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Mechanical characteristics of AL-1050 and Al-6061 alloys deformed using equal channel angular rolling process

ABSTRACT

One of the effective severe plastic deformations (SPD) techniques is Equal channel angular rolling (ECAR) process which can lead to proper ultra-fine grained (UFG) structures of material, the main objective of this work is to study the improvement in mechanical properties within 1050 and 6061 aluminum alloy sheets. There are more attempts to investigate the microstructure and mechanical properties of strips material, the influence of process parameters such as number of equal channel angular rolling passes, routes (A&C) and annealing temperature after each passes on deformation behavior of 6061 and 1050 Aluminum alloys were investigated experimentally .Results was indicated that for AL-6061 without annealing process at first pass it was the higher stress than the passes after annealing process and also the grains was fine in the first pass ,For AL-1050 it was indicated that with ambient temperature at six pass the mechanical properties was improved and its recorded the higher stress with more passes at six pass for rout C and also the fine grains of microstructure was obtained in the six pass with compared to the material with annealing process which becomes more ductility with more passes.

Keywords: *Aluminum alloys, ECAR, dislocations, Microstructure, Mechanical properties*

1. INTRODUCTION

Aluminum alloys are the best several choices for a structural component of aircrafts because of their recognized fabrication costs, performance characteristics, established manufacturing methods, design experience, and facilities, which will ensure their use in significant quantities in the future [1,2]. Moreover, Aluminum in nanoscale is already ubiquitous in everyday life through commodity products and strong growth rates [3-5].

Severe plastic deformation (SPD) methods are new appropriate techniques to refine the structure of materials and improve mechanical properties, ECAR process is one of the SPD techniques. The process conducts through multiple passes, one of them could achieve the desired mechanical properties and UFG of the material.

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In 2019 the researcher was studied and analyzed the Equal channel angular rolling process affected on fracture mechanics for several Aluminum alloys [6]. According to the previous works, number of pass, channel angle, and route of pass are the effective parameters in the ECAR process [7,8], it was Studied the Correlation Between Mechanical Properties and Structural Parameters of Al5083 Sheets Processed with ECAR to evaluate and investigate the ECAR process effect in 2017 by other researcher [9], in 2016 other researcher was studied the effects of the ECAR process on formability, mechanical properties [10,11] the Hardness of 7075 and 5052 Aluminum Alloys in the Equal Channel Angular Rolling Process in 2016 was Studied by other researcher [12], in 2012 other researcher was studied the Microstructural evolution and Mechanical properties during multi-pass ECAR of Al 1100 alloy after ECAR process [13,14].

It was illustrated in previous works that by severe plastic deformation (SPD) processes it was obtained the ultrafine-grained (UFG) materials which have high strength due to their low grain size and high dislocations density [15-18]. The effect of other SPD processes on the structural parameters of metals has been widely investigated by different researchers [19-21] some researchers was studied the Microstructural evolution and enhancement of mechanical properties of Al1050 by tubular channel angular extrusion [22].

From the previous works the aim of this research is to study the improvement of mechanical characteristics of aluminum alloys sheets by Equal-channel angular rolling using two material Aluminum alloys 1050 and AL 6061 at several parameters such as annealing temperature and change in routs, with constant die angel 115° in rolling machine with multi-passes on ECAR process.

2. EXPERIMENTAL PROCEDURE

In the present work, the Al 6061 and AL 1050 alloys conducted to ECAR, The ECAR equipment illustrated in Fig. 1(a, b, and c). As shown in figure the attachment consists of two rollers engaged with die. There was a gap of inlet between to roller and outlet channels die and its changes according to material thickness, respectively. The feeding roll of the ECAR device controlled to 5 % reduction in thickness. The diameter of the feeding and guide rolls are 57mm and the rotational speed is 32 rev/min, the dimensions of AL 6061 strip are 200 mm in length, 20 mm in width and 1.8 mm in thickness and the dimensions of AL 1050 strip are 200 mm in length, 20 mm in width and 2 mm in thickness. The chemical composition of the base metal for two materials as given in Table 1

