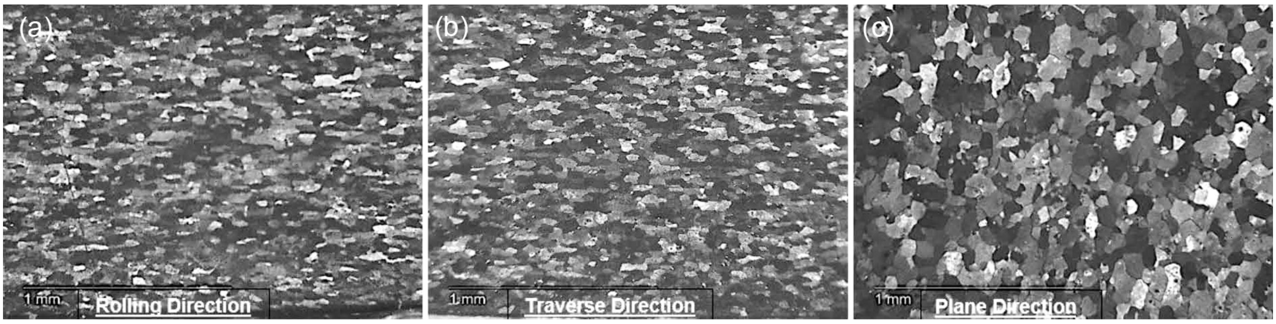

Figure 1: Microstructure of the AA2139-T351 alloy
Slika 1: Mikrostruktura zlitine AA2139-T351

Table 1: Chemical composition of AA2139-T351 sheet-metal material, in mass fractions (*w*/%)
Tabela 1: Kemijska sestava materiala pločevine AA2139-T351, v masnih odstotkih (*w*/%)

Material	Cu	Mg	Ag	Mn	Si	Fe	Ti	Zr	Sn	Ni	Cr	Al
2139-T351	4.80	0.43	0.31	0.27	0.06	0.06	0.06	0.03	<0.01	<0.01	< 0.01	Bal

Upon considering the studies in the literature, it is seen that researches were conducted to specify the mechanical properties of various aluminium alloys.

A determination of the mechanical properties of AA2139-T351 has a great importance for the aerospace industry. In this study, the mechanical properties of the AA2139-T351 aluminium-alloy sheet material were studied in detail at different strain rates and the obtained data was intended to be included into the literature.

2 MATERIAL AND EXPERIMENTAL PART

2.1 Material

In this study, the mechanical properties of the AA2139-T351 aluminium-alloy sheet material were examined depending on the strain rate. The chemical composition of this material is presented in **Table 1**. Moreover, microstructure photographs taken in the rolling direction, plane direction and traverse direction are also shown in **Figure 1**.

Tensile-test specimens in line with the ASTM E517 standard were used in the uniaxial tensile tests performed in order to determine of the mechanical properties. The cutting process was carried out on a water-jet machine to minimize the thermal effects that could have occurred in the sheet material during the preparation of the test specimens. Also, the notch effect that could have occurred during the strain was eliminated by polishing the side surfaces of the test specimens.

2.2 Experimental study

The mechanical properties of the AA2139-T351 aluminium-alloy sheet material depending on the strain rate at room temperature were determined by using a mechanical strain meter and an Instron 5500 tensile meter. According to the standard ASTM E517, the tension tests at four different strain rates (0.03, 0.003, 0.0003, 0.00003) s^{-1} were performed on the specimens with a sheet thickness of 1.6 mm in two different rolling directions (rolling direction, traverse direction). The average values were determined by repeating the tests three times for each parameter in order to reduce the margin of error. The yield strength, the tensile strength, the work-hardening coefficient, the total elongation and the anisotropy values were determined as a result of these tests, by obtaining true stress/true strain curves depending on the strain rate. In addition, the strain-rate sensitivity, work-hardening rate and load capacity on necking were examined.

3 RESULTS AND DISCUSSION

3.1 Tensile-test results

The change in the mechanical properties of the sheet material was determined by performing the tensile tests at the (0.03, 0.003, 0.0003, 0.00003) s^{-1} strain rates. The data obtained from the tensile test are given in **Table 2**.

