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ISSN 0543-5846
METABK 46 (3) 157-159 (2007)
UDC - UDK 669.715:620.175:620.178.7:539.37=111

EFFECT OF LOW STRAIN RATE ON FORMABILITY OF ALUMINIUM ALLOY

Received - Primljeno: 2006-03-14
Accepted - Prihvaćeno: 2006-12-11
Original Scientific Paper - Izvorni znanstveni rad

Effect of low strain rate on formability of aluminium alloy 2014 by means of torsion test was performed. The presented experimental results exhibit decrease of the ductility with increase and decrease of $\dot{\varepsilon}$ and T, respectively, and optimal values of $\dot{\varepsilon}$, T are thus obtained.

Key words: *aluminium alloy, torsion test, stress-strain curves, formability*

Učinak niske brzine deformacije na obradivost aluminijske slitine. Određivan je učinak niske brzine deformacije na obradivost aluminijske slitine 2014 pomoću torzionog ispitivanja. Prikazani rezultati ispitivanja ukazuju na opadanje sposobnost obradivosti slitine s porastom odnosno opadanjem $\dot{\varepsilon}$ i T. Isto tako dobivene su optimalne vrijednosti za $\dot{\varepsilon}$ i T.

Ključne riječi: *aluminijska slitina, torziono ispitivanje, krivulje naprezanje - deformacija, obradivost*

INTRODUCTION

Aluminium alloys find a wide variety of uses because of its remarkable combination of characteristics such as the low density, the high corrosion resistance, high strength, easy workability and high electrical and heat conductivity [1, 2].

The torsion test is one of the mostly used methods for the evaluation of the deformation behaviour of metals. Traditionally is used to provide basic data for the characterization of the mechanical properties of metallic materials under shear [3].

The torsion test provided hot ductility as dependent on temperatures and strain rates. The hot formability of aluminium alloys has been extensively evaluated in recent years by means of torsion test performed in a wide rage of temperatures (473 K to 773 K) and strain rates (10^{-3} to $10\ s^{-1}$) [4 - 8].

The basic indication, which specifies of torsion test for formability criterion is number of twists to the fracture, N. The criterion for strengthened characteristics is torque, M_k.

The torque-twist (torque - number of revolutions) ($M_k - N$) dates were converted into stress-strain ($\sigma - \varepsilon$) curves using [9 - 11]:

$$\sigma = \frac{\sqrt{3}M_k}{2\pi r^3}(3+m+n), \tag{1}$$

where:

σ - stress / MPa,
M_k - torque /N·mm,
r - the radius of specimens /mm,
n - strain sensitivity /–,
m - strain-rate sensitivity /–;

$$m = \left.\frac{\partial(\ln M_k)}{\partial(\ln \dot{\varepsilon})}\right|_{\varepsilon,T}, \qquad n = \left.\frac{\partial(\ln M_k)}{\partial(\ln \varepsilon)}\right|_{\dot{\varepsilon},T}, \tag{2}$$

where:

$\dot{\varepsilon}$ - strain rate /s^{-1},
T - temperature /°C;

$$\varepsilon = \frac{2\pi r N}{\sqrt{3}L}, \tag{3}$$

where:

ε - equivalent strain /–,
R - outer diameter of the twisted specimen /mm,
N - number of twists (revolutions) at torsion /–,
L - gauge length of the twisted specimen /mm.

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The paper deals with evaluation of hot formability of the 2014 alloy, which was performed by torsion test.

MATERIAL AND EXPERIMENTAL PROCEDURE

The aluminium alloy 2014 had following chemical compositions, Table 1.

Table 1. **Chemical compositions of the aluminium alloy 2014**
Tablica 1. **Kemijski sastav aluminijske slitine 2014**

Al	Cu	Mn	Si	Mg	Fe	Zr	Ti
Balance	4,32	0,77	0,68	0,49	0,29	0,12	0,03

Specimens for torsion tests 10 mm in diameter with a length of 20 mm were machined from extruded rods, Figure 1. The hot torsion test was performed on torsion

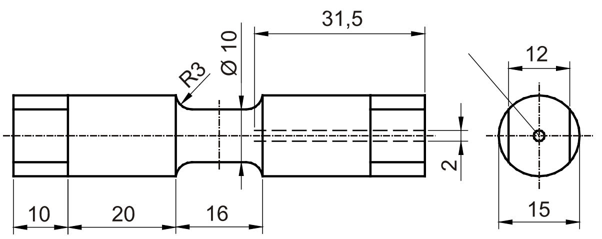

Figure 1. **The shape and dimensions (in milimetres) of the torsion specimen**
Slika 1. **Oblik i dimenzije (u milimetrima) uzorka (probe) za torziona ispitivanja**

machine at deformation temperature 300, 400 and 500 °C. Temperatures were measurement by means of a thermocouple. The specimens were mounted in water-cooled grips. The specimens were heated by induction in air with a heating rate of 1 °C/s, held for 3 min at the test temperature before the deformation was applied and then deformed to fracture at equivalent strain rates of 10^{-3}, 10^{-2} and 10^{-1} s. The samples were kept fixed in the axial direction during the deformation. The final deformation during the continuous test provides information on material formability. All specimens were water-quenched immediately after the deformation.