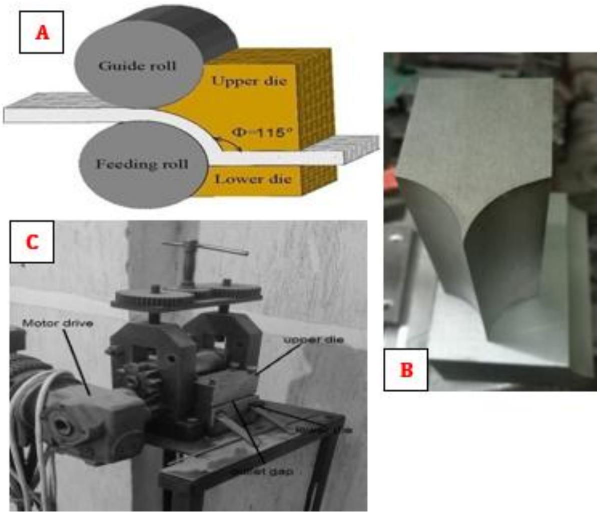

Figure 1. a) Schematic illustration of the ecar device, b) Die with angle 115°, c) The machine device used with die

Slika 1. a) Shematski prikaz ecar uređaja, b) Matrica pod uglom od 115°, c) Uređaj stroja koji se koristi s matricom

Table 1. Chemical composition of Al-6061 and Al-1050 alloys

Tablica 1. Hemijski sastav legura Al-6061 i Al-1050

AL – 6061 alloy (wt.%)							
AL	Mg	Si	Cu	Mn	Fe	Cr	Zn
99.5	0.91	0.8	0.32	0.212	0.456	0.021	0.178

AL – 1050 alloy (wt.%)						
AL	Fe	Si	Cu	Mg	Mn	Ti
99.5	0.3	0.09	0.002	0.003	0.005	0.05

The ECAR die has a 115° corner angle with 2 mm curvature nose to prevent shearing occur in sheet during process. The specimens were ECARed process through two available routes, where routes A and C described as in route A, the specimen is pressed repetitively without rotation but in route C, the specimen is rotated through 180° between pressings. For AL 6061 specimens the annealing process conducted after rout A and C at temperature 380° c for one hour and cooled in furnace according to American Society for Testing and Materials (ASTM) B918-01 [17,18] and the first sample was pass at room temperature in both routes A and C.

For aluminum alloy 1050 specimens the annealing process conducted after rout A and C at temperature 400 °C for one hour and cooled in furnace [23,24]. Microstructure is examined by using optical microscopy for specimens using standard metallographic procedures, the surface was polished and etched at room temperature for Al1050 using 2ml HF, 3ml HCl, 5ml HNO_3, 190ml DI Water [25], but for Al 6061 using 5ml HF (48%) 10 ml H_2SO_4, 85ml Water [26] and the size of grains was determined by using image tool software.

A tensile test sample was prepared according to ASTM-E8M [27] with dimensions of 100mm length 10mm width 6mm fillet radius on universal testing machine (500KN) with constant speed 0.5 mm/min.

Microhardness of strips measured by Vickers hardness tester with 685g load with 10s by pyramidal diamond indenter according to ASTM-E92 [28].

3. RESULTS AND DISCUSSION

3.1. Microstructure Inspection

Fig. 2 (a and b) shows the optical micrographs for AL 6061 of the first pass before annealing and 4-pass after annealing at rout C ECAR'ed specimens, respectively. The average grain size of the as received material was eighteen µm [29]. The average grain size of the first pass specimen was about three µm. After annealing process, the grain boundaries decreased from second pass to fourth pass at both rout A&C. The average grain size for the fourth pass was six µm in rout C. The increasing in the grain size and decreasing in grain boundaries from the first pass to third pass causes decrease in strain hardening and this mean that the stress slightly decreased, and the strain increased so the material was more ductility. After fourth pass the stress increased again, and the strain decreased because the increasing of numbers of passes increases in strain hardening of the material.

