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Characterization of double aluminium alloy specimens after ECAP

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Abstract

The Equal Channel Angular Processing or pressing, i.e. the ECAP, allows to modify the properties of materials at the microstructure level. It consists in the induction of a high amount of shear deformation in the material that leads in general to a grain size refinement, a precipitate dispersion and a redistribution of dislocations depending on experiment conditions. The objective of the present investigation is to understand how the ECAP can influence the surface and the bulk mechanical properties of double aluminium alloy specimens. Each specimen was composed of a tubular part of the series AA6026 as well as of a cylindrical part of the series AA6012 assembled together before ECAP. A negligible bonding effect was observed after ECAP and after uniaxial compression tests performed at constant temperatures varying between 200 and 300°C with different press ram velocities. The characterization of each ECAP condition was initially represented in terms of the stress versus deformation flow curves. The load versus stroke curves were preferred due to the friction acting at the forming tool- specimen interface. It was obtained a decrease in the load versus stroke levels with increasing the number of ECAP passes under the experiment conditions of the present investigation. The increase in the press ram velocity determined an increase in the load for a given stroke.

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Keywords: Aluminium alloys, ECAP, Compression tests, Temperature

1. Introduction

When a material is subjected to high level deformations such as shearing deformations, the microstructure of the material can deeply change producing material properties that could differ a lot from those of the as-is material. That

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is the typical phenomenon that occurs when deforming the material nearby the stamping flash in conventional hot or warm stamping processes or in more complex deformation processes [1-3], sometimes requiring the adaptation of forging tools. Another example could be the extrusion of alumiunium alloys that generates zones characterized by elevated deformations as reported in [4, 5]. In order to understand the material behaviour under such heavy conditions a way to reproduce that is strictly required.

Among all of the methods that could be found in literature very useful is the Equal Channel Angular Processing, or pressing, i.e. better known as the ECAP. It substantially represents a way to modify the properties of materials acting at the microstructure level [6-10]. In fact, this kind of process consists in the induction of high amount of shear deformation in the material leading to a grain size refinement, to a precipitate dispersion and to redistribution of dislocations. By means of such method it could be also possible to enhance the strength and fatigue resistances. In practice, the process consists in forcing a lubricated billet into a channel with a given geometry in order to get the desired properties. In such a process the wear resistance of the material tends to be reduced with increasing the number of passes [7].

This means that the ECAP allows to evaluate the effect of the shear deformation conditions typical of many severe stamping operations and to understand how the material characteristics can change after stamping in the volumes, between the stamping tools. The ECAPed material could have also material properties much different from those of the as-is material and such difference could be underlined by room temperature compression tests that in general evidences an increase in strength [6, 8, 11] or by in temperature tests that can evidence an increase in workability. Up today, the study of the in temperature mechanical behaviour of the ECAPed specimens is still in progress under different geometric configurations.

A configuration very interesting from the research point of view is represented by the bimetallic rod composed of different materials, as reported in [12, 13], and ECAPed together. In that way it is possible to deform and to weld together samples previously assembled, sometimes adding a third sticking element.

The objective of the present paper is to investigate the effect of the ECAP process, performed at room temperature in different passes, on the surface and on the bulk properties of double alloy specimens characterized by a tubular part and a cylindrical one inserted inside the former. The tubular part was made of AA6026 aluminium alloy while the cylindrical one was made of AA6012 aluminium alloy.

In detail, the surface behaviour of the double alloy specimens after ECAP was observed and the effect of such process on the bulk material characteristics was quantified by in temperature uniaxial compression tests. It was observed a decrease in load, for a given stroke, with increasing in temperature and number of ECAP passes. In addition, under such conditions, the microstructure of the two materials and at the two materials interface was shown putting in evidence the negligible bonding phenomena.