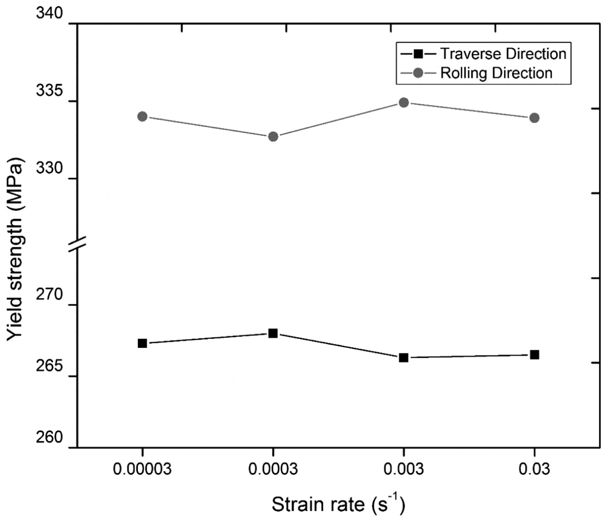

Figure 2: Yield strength – strain rate relation
Slika 2: Odvisnost meja plastičnosti – hitrost obremenjevanja

The strain rate/yield strength relationship of the AA2139-T351 aluminium alloy is shown in **Figure 2**. When **Figure 2** is examined, the yield strength between the minimum (0.00003 s^{-1}) and the maximum (0.03 s^{-1}) strain ratios is determined to be approximately between 332 MPa and 334 MPa in the rolling direction and between 265 and 268 MPa in the traverse direction. The strain rate and the yield strength are shown to vary to a very small extent. Therefore, the yield strength of the AA2139-T351 aluminium alloy is not affected by the increase in the strain rate. This outcome is found to be in compliance with the results from the studies conducted by Y. Chen et al.,[5] O. – G. Lodema et al.[6] and M. J. Hadianfard et al.[5–7]

Table 2: AA2139-T351 tensile-test results
Tabela 2: Rezultati nateznih preizkusov AA2139-T351

Direction	Strain rate	Yield strength	Tensile strength	*R* value	Elongation	Hardening coefficient
Rolling	0.03	333.9	502.4	0.730	16.3	0.156
Rolling	0.003	334.9	499.5	1.078	16.2	0.170
Rolling	0.0003	332.7	497.1	1.097	17.2	0.168
Rolling	0.00003	334.0	498.2	1.116	17.3	0.169
Traverse	0.03	266.5	473.4	0.990	15.5	0.179
Traverse	0.003	266.3	475.0	1.052	15.8	0.189
Traverse	0.0003	268.0	476.2	1.198	16.7	0.189
Traverse	0.00003	267.3	480.1	1.219	16.5	0.188

The amount of the tensile strength of a material is an extremely important parameter for the selection of the materials in engineering applications. The strain rate/tensile strength relationship is given in **Figure 3**. The tensile strength was determined to be 497–502 MPa in the rolling direction and 473–480 MPa in the traverse direction in the quasi-static strain-rate tests. The tensile strength was seen to be effected by the strain rate in a very small range. While the tensile strength was not affected by an increase in the strain rate in the study of T. Ohwue et al.,[4] a small increase in the tensile strength was found to occur in the studies of Y. Chen et al.[5] and O. – G. Lodemo et al.[6] Upon increasing the strain rate, the tensile strength of the material was found to reduce slightly depending on the occurring failure mechanisms in the study of M. J. Hadianfard et al.[7] The shift mechanisms may be delayed, especially in the soft matrix phase (α), due to an increase in the strain rate. In this case, the tensile strength of the material is thought not to significantly increase with the increasing strain rate because it may cause a premature rupture of the precipitates when the occurring tensile stress directly affects the precipitates.

The amount of elongation of the sheet-metal materials is extremely important in terms of sheet-metal forming processes. The elongation behaviour of a material under a desired amount leads to tear formation on the sheet metal before the sheet metal is formed as desired. The amount of elongation is known to decrease with an increase in the strain rate.[7–8] **Figure 4** shows the elongation behaviour of the AA2139-T351 aluminium alloy depending on the strain rate. The maximum elongation occurred at the two lowest strain rates (0.00003 s^{-1} and 0.0003 s^{-1}) in the rolling direction. The elongation capability of the material was reduced with the increase in strain rate.