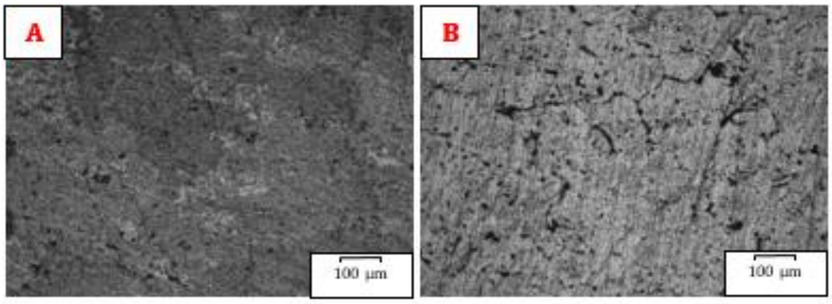

Figure 2. Optical micrograph for Al 6061 rout C a) first pass b) fourth pass

Slika 2. Optička mikrografija za Al 6061 rutu C a) prvi prolaz b) četvrti prolaz

For AL 1050 at the ambient temperature the optical micrographs shown in Fig. 3 (a and b) for the first pass and the six pass in rout C and the as received material grain size was thirty-seven µm [30]. It indicated that the average grain size decreased from as received to be twenty-one µm at first pass and decreased again to be 9.3 µm at six passes.

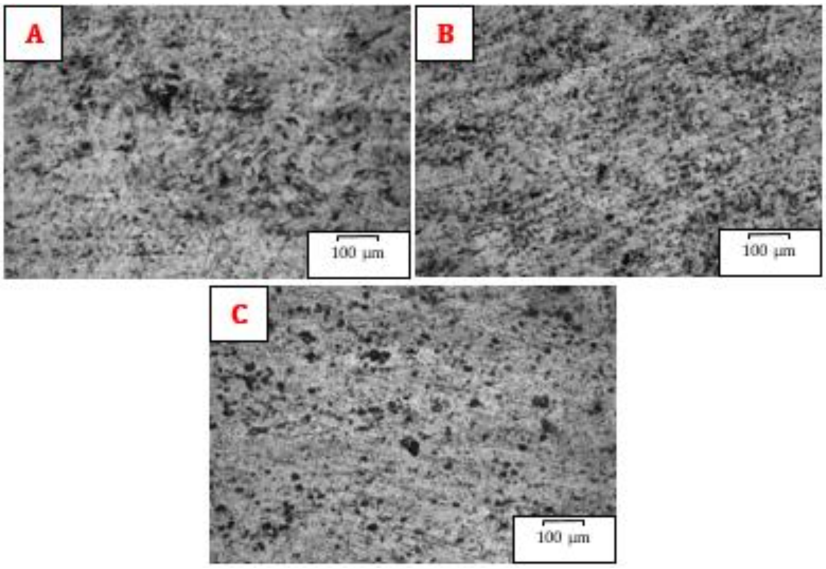

Figure 3. Optical micrograph for Al 1050 rout C a) first pass. B) six passes without annealing. C) fifth passes with annealing

Slika 3. Optička mikrografija za Al 1050 put C a) prvi prolaz. B) šest prolaza bez žarenja. C) peti prolazi sa žarenjem

This decreasing means that was an increasing in the strain hardening in the material and its cause the increasing in stress and decreasing slightly in strain of the material. After annealing process at rout C for fifth pass it shown in fig. 3c the average grain size measured to be 23.2μm and this increased from the first pass. The increasing in grain size was because of the annealing process after each pass and it cause decreasing in grain boundaries, and this cause the decreasing stress and increasing elongation of the material.

3.2. Tensile behavior

Stress and strain curves of ECARed samples with die channel angle 115^{o} for AL 6061 are shown in Fig.4 for rout A and for rout C, It was illustrated that the maximum strength of about 285 MPa was obtained at the first pass in rout C before annealing.