2. Experiment procedures

The material investigated was constituted of a bimetallic rod composed of two aluminium alloy parts: a tubular part and a cylindrical one. The tubular part got an external diameter of 10.9 mm and an internal diameter of 7.8 mm with a length of about 100 mm. The internal part of the series AA6012 was assembled with the external one of the series AA6026 in order to get a monolithic, but not welded, specimen. The obtained double aluminium alloy specimen was lubricated using graphite grease and positioned in the ECAP matrix in order to be deformed. The ECAP press with related fixtures are shown in Fig. 1(a) and Fig. 2(b), respectively. The main angle of ECAP matrix was equal to 90°. In the same figure it is also possible to observe an ECAPed specimen.

A number of maximum four passes was imposed to each specimen and the external surface observed. At the end of each pass the material was sliced in order to get microstructure information, such as grain configuration and morphology, inside each part and at the interface between parts. Some cylindrical slices of 10 mm in height were used for compression tests. These cylindrical elements were lubricated with graphite base grease in order to avoid adhesion with the tools at workpiece-tool contact interfaces. The constant testing temperatures were varied between 200 °C and 300°C using heating strips applied on the forming tools in order to reduce the heated volume, thermal gradients and testing time. The compression testing equipment is shown in Fig. 2.

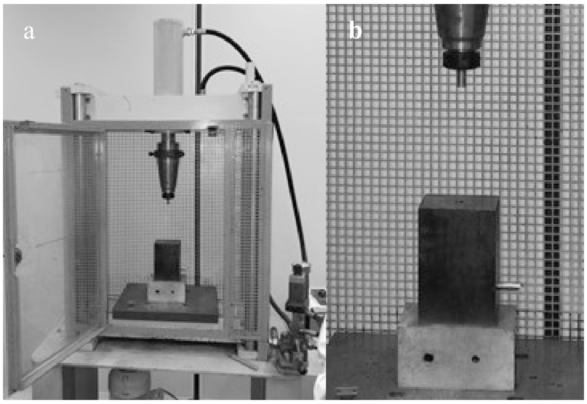

Fig.1. ECAP system: (a) ECAP press; (b) ECAP fixture.

Fig. 2. Upsetting tests configuration and heating strips applied on the forming tools.

The temperature was controlled by a thermocouple applied on each tool. A third portable thermocouple was used in order to check the temperature of the specimen prior to start each test. For each testing condition two different press ram velocities were used, that are 0.01 and 0.1 mm/s. The press ram displacement considered each time was equal to about 3 mm neglecting the effect of the springback. The stroke imposed in the tests allowed to realize the deformation of the specimen avoiding the complete adhesion at the forming tool – workpiece interface.

3. Results

When a double alloy specimen is subjected to different ECAP passes, some phenomena arise. Fig. 3 shows the ECAPed specimen under different conditions. In detail, Fig. 3(a) shows the elevated surface quality generated after one ECAP pass. Fig. 3(b) shows the internal cylindrical part and the external tubular part as they appear after one ECAP pass. Fig. 3(c) and Fig. 3(d) report the double alloy specimen after four ECAP passes. After four ECAP passes the surface quality seems to decrease and sometimes the continuity solutions appear to increase. In addition, the non uniform thickness of the tubular part can be observed. That could mean that the material experiences an hardening behaviour that in general could reduce the workability at room temperature.

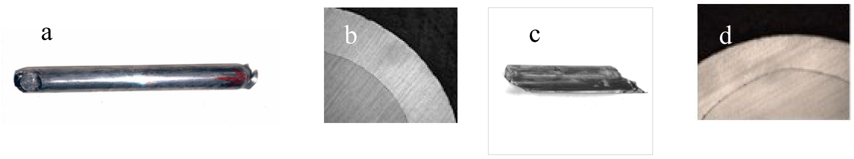

Fig.3. Typical ECAPed specimen; (a) surface quality after one pass; (b) tubular and cylindrical parts after one pass; (c) surface quality after four passes; (d) tubular and cylindrical parts after four passes.

