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Investigation of Mechanical Properties of Al/Cu Strip Produced by Equal Channel Angular Rolling

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Abstract

Equal channel angular rolling (ECAR) is a severe plastic deformation method that covered plastic deformation of sheets. In this study, the mechanical properties of bimetal sheet (Al/Cu) that joined by explosive welding method has been investigated. The specimens were annealed and severely plastically deformed by 8-pass equal channel angular rolling process at the route A. The results demonstrated that yield and tensile strengths significantly increased after the first pass. Also elongation decreased by this process. SEM images showed that a shear deformation that influenced on grain boundaries angle and grain size. By increasing the number of ECAR passes grain boundaries angle increased and grain size decreased.

1. Introduction

In recent years sever plastic deformation (SPD) have been developed because of produce appropriate structures. Equal channel angular pressing (ECAP) is one of the applicable SPD methods for producing ultra-fine grain in bulk metals, Segal (1999). Due to being non-continuous process of ECAP in spite of having excellent mechanical properties, still remains at the laboratory level. Equal channel angular extortion (ECAE) is another SPD method that produces structures by non-basal plane that create ultrafine-grained (UFG) metals with great mechanical properties.

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But in the ECAE method, a sheet produces by low thickness cause high expenses. So, the ECAR process has been considered to produce thin metal sheet by excellent mechanical properties, Furukawa et al. (1996). The ECAP wildly investigates as an important production method to produce the UFG metals, Waterloo et al. (2001). So, by shear deformation, grain sizes decrease to nano-grain and improve mechanical properties of metals, Mahmoodi and Sedighi (2012). Fig. 1 shows a schematic of the ECAR process that involves the induction of severe shear deformation to materials for improve the structure.

The effects of pre-ECAR and post-ECAR were investigated by Hyunhan (2010) to improvement the structure of AL7050. Chen et al. (2003) investigated the draw ability of AZ31 at the room temperature by the ECAR process. Mechanical properties and micro structural evolution were studied in multi pass ECAR process of AL1100, Azimi et al. (2012). Increment of strength and conductivity of pure copper by the ECAR process were investigated by Habib et al. (2011). Access to a nano-grain of AZ31 by ECAR was considered, Hassnai and Ketabchi (2011). The UFG structure by ECAR process has been studied by methods of electron microscopy. The microstructure, mechanical properties and microhardness were investigated in OFHC copper after 1st–13th passes, Kvackaj et al. (2012). Microstructural evolution during equal channel angular rolling has been investigated in 7050 Al alloy sheet that includes two types of precipitates, large plate-type MgZn2 and fine spherical Al3Zr, Nam et al. (2003).

In this study, the influences of the ECAR process have been investigated on the mechanical and microstructure properties of explosive-welded Al/Cu strip. Mechanical properties were reported after each pass. The results show that the mechanical and structural properties of bimetal sheet are significantly changed by the process.

2. Materials and procedures

Al-1050 and pure copper were joined by the explosive welding process. The results of quanto-meter test of Al-1050 and copper are shown in table 1 and 2. The dimensions of strips are 400×30×3 mm (length×wide× thickness).

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<th>Cr</th>
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Table 2. Chemical composition of Cu alloy (wt.%).

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<td>Be</td>
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</table>

Experiments were carried out on an ECAR setup with two-high rolling mill with work-rolls dimensions equal to 105 mm in diameter and a die with 3 mm in channel and an oblique angle of 115° and a curvature angle equal to 0°. To conducting the bimetal in the die, distance between the work-roll has set to 2.97 mm. Fig. 2 shows a view of the ECAR setup. The annealing of bimetals was performed at 350°C for 2 h followed by furnace cooling to room temperature. Then, the ECAR process has performed on the bimetal samples at the route A during 8 passes at the room temperature. As to ECAR route, feeding direction was unchanged between adjacent 2 passes of ECAR usually referred to route A and if feeding direction changed between 2 passes of ECAR referred to route C.
3. Results and discussion