At rout A its observed that the UTS is higher from as received material which recorded 273 MPa, While the as received material was recorded 260 MPa.

The reason for decreasing the stress from second Pass to Fourth pass has the annealing process for one hour at 380^{o}C and this mean that the higher temperature at each Pass effect on decreasing of strain hardening and this mean the decreasing of dislocation.

After annealing in each Pass and change the routs direction it was observed that the stress in each pass for rout C is higher than rout A and because of the dynamic recovery and recrystallization and the strain curve is decreased at first pass and then increased again after annealed process to be 8.6% at third pass in rout C. This means that in route C it was more effective propagation of dislocations.

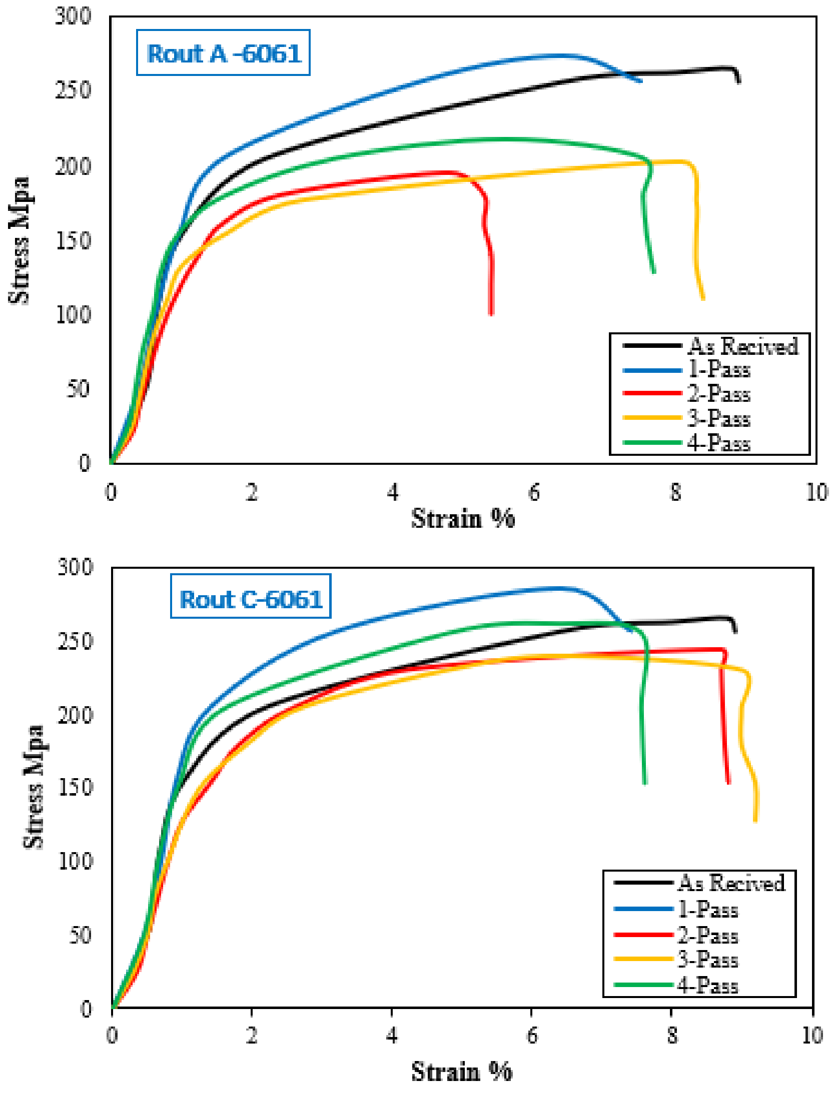

Figure 4. Al-6061 at each pass for rout A and C

Slika 4. AL-6061 na svakom prolazu za rute A i C

For AL1050 stress-strain curves of ECARed samples with die channel angle 115°degree as shown in Fig.5 for rout A and for Rout C which the as received and first pass sample was passed without annealing and then material was annealed at 400°c for one hr. and then furnace cooled.