The material gains strength through the hardening occurring depending on the dislocation pile-up in the internal structure of the material during the strain of the sheet-metal materials. The strain rate may affect the dislocation pile-up and, consequently, the material strength. Upon examining the relationship between the work-hardening coefficient and the strain rate in **Figure 5**, a slight reduction in the work-hardening coefficient is observed in the results obtained from the maximum strain-rate parameter (0.03 s^{-1}), while no change in the low strain rates is observed. When the overall results are examined,

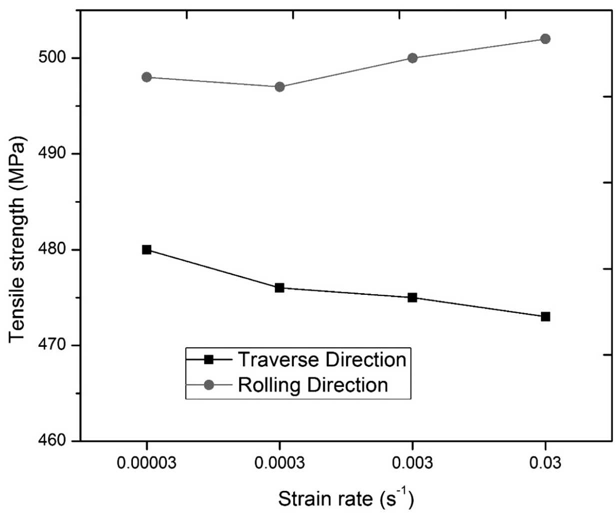

Figure 3: Tensile strength – strain rate relation
Slika 3: Odvisnost natezna trdnost – hitrost obremenjevanja

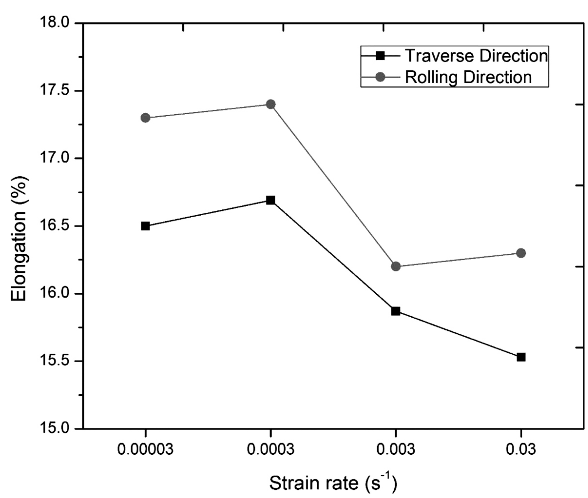

Figure 4: Elongation – strain rate relation
Slika 4: Odvisnost raztezek – hitrost obremenjevanja

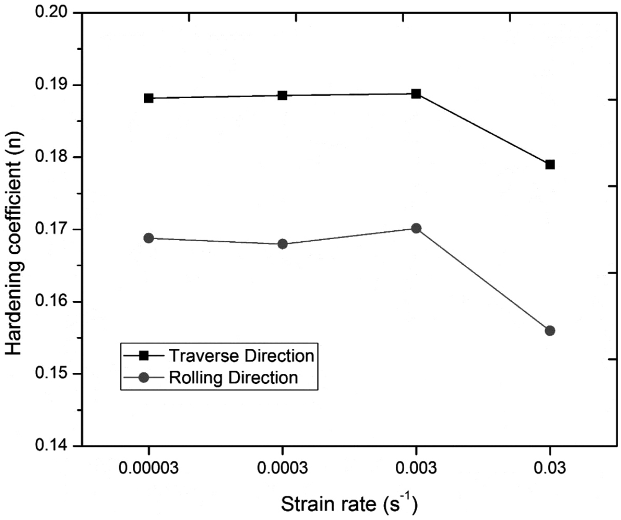

Figure 5: Hardening coefficient – strain rate relation
Slika 5: Odvisnost med koeficientom utrjevanja in hitrostjo obremenjevanja

the work-hardening coefficients obtained in the traverse direction are seen to be higher than the results obtained in the rolling direction. In the study of F. Ozturk et al.,[8] a very slight reduction in the coefficient of work hardening was seen to occur with an increase in the strain rate and the work-hardening coefficient was determined to change in a very small range depending on the strain rate.[8–9]

When the planar anisotropy value in **Figure 6** was examined, the anisotropy value was found to decrease with an increase in the strain rate. The decrease in the amount of elongation due to an increase in the strain rate supports this conclusion.