The effect of the ECAP, performed at room temperature, tends to highlight the different behaviours of the two alloys considered. Negligible bonding effects are observed. The microstructure of the two alloys after different ECAP passes can be seen in Fig. 4 with an initial configuration characterized by equiaxed grains. The effect of the first pass produces a grain morphology typical of that obtained on aluminium alloy with intensive deformation with alongated grains along the material flow. In the transverse section with increasing in the number of ECAP passes the grain morphology and size became that characterized by new smaller grains in substantial agreement with that reported in [6-11]. It is supposed an increase or a slight increase in the room temperature strength with increasing the number of ECAP passes as found on similar aluminium alloys.

In Fig. 5 a typical double aluminium alloy specimen after in temperature compression test can be observed. It is still possible to observe the inside cylindrical part and the external tubular part. The barreling occurring during deformation evidences the friction at the forming tool-workpiece interface, as also indicated in [14] in which the sensitivity of the bulge curvature to friction is described. Under such condition the friction acting at the tool-workpiece interface, notwithstanding the graphite grease used for lubrication, produces a not really uniform deformation inside the material volume with a real transverse section and deforming loads that could be very different from those got by a frictionless test.

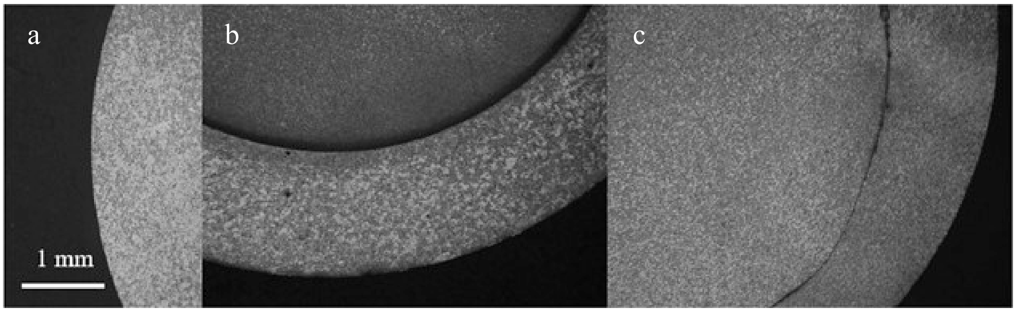

Fig.4. Main effect of ECAP can be observed in the tubular part section: (a) microstructure of tubular part as-is; (b) after one pass; (c) after four passes.

Fig. 5. Specimen shape after compression test at 200 °C.

Anyway, in Fig. 6 the results are reported in terms of the stress (σ) – deformation (ε) flow curves in which the effect of the temperature can be observed. σ and ε were calculated using the constant volume criterion and experiment data managed in order to reduce the scattering behaviour . Under the experiment configuration described in the previous paragraph it can be observed a decrease in the σ values, for a given ε, with increasing temperature for all of the ECAP conditions investigated.

Taking into consideration the barreling effect depending on the friction acting at the forming tool – workpiece interface and the variation of the lubrication conditions during testing, the results were plotted directly in terms of the load versus stroke diagrams.

In Fig. 7 the results show a decrease in the load levels, for a given stroke, when increasing temperature from 200°C to 300°C according to the behaviour of the most used aluminium alloys independently of the number of ECAP passes given to the specimen before testing. An increase in the press ram velocity from 0.01 mm/s to 0.1 mm/s produces an increase in the forming load.

The effect of the number of ECAP passes is reported in Fig.8 for in temperature compression tests performed at press ram velocity of 0.01 mm/s. In general a decrease in the load, for a given stroke, when going from the condition of one ECAP pass to that of four ECAP passes is detected for the double aluminium alloys specimens tested at 200°C and 300°C as shown in Fig. 8(a) and Fig. 8(b). The same behaviour, shown in Fig. 9, is detected for the compression tests performed at the press ram velocity of 0.1 mm/s on the ECAPed aluminium alloy specimens. This is in agreement with that found in [15-17] for similar alloys under similar conditions.