It was observed that the stress is increased at first pass in each rout A&C but in rout C is higher from rout A which recorded 118.5 and 116.5 MPa for rout C & A, respectively.

At annealing process at each pass, the UTS was decreased and it's because of the dynamic recovery and recrystallization, the structure is had new grains grow, which results in a slight decrease in the dislocation density and the effect of the strain hardening. It was increasing in strain after annealing which recorded 19.6 % in elongation at rout A when comparing with the as resaved sample which recorded 4.1 % and the material was more ductility. It was observed at the figures below that the stress was increasing from third pass to fifth pass for two routs A & C.

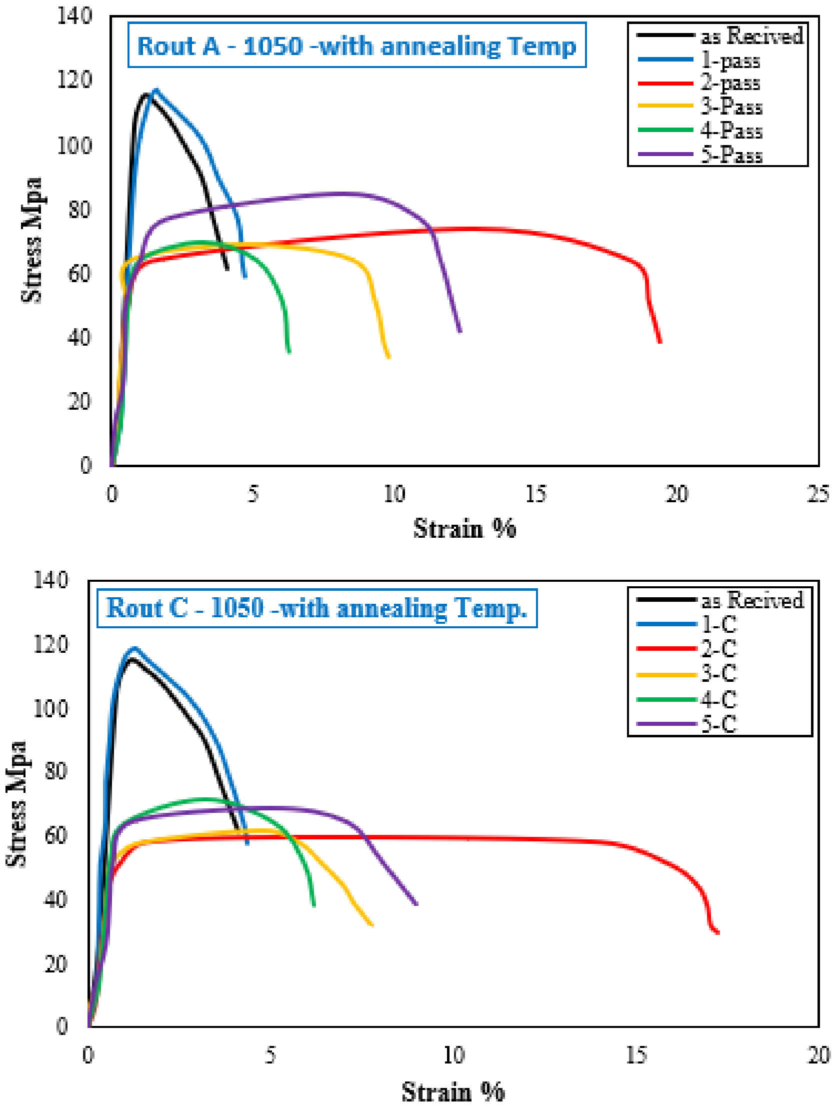

Figure 5. AL-1050 at each pass for rout A and C

Slika 5. AL-1050 na svakom prolazu za rute A i C

Stress maximum appears in the fifth pass on rout A which recorded 83MPa comparing with the as resaved sample it was decreased in stress and increase in strain because of annealing temperature and dynamic recrystallization is high. Many factors such as the temperature of the process and initial structure of the material were affected by recrystallization and dynamic recovery. Also, the final texture after recrystallization, orientation, direction, and the grain size will be effective in the final mechanical properties achieved.