In the scope of the study, the sensitivity rate between the strain-rate values used in the tests for the AA2139-T351 aluminium-alloy sheet material was determined. For this purpose, the lowest strain rate of

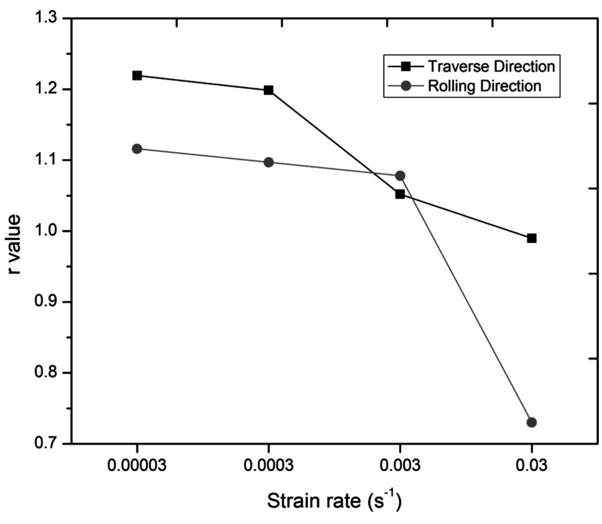

Figure 6: Anisotropy – strain rate relation
Slika 6: Odvisnost: anizotropija – hitrost obremenjevanja

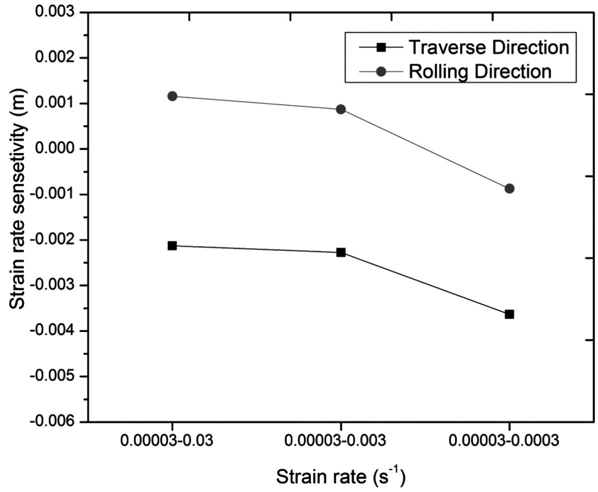

Figure 7: Strain rate sensitivity – strain rate relation
Slika 7: Odvisnost: občutljivost na hitrost obremenjevanja – hitrost obremenjevanja

0.00003 s^{-1} was selected as the reference value and it was calculated according to the formulas shown in Equation (1). When **Figure 7** was examined, it was seen that the strain-rate sensitivity was reduced as long as the rate range was decreased. When the maximum strain rate is applied, the decrease in the strain-rate sensitivity is thought to adversely affect the plastic deformation since the decrease in the strain-rate sensitivity adversely affects the plastic deformation in Equation (1):

$$\overline{m}(\dot{\varepsilon}) = \frac{\mathrm{d}(\ln(\sigma))}{\mathrm{d}(\ln(\varepsilon))} \tag{1}$$

In this study, the work-hardening rate was used to show the ability of the AA2139-T351 aluminium alloys for work hardens after the occurrence of plastic deformation. Work hardening occurs due to the dislocation movements and dislocation generation against the crystal

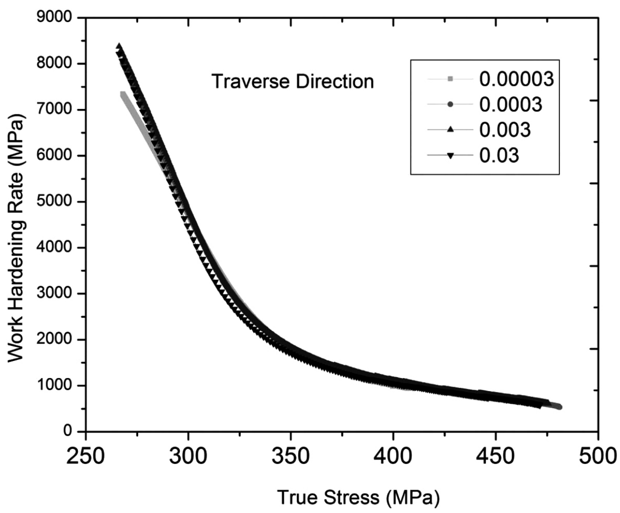

Figure 8: Work hardening rate – true stress relation in the transverse direction
Slika 8: Odvisnost: hitrost deformacijskega utrjevanja – prava napetost v prečni smeri

