Examination of the effect of homogenization processes through compression tests in aluminum alloys

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Abstract. Formability characterises the behaviour of the metals during shaping, more precisely, the accumulated deformation until rupture or fracture. Formability can be influenced by several factors and can be characterized with several methods. In this paper, the effect of the processes occurring during the pre-heating and homogenization of formable aluminium alloys was studied. Three commercial aluminum alloys, namely, 3003, 5005 and 5052 were involved into the investigation to reveal the different behaviours resulting from composition differences. The characterization of hot formability must be characterized by a rapid and simple method in cases when large number of sample series must be handled. In parallel, reliable results of the examination method is required. To fulfil both requirements, cold and hot compression tests were carried out with an Instron 5982 universal material tester equipment. The rapid heating of the samples during hot compression tests was realized with a unique own-made inductive heating device. Thus, the effect of dynamic recrystallization during hot compression, while static recrystallization during cold compression tests and subsequent annealing could be studied. The performed experiments were used to simulate the effects of the cold-rolling and hot-rolling. The resulting grain structures were studied with Barker etching technique.

1. Introduction

The Faculty of Material Science at University of Miskolc and the Arconic-Köfém Ltd. with several other Universities in Hungary started a research project together. For the Arconic-Köfém Ltd., as the manufacturer of aluminum alloys, formability of the alloys is a key issue. Thus, the goal is to develop and carry out a series of experiments which provide a rapid, precise and reliable measurement method to study the formability of large numbered sample series in a short time.

The fundamental difference between cold and hot forming is that recrystallization process occurs at the temperature of forming or not. Recrystallization is a physical metallurgical process consisting of nucleation and grain growth, of which the driving force is the increased stored energy of the metal accumulated during deformation. During cold forming, recrystallization doesn’t take place, thus dislocation density is increased. Increasing the density of dislocations will cause the material to become hardened and its formability will be depleted. During hot forming, the recrystallization takes place at the temperature of forming. Thus, dynamic recrystallization and static recrystallization must be distinguished [1-3]. The aim of this manuscript is to study the effect of recrystallization process (both static and dynamic) on the formability of three commercial aluminium alloys, namely: 3003, 5005 and 5052 subjected to different durations of homogenization [4,5].

2. Experimental
Three different formable alloys were investigated, namely the 3003, the 5005 and 5052. The composition of the examined alloys is shown in Table 1. The main alloying element of the 3003 alloy is Mn around 1% content. This content is mostly in solution and different precipitations, which greatly influences the formability. The 5xxx alloys are also formable, although they belong to the non-precipitation hardening alloy. The main alloying element of this group is the Mg around 0.7-2.45% content.

**Table 1. Composition of the examined alloys**

| Alloy | Al   | Si   | Mn  | Fe  | Mg  | Zn  | Pb  | Cu  | Cr  | Ti  | Cd  | Ni  | Zr |
|-------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| 3003  | 97.99| 0.23 | 1.1 | 0.53| 0.016| 0.023| 0.001| 0.057| 0.004| 0.022| 0.0005| -  | - |
| 5005  | 98.48| 0.14 | 0.054| 0.47| 0.77| 0.008| 0.001| 0.012| 0.014| 0.012| -  | -  | -  |
| 5052  | 96.89| 0.12 | 0.08 | 0.26| 2.41| 0.01 | 0.002| 0.044| 0.16 | 0.012| -  | -  | -  |

One of the industrial homogenizations (shown in Fig 1.) used by the Arconic-Kőfém Ltd. was applied. The peak temperature of the homogenization is 510°C, and the holding times are 1, 5 and 10 hours. Heat treatments were performed in an air furnace. The different homogenization durations modelled cases where different sections of the ingot (beginning, middle, end part) for different reasons (the non-planned execution of the heat treatment, etc.) spends different time intervals in the homogenization furnace.

![Figure 1. The applied homogenization programs](image)

Cylindrical samples were cut from the ingots and cold and hot compression tests were performed on them with an Instron 5982 type universal material tester equipment. To prevent barrelling [6,7], a small edge was left on the two flat sides of the compression samples in which a Teflon film was inserted to reduce friction between sample and sample holder. Cold compressions were performed at 23°C and hot deformations were carried out at 400°C with 1/s deformation rate up to 60% deformation. Sample heating was realized with an own-built inductive heating device providing rapid heating and cooling to prevent any recrystallization process after the compression tests.

The cold compression was followed by an annealing treatment at 500°C for 1 hour during which static recrystallization was expected to occur. The tested samples were cut in the plane of pressing (longitudinal section) embedded in resin and prepared with Barker etchant to reveal the grain structure (Fig. 2.).