For AL1050 at ambient temperature, Stress and strain curves as illustrated in Fig. 6 for rout A and rout C it was observed that the UTS increasing at each pass and the maximum stress obtained was 130 MPa at pass six at rout C.

This curve illustrated that without annealing temperature and in more Passes for pure Aluminum 1050 we can enhance the stress and get the ultra-fine grains for this material at ambient temperature. The increasing in stresses and slightly decreasing in strain were because of dislocation density and the grain size due to more passes

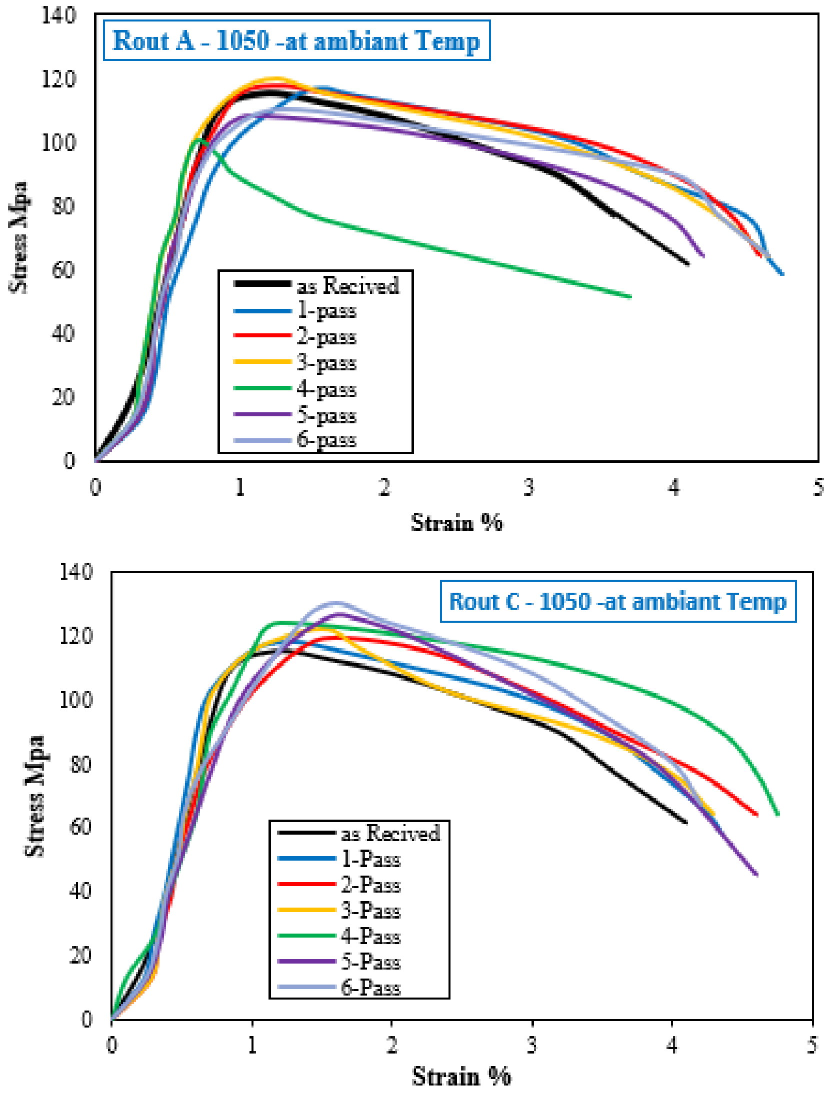

Figure 6. Al-1050 at each pass for rout A and C at ambient temperature

Slika 6. Al-1050 pri svakom prolazu za rute A i C na temperaturi okoline

3.3. Microhardness Test

For AL 6061 the hardness surface test for the sample as illustrated in Fig.7 and it observed that the maximum hardness obtained at rout C with value 50.78VHN in first pass and decreased at second pass to be 43.75VHN and continuous increasing to be 47.96VHN.

