Mechanical response and microstructural evolution of 6061-T6 aluminium alloy subjected to dynamic testing at low temperature

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Abstract. The aim of this research was to investigate an effect of low temperature on the mechanical properties and microstructure of 6061-T6 aluminium alloy (AA6061-T6) subjected to dynamic loading. The specimens were subjected to dynamic compression at a low temperature of -80°C in a range of strain rates from 1.25×10^3 1/s to 3.4×10^3 1/s to compare their mechanical responses. The deformation mechanisms were analysed through EBSD observations during which dynamic recovery, was found as the dominant one. Furthermore, microstructural analysis indicated that deformation under high strain rate conditions and temperature of -80°C enables to keep the constant initial grain size of the material after the loading applied.

Keywords: Split Hopkinson Pressure Bar (SHPB), low temperature, AA6061, microstructure, EBSD

Introduction

Aluminium alloys of the 6xxx series have been widely used in the automotive industry due to their high strength to weight ratio, suitable weldability and machinability, good erosion resistance, and relatively low cost. However, the low formability and significant spring back of AA6061 at room temperature limit their ability to form complex-shaped components by using conventional forming technologies. Thus, the low-temperature forming processes were introduced to enhance the formability of aluminium alloys on the one hand, and to avoid severe localized thinning and microstructure deterioration caused by the hot forming on the other. Since aluminium alloys have been widely used at low temperature and cryogenic conditions, the knowledge of deformation mechanisms occurring under both, static and dynamic conditions should be expanded. It was also reported, that the application of higher strain rates can potentially improve the efficiency of certain forming processes. As a consequence, deformation mechanisms at high strain rates require systematic thorough investigations. Hence, the microstructural evolution of commercial AA6061 was discussed in this research during low-temperature compression in a wide range of strain rates. The dominant deformation mechanisms were identified using Scanning Electron Microscopy (SEM) and Electron Backscatter Diffraction (EBSD).