Cold compression
3. Results
Figures 3-5 show the true strain-true stress of the examined alloys homogenized for 1, 5 and 10 hours during cold and hot compression tests; and the grain structure after the tests and subsequent annealing in case of cold compression and after tests in case of hot compressions.
Alloy 3003

Figure 3. True strain-true stress curves of alloy 3003 during a) cold compression tests and grain structure after cold compression and annealing b) hot compression tests and grain structure after hot compression
Alloy 5005

![Graph showing true strain-true stress curves of alloy 5005 during cold compression tests and grain structure after cold compression and annealing.](image1)

*Figure 4.* True strain-true stress curves of alloy 5005 during a) cold compression tests and grain structure after cold compression and annealing b) hot compression tests and grain structure after hot compression
Alloy 5052

![True strain-true stress curves of alloy 5052 during a) cold compression tests and grain structure after cold compression and annealing b) hot compression tests and grain structure after hot compression](image)

**Figure 5.** True strain-true stress curves of alloy 5052 during a) cold compression tests and grain structure after cold compression and annealing b) hot compression tests and grain structure after hot compression
In Fig. 3, it can be seen that the true strain-true stress curves of alloy 3003 obtained during cold and hot compression tests are very similar in case of different homogenizing durations. According to the micrographs, after cold compression tests and annealing, most of the grains are elongated suggesting that recrystallization partially occurred during the annealing. It is true for all three alloys that after hot compression tests, the grain structures are mixtures of grains that are severely deformed and others that are mildly deformed. The less deformed grains were formed during the dynamic recrystallization occurring during the compression. Their slightly elongated shape is the result of the combination of dynamic recrystallization and compression [8].

In Fig. 4, the true strain-true stress curves of alloy 5005 obtained during cold and hot compression tests are very similar in case of different homogenizing durations. After cold compression and annealing, equiaxial grains are present which means that the classic, high-angle grain boundary involved recrystallization occurred during the annealing treatment [8].

In Fig. 5, the true strain-true stress curves of alloy 5052 obtained at different homogenization durations during cold compressions completely match with each other. As for hot compression tests, a slight difference can be seen: the sample homogenized for 10 hours has lower stress values compared to the other two. After cold compression and annealing, the grain structure is equiaxial and the grains are finer compared to the alloy 5005 after cold compression and annealing. This suggests that the classic, high-angle grain boundary movement assisted recrystallization occurred with higher nucleation rate compared to the 5005 alloy.

Fig. 6. shows the maximal values of true stress of the three alloys as a function of homogenization time. As can be seen, the maximal stresses of cold compression tests do not depend upon the homogenization time. The values of alloys 3003 (Mn content 1.1 m/m%) and 5005 (0.054 m/m% Mn and 0.77 m/m% Mg), are close, but that of 3003 are slightly smaller. Alloy 5052 has the highest maximal stress value. This is probably due to the high (2.41 m/m%) Mg content [8].

![Figure 6. Maximal true stress values as a function of homogenization time of the 3003, 5005 and 5052 alloys](image-url)
4. Conclusions

The hardening behaviour was examined with cold and hot compression tests of 3003, 5005 and 5052 alloys subjected to different durations of previous homogenization heat treatments. In addition, grain structures formed after cold compression and subsequent annealing, and hot compression was examined. It was found that the variation in the homogenization time between the 1 … 10 h interval does not have a major effect on the obtained true strain-true stress curves of all three alloys or resulting grain structure. Alloys 3003 and 5005 showed similar maximal true stress values, while alloy 5052 had higher maximal stress values after both cold and hot compressions. The maximal compression stresses are due to the high Mg content of alloy 5052 (2.41 wt%). For alloy 3003, the high angle boundary involved classic recrystallization occurred partially, while for alloys 5005 and 5052 it took place completely. The domination of high angle grain boundary involved recrystallization is probably owing to the higher Mg content of alloys 5005 and 5052 (0.77 and 2.41 wt%, respectively). For alloy 5052, the classic recrystallization occurred with higher nucleation rate. Again, this is due to the high Mg content, which supports secondary phase precipitation, which in turn promotes nucleation during classic recrystallization. Thus, it was shown that the increasing Mg content increase compression stresses and promotes high angle grain boundary recrystallization in Al alloys. The effect of Mg on mechanical properties are in agreement with observations on AlCuMg alloys [9] and on AlMgSi alloys [10]. Thus, the applied method is suitable to reveal the effect of Mg content on mechanical properties of formable Al alloys through simple and rapid examinations. It was observed for all three alloys that after hot compression tests, the grain structures were mixtures of grains that are severely deformed and others that are mildly deformed. This is characteristic of the dynamic recrystallization that occurred during hot compression.

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