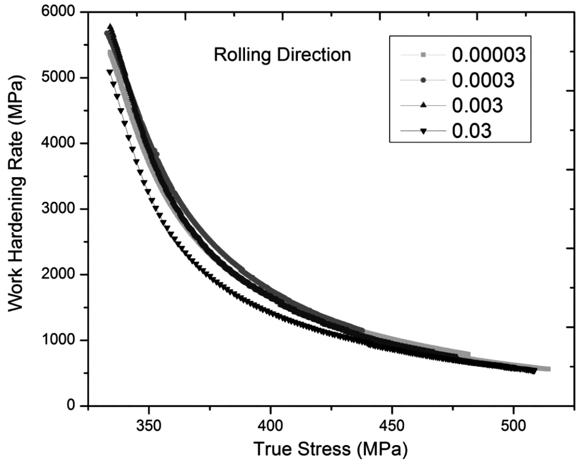

Figure 9: Work hardening rate – true stress relation in the rolling direction
Slika 9: Odvisnost: hitrost utrjevanja – prava napetost v smeri valjanja

structures of alloys.[9] The change in the work-hardening rate due to the strain rate is shown **Figures 8** and **9**. The work-hardening rate was determined to decrease with the increasing stress in the rolling direction. It is possible to interpret this case as a decrease in the work-hardening rate with the increase in the amount of strain. When the work-hardening-rate values obtained in the traverse direction and the rolling direction are compared, a higher amount of the work-hardening rate is found in the traverse direction than in the rolling direction. The reason for this is thought to be the fact that the work-hardening-coefficient result obtained for the traverse direction is higher than that obtained for the rolling direction although very close tensile-strength values are obtained.

The behaviour of the material strain due to reaching the maximum tensile strength up to fracture is referred to as the necking.[10]

The load-carrying capacity of a material during its necking behaviour depending on the strain rate was

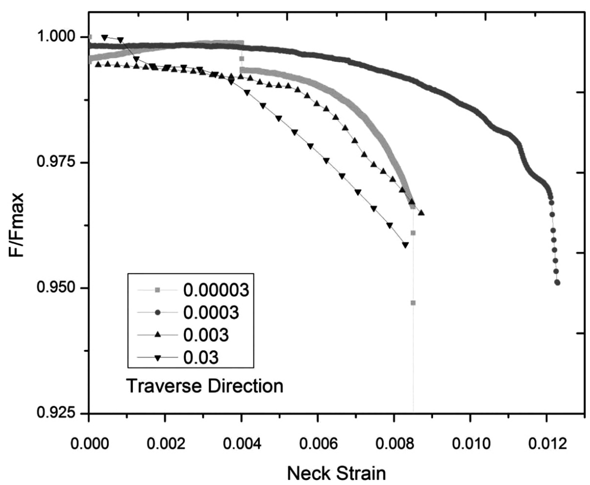

Figure 10: Transverse-direction loss of the load-carrying ability of the neck strain
Slika 10: Zmanjšanje nosilnosti v prečni smeri od napetosti v vratu

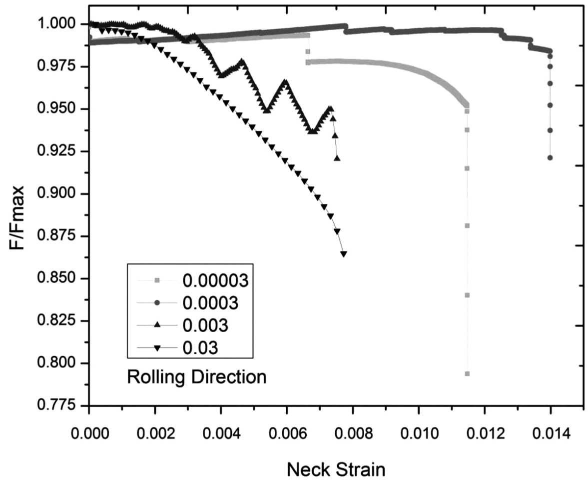

Figure 11: Rolling-direction loss of the load-carrying ability during the necking
Slika 11: Zmanjšanje nosilnosti v smeri valjanja od napetosti v vratu

studied in the current study. Upon analysing the relationship between the load-carrying capacity and the strain rate in **Figures 10** and **11**, the fracture behaviour of the material was found to occur early with the increasing strain rate in the direction of rolling, and the load capacity of the material during the necking was determined to decrease with the increasing strain rate. The materials with a high tensile strength were seen to show their fracture behaviour earlier in the study of F. Ozturk et al.[8] When the traverse-direction and rolling-direction losses of the load-carrying ability during the necking were compared, the earlier fracture was determined to occur in the rolling direction having a higher tensile strength.

4 CONCLUSIONS

It was found that the semi-static strain rates, the yield strength, the tensile strength and the work-hardening coefficient of the AA2139-T351 aluminium alloy are not significantly affected by the strain rate. The amounts of the elongation and anisotropy (r) tend to decrease with an increase in the strain rate. The material shows a negative strain-rate sensitivity. The work-hardening rate was found not to be significantly influenced by the strain rate. The load-carrying ability during the necking decreased slightly with the increase in the strain rate.

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