Concerning the morphology of the specimen after in temperature compression test, Fig. 10 shows the not realized bonding effect for those specimens previously subjected to one ECAP pass and a negligible bonding effect for those specimens characterized by four ECAP passes. Under the condition of the present investigation the temperature reached during the Equal Channel Angular Processing and during the subsequent compression test does not determine the real diffusion or deformation bonding conditions described in [18, 19].

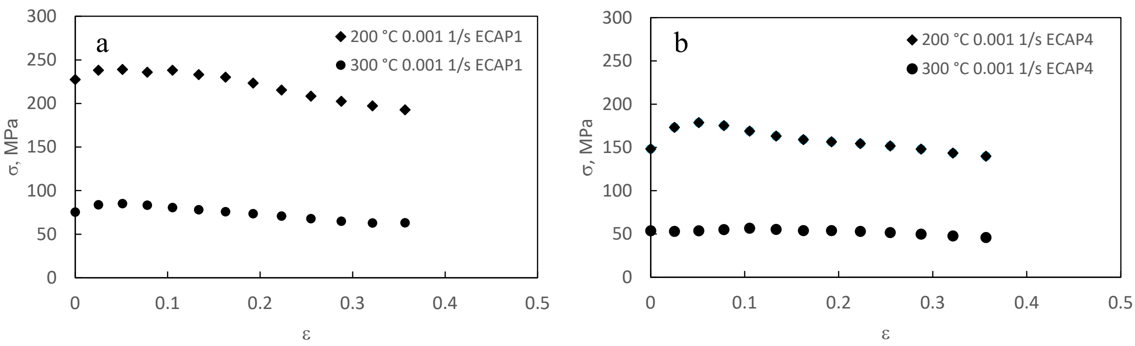

Fig.6. σ versus ε curves obtained by compression test at temperatures of 200 °C and 300 °C at 0.001 1/s and 0.01 1/s on specimens; (a) after one ECAP pass; (b) after four ECAP passes.

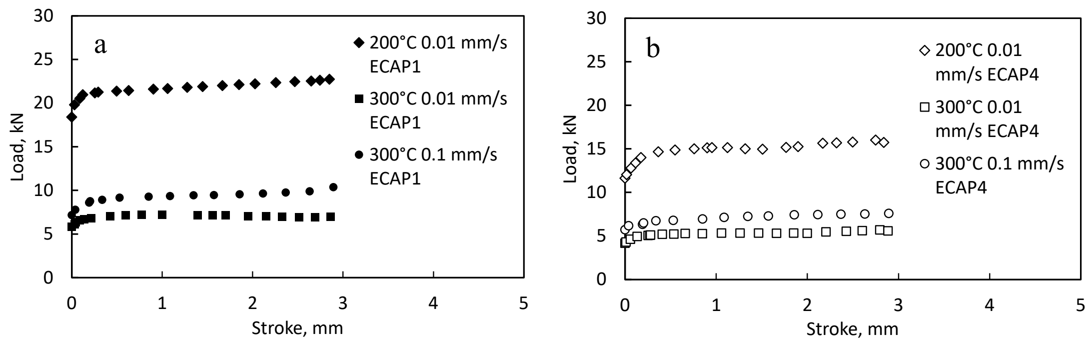

Fig. 7. Load versus stroke curves obtained by compression tests on specimens at 200 °C and at 300 °C with press ram velocities of 0.01 mm/s and 0.1 mm/s; (a) after one ECAP pass; (b) after four ECAP passes.