This decreasing was because of the annealing process after first pass, and it increase again due to increasing passes as illustrated before in this paper. The increasing in temperature affected on dynamic recovery and decreasing the dislocation of grains and it verified that the hardness versus grain size obey Hall–Petch relationship [31,32].

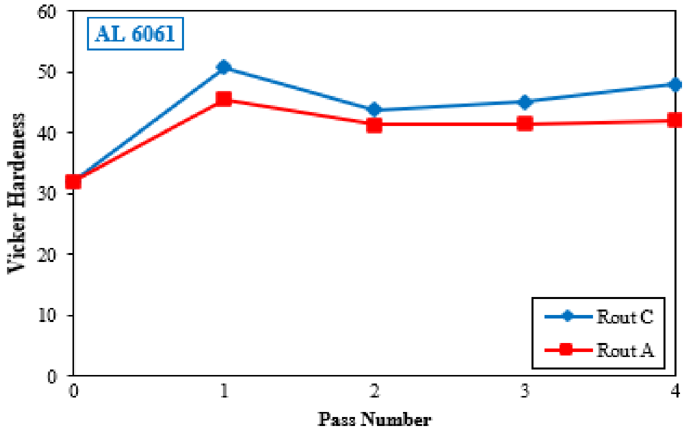

Figure 7. Micro hardness test for Al 6061 with annealing process after first pass

Slika 7. Ispitivanje mikro tvrdoće za Al 6061 s postupkom žarenja nakon prvog prolaza

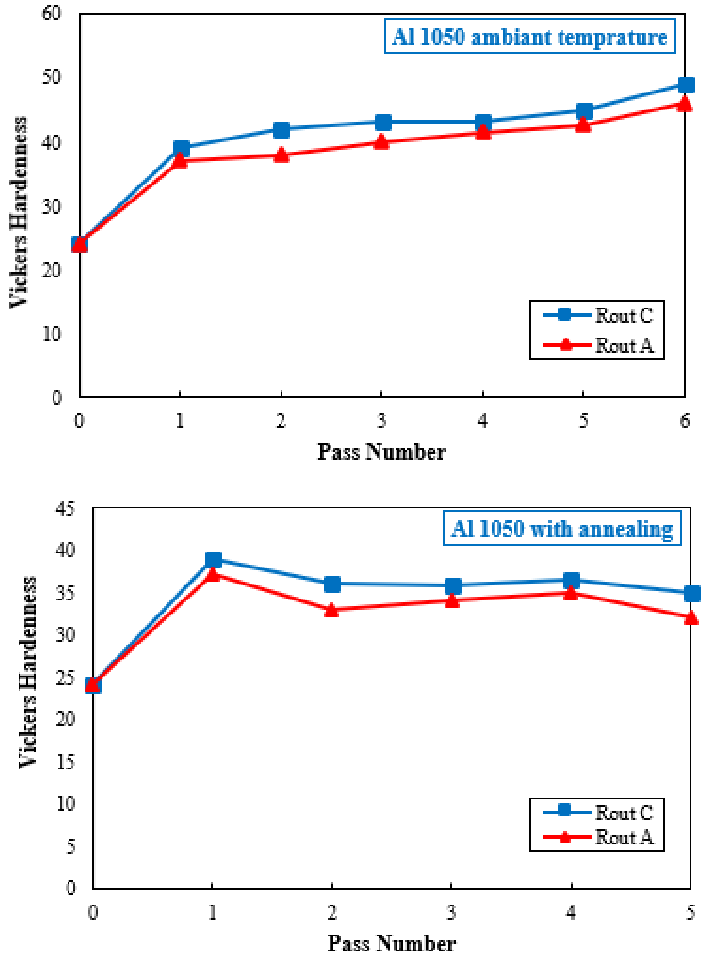

Figure 8. Micro hardness test for Al 1050 a) at ambient temperature, b) at annealing process

Slika 8. Ispitivanje mikro tvrdoće za Al 1050 a) na sobnoj temperaturi, b) u procesu žarenja

For Al-1050 the results of surface hardness test at the ambient temperature shown in Fig.8 a, micro hardness increases with the increasing number of passes, at ambient temperature for the six passes, hardness was obtained value 49 VHN in rout C and its higher than rout A 46 VHN in the ambient temperature.

