MECHANICAL RESPONSE OF 6061-T6 ALUMINIUM ALLOY SUBJECTED TO DYNAMIC TESTING AT LOW TEMPERATURE

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1. Introduction

The adaptation of low-temperature among conventional forming methods including incremental forming, deep drawing or hydro-bulging significantly extends the forming window for aluminium alloys. In order to successfully form such materials, the constitutive models have been generally used to predict their deformation behaviour for different forming processes.

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 $\times10^3$ 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.

2. Materials and methods

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.

3. Results and discussion

Figure 1 presents the stress-strain curves of AA6061-T6 determined from dynamic tests at room temperature and -80°C. The alloy in question 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 microstructural evolution observations were performed by using SEM-EBSD investigations and presented in the form of IPF maps (Fig.2). 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.

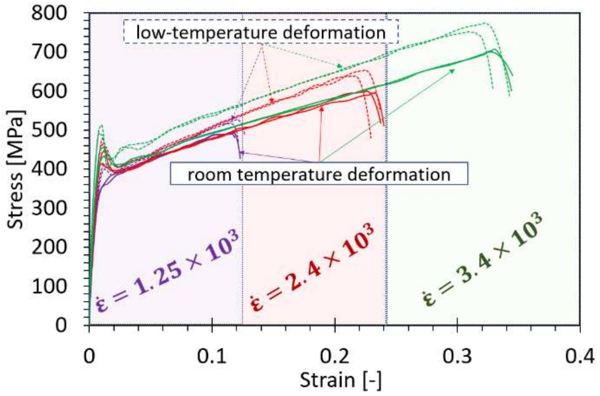

Fig. 1. Comparison of dynamic stress-strain characteristics of AA6061-T6 compressed under different values of strain rate and temperature.

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 (Fig.2c). 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.

4. Conclusions

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.

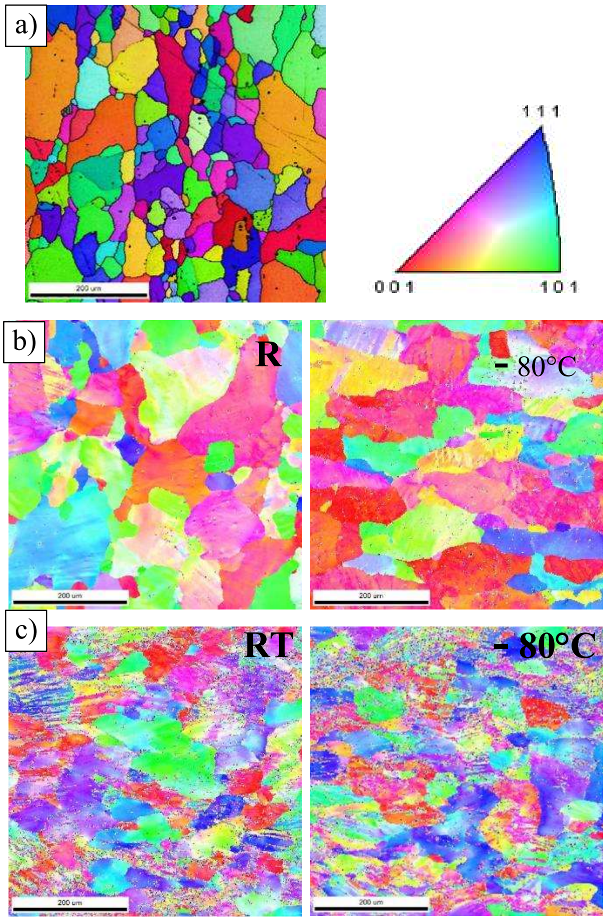

Fig. 2. IPF maps of as-received AA6061-T6 alloy (a), deformed at the strain rate of 1.25×10^3 1/s (b) and 3.40×10^3 1/s (c) under low-temperature conditions and at room temperature.

References

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