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Mechanical properties analysis of an Al-Mg alloy connecting rod with submicrometric structure

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Abstract

In spite of the fact that SPD processes considerably improve the mechanical properties of the thus processed materials, in a large number of cases, it is necessary the subsequent employment of a traditional manufacturing process, such as a forging process, in order to obtain the final shape of a specific part. Thus, in general, it is necessary to use a thermal treatment for the material before it is forged. In this research work, the measurement of the mechanical properties of an isothermally forged connecting rod is to carried out. The results obtained for an AA5754 aluminium alloy are to be compared in the case of two different starting states: after an annealing heat treatment and after having been previously ECAP deformed. It is observed an increase of 21% in the HV microhardness in relation to that attained in the connecting rod forged from the material without previous ECAP deformation.

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Keywords: ECAP, Isothermal forging, microhardness, FEM

1. Introduction

In recent years, numerous Severe Plastic deformation (SPD) processes have been developed with the aim of obtaining nanostructured materials. However, ECAP (Equal Channel Angular Pressing) still remains to be the most widely used process as the highest improvements in the mechanical properties are obtained in the ECAP-processed materials. Moreover, in spite of the fact that there is a great deal of bibliography concerning the improvements

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obtained in the mechanical and in the microstructural properties of the ECAP-processed materials, a few mechanical components have only been manufactured from these materials [1-2]. In [1] the results obtained after the isothermal forging of a straight blade previously ECAP processed are shown for an AA5083. In this study, an isothermal forging is carried out at different temperature values, where the optimum temperature is found to be 175 °C. Higher microhardness values are obtained for the forged blade after two ECAP passages than in the forging with no previous processing. In [2] a work methodology is proposed in order to manufacture bolts of AA6061 (T6 state) in an industrial way, carrying out an extrusion process after one and two ECAP passages. In [3] SEM micrographs and microhardness values of an AA6061 micro-gear are shown after its manufacturing by means of several ECAP passages (8 to 12). Forging temperatures in [3] are 443 K and 553 K, where in the first case an important improvement of the mechanical properties is achieved in relation to the only ECAP processed material. Nevertheless, a decrease in these mechanical properties is obtained after the extrusion at higher temperatures. A micropart with a length of approximately 7 mm was extruded out without visible defects [3]. In [4] the authors examine the effects of scaling up the ECAP process. For this purpose, an aluminum alloy 6061 is used and microstructural and mechanical characterizations are carried out. Furthermore, two parts are forged at different temperatures after the ECAP process. The route used is BC, and they also forged the parts using different number of passages. In [5] a special split die design is carried out in order to manufacture impellers by using a magnesium alloy AZ31, which is forged after being processed by ECAP.

In order to carry out the isothermal forging of a material after a severe plastic deformation process, it is necessary to take into account that the material may undergo a recrystallization process, which leads to an important loss of the properties obtained after the SPD process [6]. However, if the process is carried out at a lower temperature and at a velocity fast enough (with no time for a dynamic recrystallization), a stress relief takes place in the material, which allows the forging of the desired part to be performed but only with a slight decrease in the good mechanical properties previously achieved in the ECAP process.

In [7] the steps followed in the design of dies for manufacturing blades are shown in the case of a Francis type turbine. The design is carried out taking the material flow into account in the case of an AA5083 after two ECAP passages with route C. In this research work, it is stated that it is very important to find the adequate temperature for getting a part with no cracks as well as a correct die filling, where this means that there are no empty zones in the die cavity or zones with a surplus of material, thus causing a high forging force. The selected temperature is 250 °C and the results are compared with those obtained for blades forged from material with no previous pre-deformation. In [8] a similar study is made but in this case the part to be manufactured is a ring which may be used as a bearing. The starting material is AA5083 and the study is carried out with the help of design of experiments (DOE) in order to obtain the optimum design of the dies which allows the ring to be manufactured with a correct die filling and with the lowest possible forging force.

In this paper, the properties of a connecting rod made of AA5754 previously ECAP-processed with two passes (N2) and route C are studied. The forming process used to manufacture the connecting rod has been the isothermal forging. Taking into account the high accumulative plastic deformation during ECAP, to forge the rod, it is necessary to use isothermal forging [7-9].

