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INFLUENCE OF DCAP PROCESS ON THE MECHANICAL PROPERTIES OF 6061 Al-ALLOY SHEET

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Abstract. Materials with ultrafine-grained (UFG) structures can be produced by imparting high plastic strains. For bulk UFG material production, several processing techniques like ECAP have been developed and successfully applied. The handicap of ECAP system is its inconvenience for continuous deformation of aluminum alloy sheets which are widely used as structural components. Dissimilar channel angular pressing (DCAP) is one of the promising techniques used for continuous sheet or strip deformation. In this process, the workpiece is fed into the die by using a feeding roll. The forming die is composed of two intersecting channels, whose thicknesses are different from each other in a way that the thickness of the inlet channel is slightly smaller than that of the outlet channel.

The aim of this study is to investigate the enhancement in mechanical properties of 6061 Al-alloy sheets that are subjected to DCAP passes. A DCAP system was manufactured which is capable of deforming 110x250x2 mm size sheets. DCAPed samples were characterized by tensile tests and hardness measurements. It has been observed that a remarkable improvement in strength was obtained without a significant reduction in ductility.

1. INTRODUCTION

Ultrafine grained (UFG) materials have a grain size which ranges 10 to 1000 nm. Small grain size with large volume fraction of internal interfaces give these materials unique properties like high strength, good ductility, high wear resistance, excellent plasticity, etc. In recent years there is considerable interest in fabricating materials with ultrafine grain size. Researches have demonstrated that materials with an ultrafine grained structure can be produced by imparting high plastic strains. There are several methods to obtain ultrafine grain size in bulk materials. Principally these methods are based on the introduction of severe plastic deformation such as reciprocating extrusion [1], torsion under hydrostatic pressure [2], equal channel angular pressing (ECAP) [3-5], accumulative roll bonding [6], etc.

Among these techniques, ECAP has gained a commercial significance, since it can be used as new forming technique through which various bulk ultrafine grained materials can be produced with relative ease without changing their cross sectional shape [5,7-9]. Under the appropriate channel geometry, a strain of ~1 can be introduced into the work piece at a single passage through the die [10-13].

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Unlike other metal forming techniques, deformation induced by ECAP is relatively uniform throughout the specimen [14-16]. Since the cross sectional shape does not vary significantly before and after ECAP, a multi pass operation is also possible [11,17-19].

In earlier studies, it was obvious that processing of long and thin work pieces are impossible with ECAP and the limitation of work piece length makes ECAP a discontinuous process. This situation acts as a major drawback for wider commercial applications of ECAP. However, to overcome this drawback, a novel ECAP-based method called dissimilar channel angular pressing (DCAP) had been proposed [20,21], which can introduce large shear deformation to a long and thin work piece.

In this study, a Dissimilar Channel Angular Press was designed and Al-6061 type sheets were deformed up to 5 passes to investigate the enhancement in mechanical properties of the alloy.

2. EXPERIMENTAL PROCEDURE

The DCAP system used in this study is composed of a rolling system and a forming die (Fig. 1). The rollers having a diameter of 50 mm are used to feed the workpiece into the specially designed forming die. The forming die is structured by two channels, whose thicknesses are different from each other and intersecting at an angle of 120°. The thickness of the inlet channel is slightly narrower than that of the outlet channel to deform the specimen by preserving the initial thickness of the workpiece.

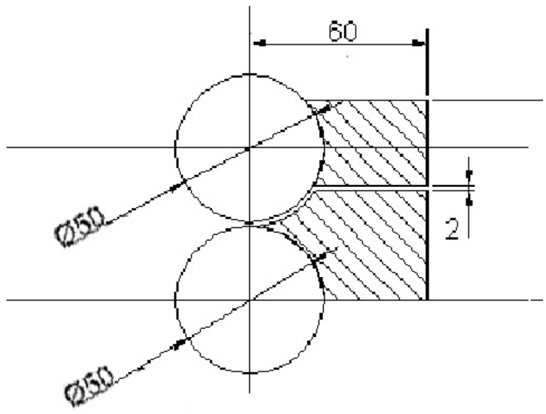

Fig. 1. Cross-section of DCAP system.

For multi-pass operation operable it is required to control the inlet channel cavity thickness in the design stage. Larger channel makes feeding difficult and narrower ones result in a thinner specimen. Hence, FEM analyses with Marc software were carried out to decide on the optimum inlet channel cavity thickness.

Finally; aluminum strips having the dimensions of 110 mm x 300 mm x 2 mm were fed to the DCAP system at room temperature with a feeding rate of 20 cm/min. The sheets were annealed at 450 °C for 16 h before deformation. For die cavity size 1.95 mm was selected. Deformed specimens were characterized by hardness and tension tests. For hardness measurements; Brinell hardness numbers were obtained with 2.5 mm ball indenter under 613 N load. For tension tests, the samples were prepared according to ASTM B557M-02a standard.