The hardness measurements were performed using a Vickers hardness tester with a load of 10 kg for 15 s. Hardness values were averaged over five measurements taken at different points on the cross-section.

EXPERIMENTAL RESULTS AND DISCUSSION

Microhardness

The microhardness curves are illustrated in Figure 2. Analysis of the figure reveals that in the samples tested at deformation temperature the variation in hardness is quite similar tendency. Microhardness values is markedly higher at deformation temperature 500 °C.

The results were achieved corresponding with measurements data of Bardi [12]. Sadeler et al. [13] have concluded that using a homogenisation treatment was acquired with increasing homogenisation temperature the hardness of materials increases.

On the other hand, Totik et al. [14] observed that the hardness of materials decreases with increasing homogenisation temperature. This can be explained most probably due to wide stacking on the score of a small amount of the alloy elements of AA 2014 alloy. Phase $CuAl_2$ were solute over temperature of 450 °C [15].

Totik and Gavgali [16] have found that microhardness decrease with increased deformation temperature until 450 °C, this result is in agreement with studied by Wouters et al. [17] and Spigarelli et al. [18].

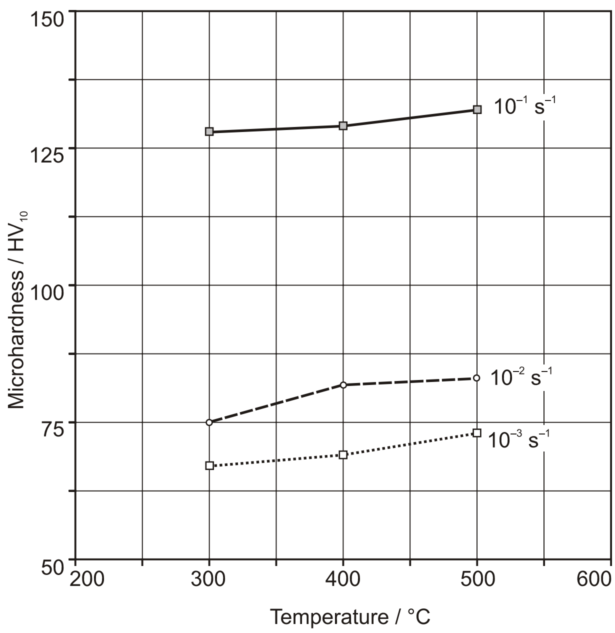

Figure 2. **The microhardness curves of aluminium alloy 2014**
Slika 2. **Krivulje mikrotvrdoća aluminijske slitine 2014**

Stress-strain curves

The results of hot torsion test were stress-strain curves. The stress-strain curves are illustrated in Figure 3.

Every curve shows a rapid increase in the stress to a peak (maximum) value, followed by a gradual decrease towards a steady state regime which is not reached before fracture as also presented in [17].

The lower deformation temperature was considered to be optimal; this assumption confirmed also in [11], who recorded similar results at temperature 350 °C, as well as, especially like a materials, in literature [12]. The maximum ductility had recorded at temperature 300 °C, with increasing deformation temperature the decrease material ductility. Curves divided to four group according to view of deformation rate. The similar behaviour of curves observed at deformation temperature 300 °C at a smallest deformation rate of 10^{-3} and 10^{-2} s^{-1}, respectively. Curves show a

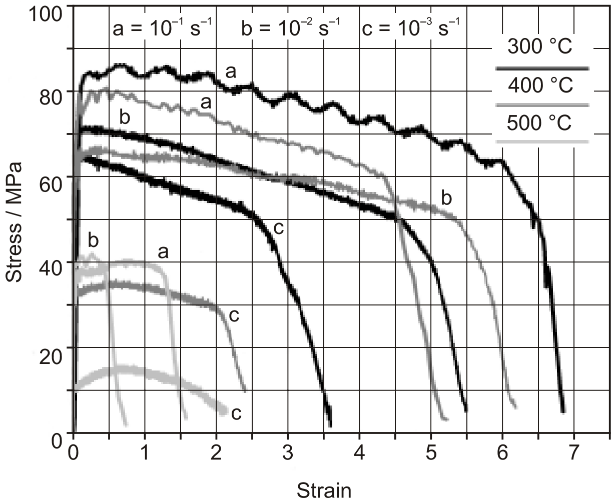

Figure 3. **The stress-strain curves of hot torsion test**
Slika 3. **Krivulje naprezanje - deformacija torzionog ispitivanja u toplom stanju**

rapid increase in the stress to a peak value, followed by a gradual decrease towards a steady state regime which is not reached before fracture. Results of first group corresponding with results in [12]. The shape of curve has been markedly changed with increasing test temperature. The curve has a convex shape. The curve has a cyclic character at a medium deformation rate of 10^{-1} s^{-1}. The oscillation of curve has been associated according in [18] with grain softening. These shapes exhibited cyclic variety of hardening and softening, respectively.