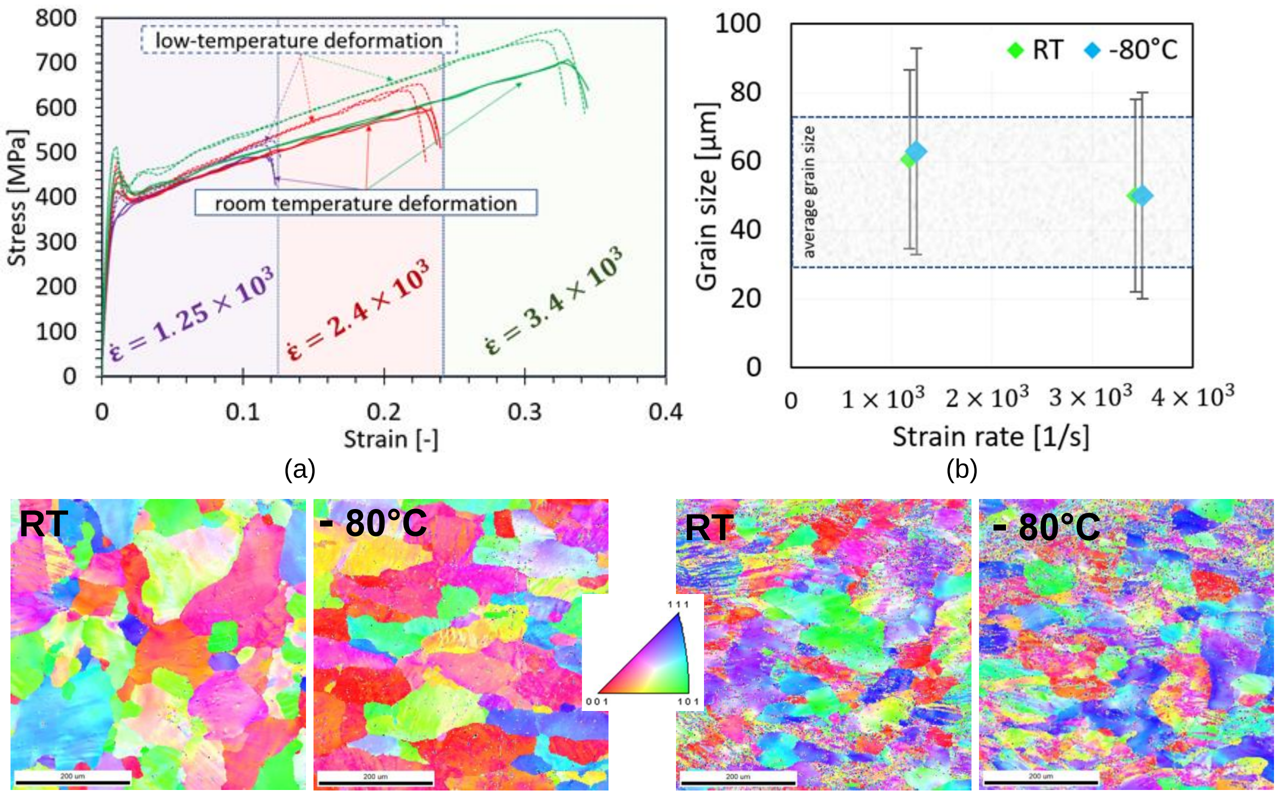
Results

The as-received, commercial AA6061-T6 alloy with an average grain size equal to 50±20 μm was used in this study. Dynamic testing was carried out by using the SHPB setup with low-temperature environmental chamber. The mechanical properties of the aluminium alloy were characterized at strain rates ranging from 1.25×10^3 1/s to 3.40×10^3 1/s and a temperature of -80°C. The additional tests under the same conditions, however, at room temperature were performed for the comparative studies. All the stress data were provided in nominal stress (force/original cross-sectional area of the material before any deformation). The microstructural characterization was performed on high-resolution Quanta 3D FEG (SEM/FIB) scanning electron microscope system equipped with an integrated EDS/EBSD system (EDS - energy dispersive X-ray detector, and EBSD - electron backscatter diffraction analysis system) operated at 20 kV.

Figure 1a presents the stress-strain curves of AA6061-T6 determined from dynamic tests at room temperature and -80°C. The alloy exhibited a rise of the plastic flow stress and maximum stress at the low-temperature. Each value was obtained by measuring at least two specimens and experiments showed a standard deviation less than 5%. In comparison to the room temperature testing, a relative improvement in nominal stress of approximately 10% was achieved regardless of the strain rate used. On the other hand, a much lower increase of the plastic flow stress was observed (around 5%). The higher increase in the nominal stress compared to that of the plastic flow stress was related to the faster strengthening of the material at low temperature.

The as-received AA6061-T6 was characterized by an average grain size of 50μm ±20μm. The dynamic deformation applied by using SHPB under both, room and low temperature did not affect its evolution significantly, since only the grain shape is changing, not their equivalent size (Fig.1b). Although a slight grain sizes increase was found under the strain rate of 1.25×10^3 1/s, their average sizes obtained for the highest strain rate were almost the same as those for the as-received material. Thus, it could be concluded, that in terms of changes in the average grain size, AA6061-T6 is not sensitive to high strain rate deformation under both room and low temperature conditions.

The microstructural evolution observations were performed by using SEM-EBSD investigations and presented in the form of IPF maps (Fig.1c-d). One should conclude, that dynamic deformation led to a significant increase of low-angle boundaries (LAB) since their fraction increased from 0.330 in the as-received state to 0.629 and 0.642 at room temperature and -80°C, respectively. It can be also observed, that dynamic testing at room temperature is leading to the prominent orientation in [001] direction while the low-temperature condition keeps the orientation at the state similar to the as-received material.
Generally, it could be observed that RT compression leads more likely to slip lines formation, whereas under low-temperature conditions a general reduction of slip lines and a smaller number of highly deformed areas can be observed. Such effect enabled to conclude, that the same slip systems are activated during deformation at room and low temperature. It is known, that material recovery is more dominant at room than at low temperature. Under the same strain rate applied, more dislocation annihilation should occur at room temperature.



(c) (d)

Fig. 1. (a) Comparison of dynamic stress-strain characteristics of AA6061-T6 compressed under different values of strain rate and temperature; (b) Comparison of the average grain size distribution as a function of strain rate at room and low temperature. IPF maps of AA6061-T6 alloy deformed at the strain rate of 1.25×10^3 1/s (c) and 3.40×10^3 1/s (d) under low-temperature conditions and at room temperature.

The aluminium alloy exhibited relatively low temperature and strain rate dependency since with the temperature decrease to -80°C, the typical stress parameters like those describing yielding process initiation and maximum stress increased by around 5-10%, only. The alloy was able to absorb more energy at low-temperature while achieving the same deformation level as that obtained during the room temperature test. Such phenomena were related to the higher dislocation density, and as a consequence, higher strain hardening rate responsible for the improved strength of the alloy at low temperatures. The main deformation mechanism of aluminium alloy subjected to dynamic deformation under low-temperature conditions was represented by dynamic recovery.

References

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