

Dynamic and Static Softening Behaviors of AA2024 Aluminum Alloy Under Hot Deformation Applications

H. Arabshahi

Department of Physics, Ferdowsi University of Mashhad, Mashhad, Iran

Abstract---The dynamic and static softening behaviors during multistage hot deformation of aluminum alloys have been studied by double-hit compression testing in the temperature range of 300-400 °C. The interrupted deformations were conducted with delay times varying between 30 and 120 seconds after achieving a strain of approximately 0.4 in the first stage. It was indicated that the considerable dynamic softening and exceptional softening associated with a structure softening exist in alloy deformation at 400 °C, leading to an initial flow stress value at the second deformation lower than that at the first deformation. For all alloys studied, the static softening increases with increasing deformation temperature and holding temperature and delay times.

Keywords: Dynamic softening, work softening, work hardening, dynamic precipitation .

I- INTRODUCTION

The complex changes in metallurgical structures which occur during multistage hot deformation, such as hot-rolling and hot-forging, results from the balance which is achieved between work hardening and softening. Utilization of the restoration mechanism during and after processing to provide suitable flow stress and ductility during multistage hot deformation requires knowledge of how they respond to each control parameter, including dynamic deformation temperature, strain and strain rate, also static temperature and time for interstage or post-processing [1–4]. Establishing the recrystallization kinetics model and flow stress equation for multistage hot deformation also requires quantitative understanding of the dynamic softening during deformation and static softening in the interstage duration [5–7]. Usually, the degree of dynamic softening has been quantitatively determined by the relative softening RS or a quasistatic softening technique, static fractional softening has been determined by three different methods, namely the offset-stress method, the back-extrapolation stress method and the strain-recovery method [7–8]. However, fundamental knowledge about these is rarely reported

for aluminum than that for steel.

The present study is aimed to examine the grain refinement in as-extrude 2024 aluminum alloy under double-hit compression test. This article is organized as follows. Details of the material and experimental procedure which is used are presented in Sec. II and the experimental results are interpreted in Sec. III.

II- MATERIAL AND EXPERIMENTAL PROCEDURE

The material was in the extruded condition and its composition satisfies the specifications for alloy AA2024 according to table 1.

Table 1. Chemical composition of the AA2024 alloy

Element	Cu	Mg	Mn	Fe	Si	Ti	Zn	Al
Wt%	3.92	1.5	0.26	0.50	0.60	0.01	0.09	Base

Cylindrical compression specimens with 10 mm in diameter and 15 mm length were machined parallel to the extrude axis. The samples were homogenized at 500 °C for 16h (T_1). The initial microstructure is composed of dendrite lamellas lying parallel to the billet axis, as it is shown in Fig. 1.

The samples were deformed in compression at constant crosshead speed using a modified servo-hydraulic system with an INSTRON-8500 controller equipped with a heating chamber. Specimens were strained to $\epsilon=0.4$ with the constant strain rate of 0.1 s^{-1} where steady state flow was achieved, and rapidly decreasing strain rate from 0.1 s^{-1} to 0.01 , 0.001 and 0.0001 s^{-1} , respectively.



Figure 1. Initial microstructure of 2024 Al alloy versus direct Extrusion.

III- EXPERIMENTAL RESULTS

Under constant strain-rate conditions, the flow stress at a strain of 1.0 increases with increasing structures obtained at a strain of 1.0 after (a) increasing and (b) decreasing strain-rate histories. The internal microstructural parameters measured for these conditions are compared in figure 3. After an increasing strain rate, all the parameters are similar to those measured after the constant strain- rate history. This suggests that microstructural changes during the increasing transient occur at a rate which is fast enough to match the change in strain rate. The work softening is due to solute depletion, particle coalescence and enhancement of dynamic recovery. It may be seen that in most cases there is a transient period during which the flow stress drops and eventually reaches a constant stable. At low second strain rate (0.0001 sec^{-1}), the strain value reach to a steady-state is ~ 0.1 , also with these conditions, dynamic softening has to occurred but at higher second strain rate (0.01 sec^{-1}) before reaching to a new steady-state work hardening is produced.

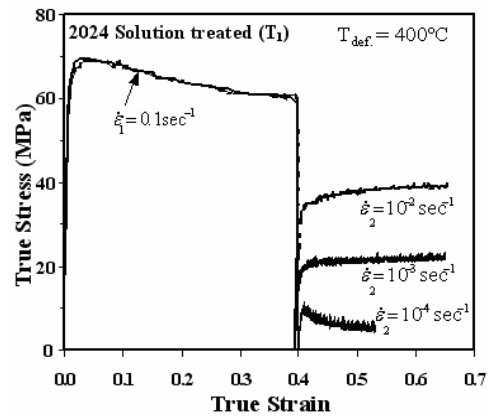
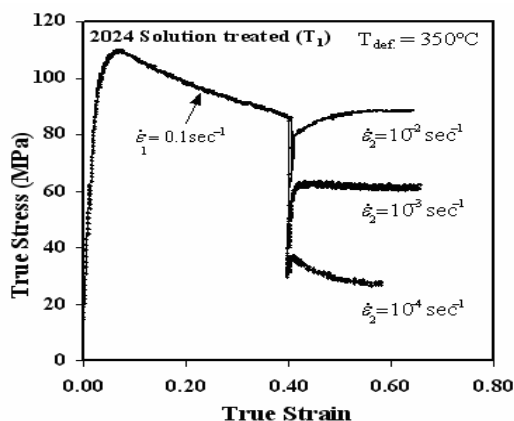


Figure 2: True stress-true strain curves for specimens deformed at, 350 °C and 400 °C to a strain of 1, at strain rate of 0.1 sec^{-1} , at which time a strain rate reduction was imposed.