Fracture strain

Fracture strain is generally considered to represent ductility of the experimental material. The relationship of fracture strain ε_f vs. deformation temperature T and deformation rate $\dot{\varepsilon}$ is shown in the Table 2. Evaluation of fracture strain is not so simple because it varies sensitively with the specimen shape and dimension, but if careful evaluation is carried out, fracture strain can be a reliable measure for ductility of metals.

Table 2. **Relationship of fracture strain ε_f vs. temperature and strain rate**
Tablica 2. **Odnos prijelomne deformacije ε_f prema temperaturi i brzini deformacije**

	T / °C	s_p / MPa	ε_f / –
10^{-3} / s^{-1}	300	66	2,8
	400	36	2,0
	500	16	1,5
10^{-2} / s^{-1}	300	72	4,7
	400	44	2,3
	500	21	1,7
10^{-1} / s^{-1}	300	86	6,3
	400	55	3,3
	500	29	1,0

The figure illustrates clearly the improvement in ductility with rising test temperature. The ductility increases with decreasing deformation temperature T and increasing deformation rate $\dot{\varepsilon}$. The highest value of fracture strain ε_f achieved at deformation temperature 350 °C. The smallest experimental scatter showed deformation rate 10^{-3} s^{-1}.

CONCLUSIONS

The result shows that the experimental stress-strain curves were not reached a steady state regime. The investigation was recorded only gradual curves decrease up to fracture of materials. On the basis graphically relationships of stress-strain curves is optimal conditions for hot workability of aluminium alloy 2014 in accordance low deformation regime is deformation temperature, T = 300 °C, and deformation rate, $\dot{\varepsilon} = 10^{-3}$ s^{-1}.

REFERENCES

[1] I. Mamuzić, Metalurgija 43 (2004) 1, 3 - 12.
[2] A. Smolej, E. Slacek, R. Turk, Metalurgija 41 (2002) 3, 149 - 155.
[3] J. P. Hou, C. Ruiz, A. Trojanowski, Materials Science and Engineering A 283 (2000) 1-2, 181 - 188.
[4] S. Spigarelli, M. Cabibbo, E. Evangelista, J. Bidulská, J. of Materials Science 38 (2003) 1, 81 - 88.
[5] A. Peterčaková, I. Pokorný, Kovové Materiály 41 (2003) 6, 389 - 401.
[6] H. J. McQueen, Materials Science and Engineering A 238 (1998), 219 - 274.
[7] J. Bidulská, T. Kvačkaj, M. Cabbibo, E. Evangelista, R. Bidulský, Acta Metallurgica Slovaca 12 (2006) 2.
[8] H. J. McQueen, M. E. Kassner Scripta Materialia 51 (2004) 5, 461 - 465.
[9] L. Ceniga: Private information.
[10] B. Verlinden, P.Wouters, H. J. McQueen, E. Aernoudt, L. Delaey, S. Cauwenberg, Materials Science and Engineering A 123 (1990), 229 - 237.
[11] E. Evangelista et al.: In. Hot Deformation of Aluminum Alloys. Ed. Langdon, Merchant, Morris, Zaidi, The Minerals, Metals & Materials Society (1991), 121 - 139.
[12] F. Bardi, M. Cabibbo, S. Spigarelli, Materials Science and Engineering A 334 (2002) 1 - 2, 87 - 95.
[13] R. Sadeler, Y. Totik, M. Gavgali, I. Kaymaz, Materials and Design 25 (2004) 5, 439 - 445.
[14] Y. Totik, R. Sadeler, I. Kaymaz, M. Gavgali, J. of Materials Processing Technology 147 (2004) 1, 60 - 64.
[15] M. Cabibbo, E. Evangelista, J. of Materials Science 41 (2006) 16, 5329 - 5338.
[16] Y. Totik, M. Gavgali, Materials Characterization 49 (2002) 3, 261 - 268.
[17] P.Wouters, B. Verlinden, H. J. McQueen, E. Aernoudt, L. Delaey, S. Cauwenberg, Materials Science and Engineering A 123 (1990), 239 - 245.
[18] T. Sakai, J. J. Jonas, Acta Met. 32 (1984), 189.

Acknowledgment

Jana Bidulska is grateful for the help of colleagues from the Department of mechanic of Ancona, Italy.