After each pass of the ECAR process images of specimens were taken by optical microscopy and SEM. To study the strength of the ECARed samples, the biaxial tensile test has performed based on ASTM-E8 with a constant strain rate of $2 \times 10^{-3}$ s$^{-1}$. Also, to evaluate the impact of the ECAR routes and numbers of passes on the properties of the ECARed bimetals, the Vickers microhardness test based on ASTM E384-11 was carried out using a 200g loads. These tests were performed to show the effects of toughness and annealing after the ECAR process in each pass. Stress–strain curves of ECARed samples from 1 to 8 passes and annealed sample have been presented in fig. 3. As can be observed from fig. 3, by increasing the number of ECAR passes, the strength increases and elongation decreases. The yield strength increased significantly after the first pass but tensile strength did not have considerable changes. The variation of the yield and tensile strength as a function of number of ECAR passes have been shown in fig. 4. As can be seen in fig. 4, the increasing of strength was continued until 6 pass but in final passes the ratio of increasing is lower than the first passes. The elongation of the Al/Cu sheet was significantly decreased until 4th pass. However elongation from 4 to 8 pass was very slightly. The yield strength in metals that is equally and uniformly, changed by volume changes in contexture of material. Also, strain hardening is occurred in materials because of plastic deformation and it is one of the main reason of increasing yield and tensile stress at the first pass. By following the ECAR process until 4 pass, dislocation plans are enforced and it is the reason of strain hardening at the Al/Cu bimetal. The increasing of strain hardening with decreasing the grain sizes caused by plastic deformation is the main reason of increasing dislocations in first pass of ECAR. Fig. 5 shows the optical microscopy and SEM images of Al/Cu bimetal sheets joined by explosive welding process. As shown in fig. 5, the angles of grain boundaries in first passes of ECAR are low. But by following this process until 8 pass, the angle of grain boundaries increased. So, by increasing the grain boundaries angle, the mechanical properties of Al/Cu samples were improved.
According to increase the grain boundaries angle and decrease the grain sizes, barrier to the movement of dislocation was occurred and it caused the improvement of strength and increasing the strain hardening. So, by increasing the strain hardening, elongation of samples was decreased. However as it shown in the last pass, elongation is very low and strengths have high value, Hassani and Ketabchi (2011). Fig 6 shows the Vickers microhardness of Al/Cu bimetal sheet during 8 pass ECAR process versus the pass number. The microhardness test was experiment according to ASTM E-92 standard test. As it shown in Fig. 6, the microhardness is significantly increased in the first and second passes. This occurs because of contact between sheets and rolls. The microhardness value is increased until 6 pass slightly.
The significant increase of the microhardness at the first 2 pass due to strain hardening is because of changing in grain boundaries in micro structure of Al/Cu sheet, Shaarbaf and Toroghinejad (2008). By following the ECAR process after 6 pass, a slight decrease was measured. The reason of this decline is ultrafine grain in micro structure of bimetal samples. As shown in Fig. 6, by continuing ECAR until eight pass the value of microhardness was decreased because of ultrafine grain and micro structure in Al/Cu sheet. In other words, dislocations caused to decrease the microhardness in last 2 pass, Tamimi et al. (2009).

4. Conclusion

In this study the effects of ECAR process on the mechanical and metallurgical properties of Al/Cu bimetal sheet were investigated and results are reported as follow:

- After the first pass of the ECAR process, the yield and tensile strength significantly increased and elongation decreased.
- Strain hardening after the first pass of the ECAR process was the main reason of decreasing the elongation.
- The microhardness of samples after the first passes of the ECAR process significantly increased and remained constant until 6 passes. After that, a slight decreasing was observed.
- Images of optical microscopy and SEM show the improvement of microstructure of samples at the first pass rather than the next passes.

Acknowledgements

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References