At the annealing process at 400^{o}c shown in Fig.8 b, hardness was recorded 36.5 VHN at the fourth pass of ECARed in rout C which is about

34% less than the ambient temperature in hardness.

By comparing the micro hardness variations for ECARed samples at different temperatures at Fig. 8 (a and b), it was illustrated that as the temperature rises in similar passes the hardness decreases and this was due to reduction the effect of strain hardening rate with increasing temperature. Actually, dynamic recovery causes some of the effects of strain hardening and dislocation to be neutralized, and as a result, hardness is reduced [33].

Dynamic recovery has the main effect on reducing hardness, it is also like the tensile strength variations, and the possibility of dynamic recrystallization is higher at 400 ^{o} c temperature. It's observed that at room-temperature dynamic recovery can be enhanced the UFG, due to the high-energy and unstable grain boundaries [16,34,35].

4. CONCLUSIONS

ECARed Process with die angle 115^{o} for two materials AL- 6061and AL 1050 at annealing process and AL-1050 at the ambient temperature and the main points resulted from this study are as follows:

- For rout C, the average grain size for Al-6061 alloy increases where it is was 3 μm at first pass and increasing to be 6 μm after fourth pass.
- For rout C, the average grain size for Al 1050 alloy at first pass was 21μm and decreasing to be 9.3 μm after six passes at ambient temperature and 23.2 μm at fifth pass after annealing process.
- The maximum tensile stress for AL 6061 was 285 MPa at first pass before annealing process for rout C.
- The maximum tensile stress for Al-1050 at ambient temperature was 130 MPa at six passes for rout C but the elongation of this material was increased to be 19.6% at the second pass after annealing temperature.
- For AL 6061 we can obtained the maximum Vickers hardness number at first pass for rout C was 50.78 HVN
- For Al 1050 the maximum Vickers hardness number with increasing the number of passes at ambient temperature and its recorded 49 HVN at six passes for rout C.

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IZVOD

MEHANIČKE KARAKTERISTIKE LEGURA AL-1050 I AL-6061 DEFORMISANIH KORIŠĆENJEM RAVNOKANALNOG PROCESA UGAONOG VALJANJA

Jedna od učinkovitih tehnika teških plastičnih deformacija (SPD) je proces jednakokanalnog kutnog valjanja (ECAR) koji može dovesti do pravilne ultrafino zrnate (UFG) strukture materijala, glavni cilj ovog rada je proučavanje poboljšanja mehaničkih svojstava unutar 1050 i 6061 listova aluminijske legure. Postoji više pokušaja istraživanja mikrostrukture i mehaničkih svojstava materijala traka, utjecaja procesnih parametara kao što su broj jednakih kanalnih kutnih prolaza valjanja, rute (A&C) i temperatura žarenja nakon svakog prolaza na deformacijsko ponašanje 6061 i 1050 aluminijskih legura. ispitan eksperimentalno. Rezultati su pokazali da je za AL-6061 bez procesa žarenja u prvom prolazu to bilo veće naprezanje od prolaza nakon procesa žarenja, a također su zrna bila fina u prvom prolazu. Za AL-1050 je naznačeno da je uz temperaturu okoline u šest prolaza mehanička svojstva su poboljšana i zabeleženo je veće naprezanje s više prolaza u šest prolaza za način C, a također su fina zrna mikrostrukture dobivena u šest prolaza u usporedbi s materijalom s postupkom žarenja koji postaje duktilniji s više prolazi.

Ključne reči: *Legure aluminijuma, ECAR, dislokacije, mikrostruktura, mehanička svojstva*

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