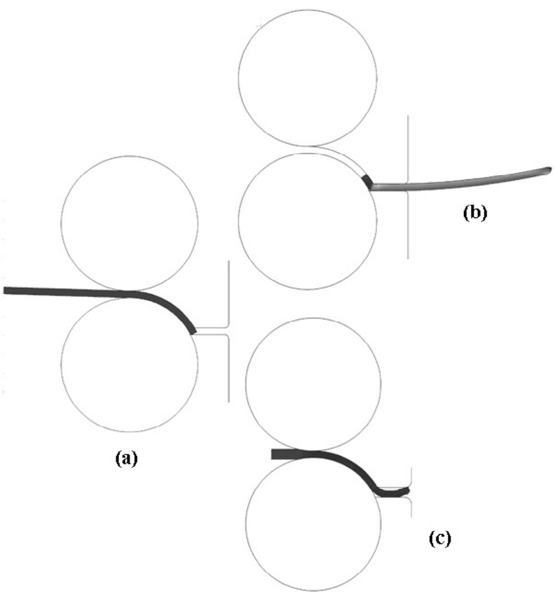

Fig. 2. (a) Sample feeding in DCAP, (b) Sample exit with 5% reduction by inlet channel (c) Sample exit with 20% reduction by inlet channel.

3. RESULT AND DISCUSSION

FEM analysis showed that the entrance deformation applied by the rolls must not be greater than 8% to make the specimen fill the DCAP outlet channel. This is the necessity of no cross sectional change during the operation. Some results representing the successful and wrong deformation amount are given in Fig. 2.

DCAP system's unique property is the higher strain values attainable by means of shear deforma-

Table 1. Strain values imparted to specimen for each DCAP pass.

N	1	2	3	4	5
ε	0.602	1.203	1.805	2.407	3.008

tion in a single pass. In Fig. 3, a sample snapshot from FEM analysis was presented: there is a variation of strain along the sample surface from 0.3 to 0.6 for one passage. This high strain values might only be reached by rolling with extreme percent reduction. It was thought that, since there is no cross-sectional change, all the energy was consumed for dislocation creation, and hence better mechanical properties could be obtained.

Retaining the initial thickness of the DCAPed specimens makes multi-pass operation possible, which in turn, can enhance material properties. So far 5-pass deformation was succeeded. The improvement in the hardness is presented in Fig. 4.

In metal forming, it is usual to analyze the variations in the mechanical properties by correlating them with the effective strain. The effective strain attainable from DCAP can be expressed in terms of the passage (*N*), the thickness ratio (*K*), and the oblique angle (Φ) [4].

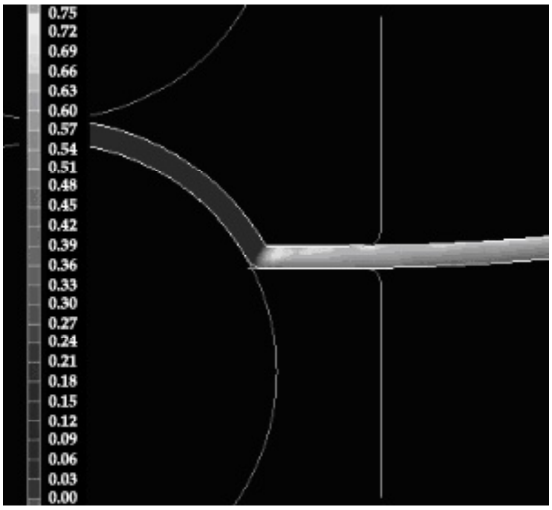

Fig. 3. FEM analysis of strain variation on strip surface during DCAP processing.

Table 1 summarizes the strain values attained for each pass through a 120° die for *K*= 0.950.

$$\varepsilon = \frac{2N}{\sqrt{3}} K^2 \cot\left(\frac{\Phi}{2}\right). \quad (1)$$

Tension test results showed a pronounced improvement in strength (Fig. 5). The strength increases as the DCAP pass number increases with-

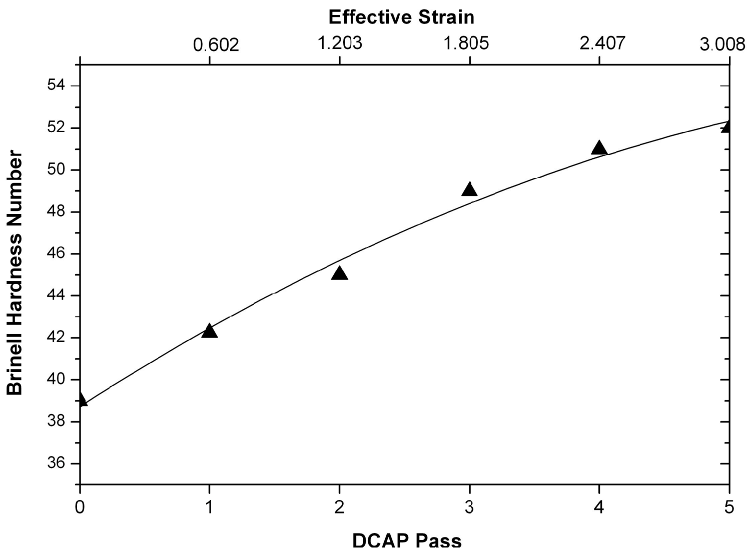

Fig. 4. Variation of sample hardness with DCAP pass number and accumulative strain (0 pass corresponds to annealed condition).