To perform this study, measurements of Vickers microhardness are taken at the zone where the maximum accumulated plastic strain is achieved by finite volume simulations.

2. Experimental Methodology

This section outlines the manufacturing process of connecting rods and the microhardness measurements carried out.

2.1. Manufacturing of connecting rods

The procedure carried out to manufacture the connecting rods which are to be tested is shown in this section. The initial material is an AA5754 manufactured in the form of rods through an extrusion process with a diameter of 20 mm as it is shown in Figure 1a. It is then subjected to an annealing heat treatment as follows: the furnace temperature is increased from room temperature up to 345 °C during 1 h, this temperature is maintained during 2 h and subsequent slow cooling in the furnace (no more than 20 °C per hour) down to room temperature [9]. The chemical composition of the AA5754 employed can be observed in Table 1

Table 1. Chemical composition of the alloy employed

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
%	0.17	0.38	0.05	0.32	3.02	0.05	0.04	0.02

Subsequently to the annealing treatment (N0), the material is ECAP processed in a press specifically designed for this purpose [8] at room temperature. Processing route C is used with two passages (N2), that is to say, with a rotation of 180º with respect to the extrusion direction between passages. The processed billets are turned in such a way that the zones which have not undergone severe plastic deformation are removed. Then, the billets are again turned in a CNC lathe in order to obtain the preform from which the connecting rod is forged. The forging process of the connecting rod consists of two strokes. Before the first forging stroke, the preform is introduced in the dies heated at the specific temperature during five minutes (this waiting period is necessary for the preform to reach the required temperature) and then it is forged. The first forging stroke gives the external shape to the initial preform and the second stroke creates the inner hollows (Figure 1b)). Lastly, the flash is removed in a milling machine and the two holes where the shafts are housed are drilled.

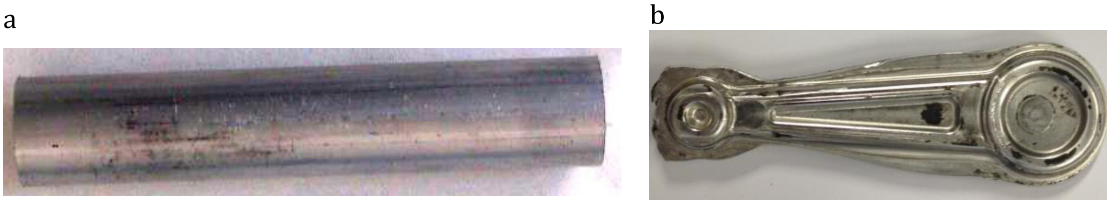

Fig. 1. Manufacturing of connecting rods. (a) N0 (b) Manufactured connecting rod

Figure 2 shows optical micrographs for each of the two starting states. In the case of the alloy which has been ECAP processed twice (N2), a large number of deformation bands is observed, where these are caused by the SPD process [10].

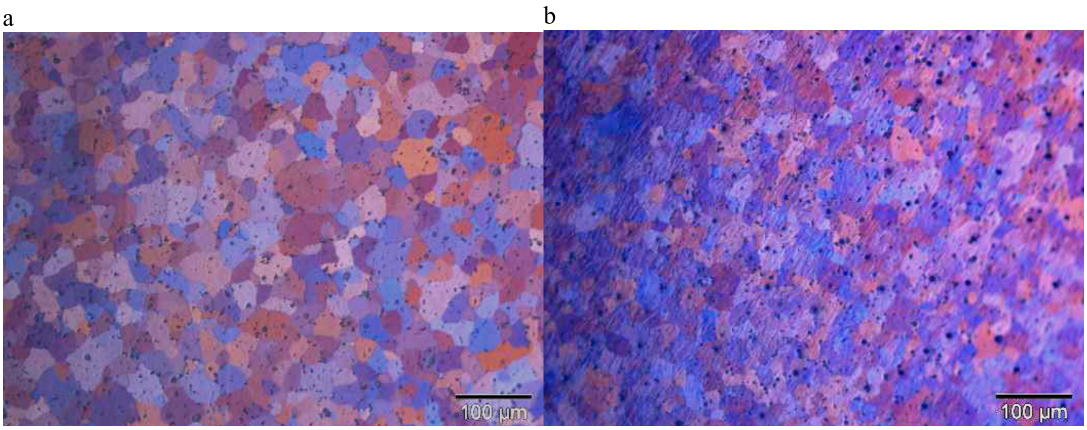

Fig. 2. AA5754 optical micrographs from N0 and N2 microstructure starting states. (a) N0 (b) N2