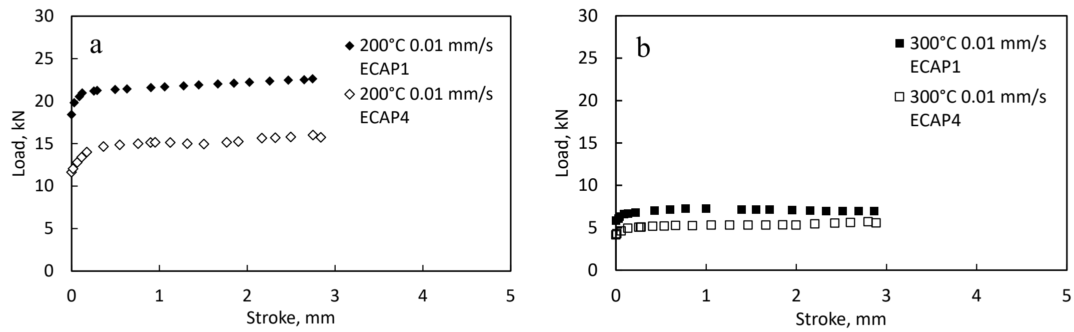

Fig.8. Load versus stroke curves obtained by compression test at 0.01 mm/s on specimens after one ECAP pass and after four ECAP passes; (a) testing temperatures of 200 °C; (b) testing temperature of 300 °C.

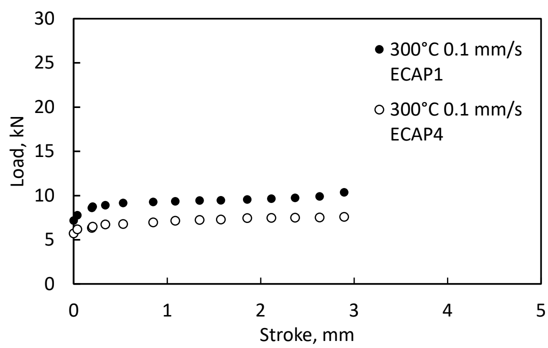

Fig.9. Load versus stroke curves obtained by compression test at 0.1 mm/s at temperatures of 300 °C on specimens after one ECAP pass and after four ECAP passes.

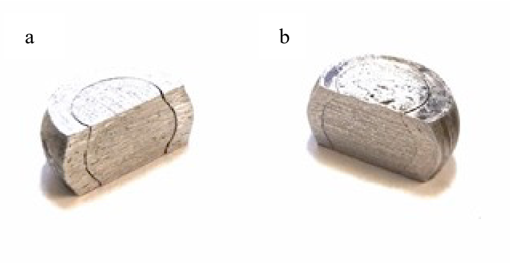

Fig. 10. Double aluminium alloy specimens deformed by in temperature compression tests: (a) previously deformed by one ECAP pass; (b) previously deformed by four ECAP passes.

4. Conclusions

The present paper leads with the study of the effect of the Equal Channel Angular Processing on the surface and bulk mechanical properties of double aluminium alloy specimens in which the internal cylindrical part was made of AA6012 aluminium alloy and the tubular one was made of AA6026. The results obtained can be summarized as follows.

The surface of the double alloy specimen is improved in terms of the surface quality after one ECAP pass. After four ECAP passes the surface of the specimen seems to be worsened with an increase of continuity solutions. A negligible bonding between the cylindrical and the tubular surfaces of the specimens after ECAP at the room temperature is detected.

The compression tests were performed at constant temperature varying between 200°C and 300°C with two different press ram velocities that were 0.01 and 0.1 mm/s. The barreling occurring on the specimens after compression evidences a not negligible friction at the forming tool-workpiece interface. For that reason the results were plotted in terms of the load versus stroke diagrams. The load-stroke curves obtained on the double alloy specimens after the same condition in terms of ECAP passes evidence an increase in the load, for a given stroke, with decreasing temperature and increasing press ram velocity.

When the different conditions in terms of ECAP passes are compared to each other it can be observed a decrease in temperature compression load, for a given stroke, going from one ECAP pass to four ECAP passes. The microstructure observations allow to specify that an increase of the number of ECAP passes produces a slight decrease in the grain size.

The morphology of the specimen after in temperature compression test shows a not realized bonding effect for those specimens previously subjected to one ECAP pass and a negligible bonding effect for those specimens characterized by four ECAP passes.

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