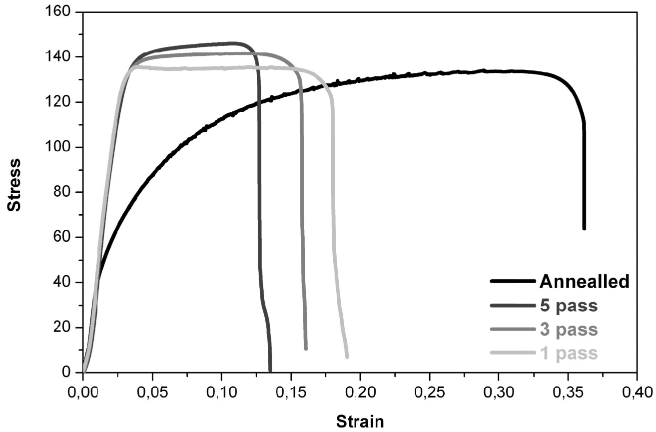

Fig. 5. Improvement in the strength of Al-6061 sheets via DCAP processing.

out so much ductility loss. After single DCAP pass, the yield strength of the material increased from 45 to 130 MPa. This increase might possibly due to grain size refinement as stated by Hall-Petch relation. An interesting finding was the observation of perfectly plastic behavior in the material after 1 and 3 passes. However, this behavior was changed towards strain hardening in the following DCAP passes as the dislocation density and the probability of dislocation interaction during tension increases.

The cellular structure generated as a result of dislocation tangle first transforms to a granular one, which later will be transformed to the UFG by the partial annihilation of dislocations of opposite signs at the cell boundaries when further deformation is applied [18,19,22]. Hence, the ultrafine grain structure can be obtained only when both the accumulative strain and the strain per each passage imparted to the specimen exceeds certain values. When the specimens were processed through the 120° channel, the accumulative strain level to attain the ultrafine grains was found to be ~2.4 (N=4). So this mechanism could possibly be the fact of easy dislocation glide and perfect plastic behavior in the early deformation passes and the strain hardening in the later passes.

X-ray analysis had been established to have a quick check of microstructural features in the level of 4 pass deformation (N=4). Fig. 6 shows the comparison of the X-ray peak spectrums of annealed

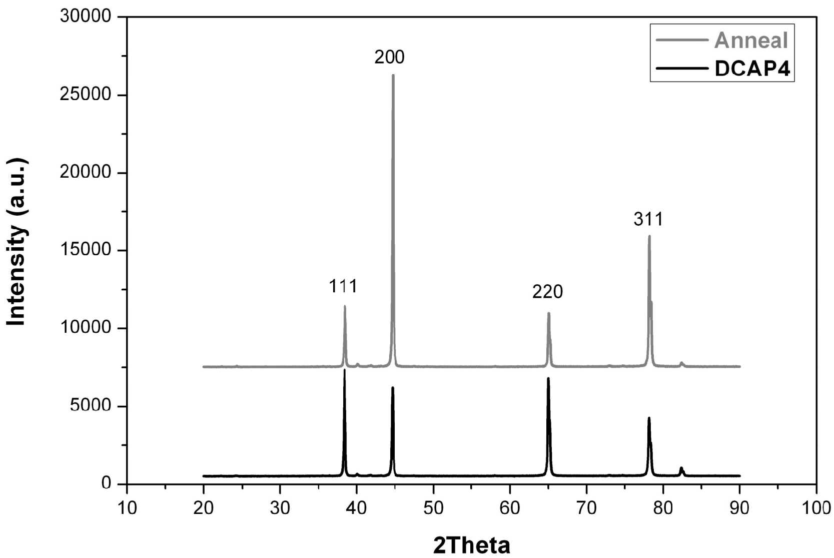

Fig. 6. Effect of DCAP on X-ray peak data.

and DCAPed samples. There is a texture along (200) and (311) in the annealed case; however no preferred orientation remains after 4 DCAP passes. The Rietveld refinement method on the X-ray data revealed sub-structure sizes in the range of 130-135 nm after severe plastic deformation via DCAP.

4. CONCLUSIONS

From the study on DCAP processing of 6061 Al alloy sheets, the following conclusions were drawn:

- FEM analysis showed that the DCAP deformation applied by the rolls must not be greater than 8% to make the specimen fill the outlet channel completely.
- DCAP processing of the annealed sample causes approximately 100% improvement in yield strength with a slight reduction in ductility.
- The deformed material showed a perfectly plastic behavior after 1 and 3 DCAP-passes, however a slight strain-hardening occurred in the material after 5 DCAP-passes.
- X-ray diffraction analysis using Rietveld refinement method showed that grain sizes in the range of 130 nm were obtained after 4 DCAP passes.

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