2.2. Design of the forging study at 150 °C

The forging of the connecting rod is carried out both for the starting material with no previous plastic strain (N0) and for the previously ECAP deformed material (N2) at room temperature. The selected temperature value is T=150 ºC for both initial states. Given the difference in terms of plastic strain which exists between the different zones along the connecting rod, a study zone is selected, where this is the zone with the highest plastic strain and on this, the HV microhardness measurements are taken. This selected zone is shown in Figure 3 and it is selected from finite volume simulations, as is shown in the results section..

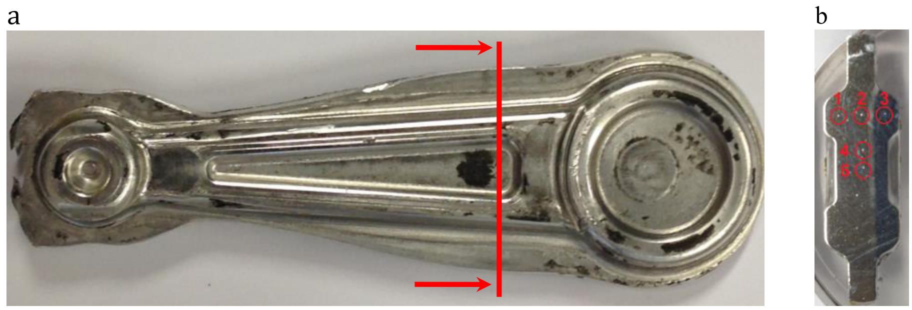

Fig. 3. Selection of the zone cut and points where HV microhardness is measured. (a) Section to be cut in the connecting rod (b) Cross section

In the cutting zone shown in Figure 3, five points where microhardness is to be measured are chosen. In order to take the microhardness measurements at the study cross-section shown in Figure 3, the cut pieces were embedded into resin and polished to mirror finish. Table 2 shows the results of the HV microhardness measurements taken from the connecting rod forged in each of the two starting states.

Table 2. Microhardness measured in the connecting rod forged at 150 °C

Starting state	N0	N2
HV1	92.9	106.2
HV2	86.9	106.6
HV3	88.3	110.7
HV4	98.9	109.9
HV5	99.7	132.0
Mean	93.3	113.1
Standard deviation	5.9	10.8

Figure 4 plots the obtained results. It is observed that for all the study points under consideration, the connecting rod forged after N2 presents higher microhardness values. Furthermore, it may be observed that HV1, HV2 and HV3 measurements, which correspond to the three horizontal points shown in Figure 3b, present a very similar value and on the other hand, HV4 and HV5 measurements increase significantly. In the section below, a comparison is made between these results and those obtained from the finite volume simulations.

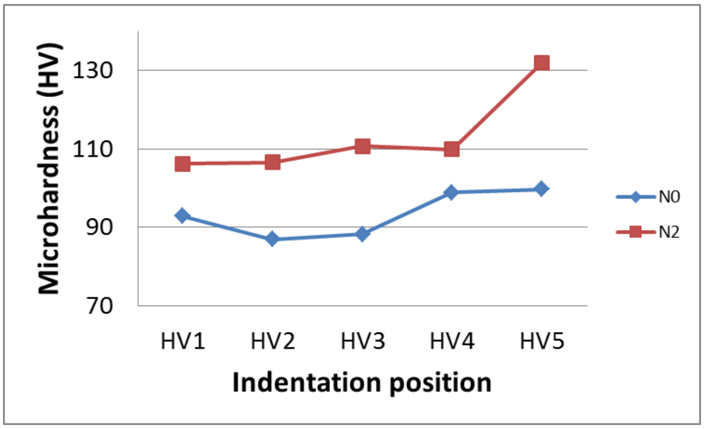

Fig. 4. Microhardness measurements at each point for any of the two starting states

3. Results

As was previously-mentioned, Figure 4 shows that the connecting rod forged from material previously ECAP deformed presents higher microhardness values for all the study points under consideration. The zone with the highest values is found to be in the body of the connecting rod but at the zone close to the bigger head. The selection of this study zone is related to Figure 5, where the equivalent plastic strain results obtained from the finite volume simulations are depicted. In order to carry out the finite volume simulation a flow stress curve for the AA5754, which has been processed up to N2 by ECAP, is used. This flow stress has been determined from compressionstsA 1 mm tetrahedral meshing is used. Moreover, a remeshing criteria is applied every 10% of the loadcase time. Moreover, a shear friction coefficient of 0.4 is considered. It may be observed in Figure 5 that the highest plastic strain value takes place at the connecting rod body zone which is close to the bigger head. At the centre of this head, there is also high plastic strain but one has to take into consideration that this material zone is removed when the hole is drilled in the last manufacturing step of the connecting rod and therefore, it has not taken into account. Also, in Figure 5 the selected cross section with the five points where the microhardness measures have been taken is showed.

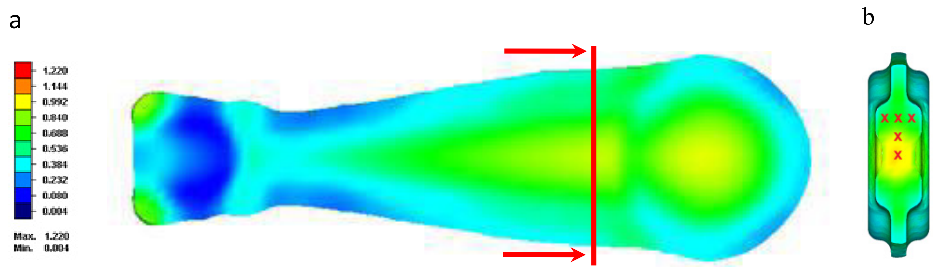

Fig. 5. Equivalent plastic strain distribution of the connecting rod obtained from finite volume simulations

Finally, Figure 6 shows optical micrographs of the forged connecting rod. If they are compared with those from previous Figure 2, new small size grains are observed to have appeared, which indicates that a partial recrystallization has occurred, thus allowing the connecting rod to be forged with no significant loss of hardness.

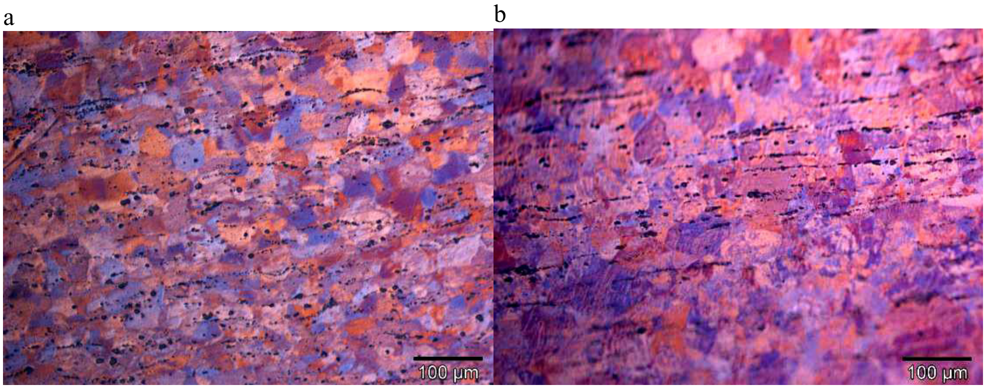

Fig. 6. Optical micrographs of the connecting rod forged. (a) N0 (b) N2

4. Conclusions

This research work deals with the forgeability of an AA5754 connecting rod manufactured from two different states: after an annealing heat treatment (N0) and after having been previously ECAP deformed with two passages (N2) and using route C. The isothermal forging temperature finally selected is 150 ºC. It is observed that the connecting rod manufactured after N2 shows an increase in the HV microhardness values of 21 %, in relation to the connecting rod forged from the N0 state. Furthermore, it has been stated that the highest microhardness values obtained experimentally coincide with the zones with the highest accumulated plastic strain values attained from the finite volume simulations.

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