Micrographs of specimens, with a reduction in strain rate at 350 °C, are shown in figure 4. The boundaries of lamellar grains, roughly parallel to the billet axis (Fig. 1) and the compression direction, are gradually rotated by compression (Fig. 3) and become almost perpendicular to the compression axis. At a strain rate of 0.001 sec^{-1} (Fig. 3b), many fine grains with moderate to large angle boundaries are developed in colonies accompanied by formation of relatively coarse grains with low to moderate angle boundaries.

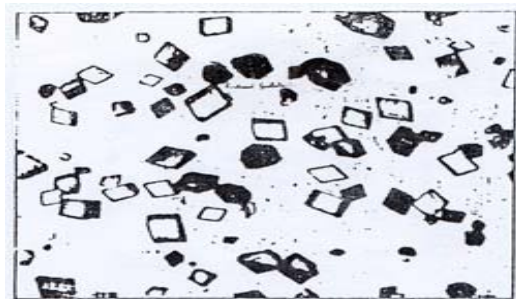
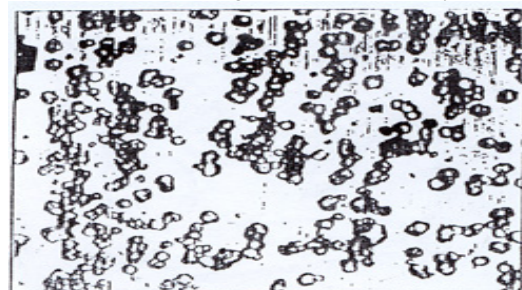


Figure 3: Microstructure change of AA2024 Al alloy after



compression at 350 °C with a strain rate of 0.1 sec^{-1} and subsequently at reduced strain rate of 0.01 sec^{-1} and 0.001 sec^{-1} .

In low secondary strain rate (0.00001 sec^{-1}), deformation bands and GNBs are increased due to rotation and sliding of grain boundaries. This suggests that those deformation bands subdivide original coarse grains even at early stages of deformation. Further deformation leads to an increase in these misorientation angles and the numbers of GNBs. The present as-cast aluminum alloy has, however, an unusual coarse lamellar grain structure with non-symmetric shapes, i.e. having alternating straight and corrugated grain boundary segments (Fig. 1). When grain boundary sliding (GBS) takes place under such structure conditions, it may operate inhomogeneously and result consequently in development of inhomogeneous strain gradients followed by GNBs [9,10]. However, the grain boundary sliding (GBS) takes place at present deformation conditions and plays an important role in fine-grained evolution and flow softening during deformation [11-13].

The flow stress is increased with further straining at 400 °C and after reaching the maximum value, it is reduced (Fig. 3b). The work softening is due to solute depletion, particle coalescence and enhancement of dynamic recovery. Thus, the peak value at 400 °C is lower rather than the peak value at 350 °C. It may be seen that in most cases there is a transient period during which the flow stress drops and eventually reaches a constant stable. At low second strain rate (0.0001 sec^{-1}), the strain value that is required to reach a steady-state is ~ 0.1 , also with these conditions, dynamic softening has occurred, but at higher second strain rate (0.01 sec^{-1}) before reaching a new steady-state, work hardening is produced. In conclusion, GBS occurs inhomogeneously in the initial coarse and lamellar grains, resulting in local lattice rotation and forms deformation bands during double-hit compression testing. By decreasing the strain rate, GNBs can join the adjacent sub-grain (micro-band) boundaries to increase their misorientation and so retain the overall local lattice curvature. As a result, highly inhomogeneous deformation can develop in the grain interiors and then provide sites formation of GNBs. The number and the misorientation angle of deformation bands increase with decreasing strain rate and high temperature, finally causing new fine grains to form in the microstructure.

IV- CONCLUSION

The considerable dynamic softening and exceptional softening associated with a structure softening exist in aluminum alloys deformation at 400 °C, leading to an initial flow stress value at the second deformation lower than that at the first deformation. For all studied alloys, the static softening increases with increasing deformation temperature and holding temperature and delay times, but the increment for AA2024 alloy is much higher than that for other alloys in the same hot deformation conditions.

REFERENCES

- [1] J. J. Urcola and C. M. Sellars, *Acta. Metall.*, Vol.16, 1987, pp. 2631-2633
- [2] Young, C. M., Robinson, S. L. and Sherby, *Acta. Metall.*, Vol.23, 1995, pp. 633-638
- [3] C. M. Sellars, and Q. Zhu, *Mat. Sci. Eng.A*, Vol. A280, 2000, pp. 1-7.
- [4] Y. Huang, and F. J. Humpherys, *Acta. Mat.* Vol.45(11), 1997, PP. 4491-4503.
- [5] G. J. Baxter, T. Furu, J. A. Whiteman, and C. M. Sellars, *Acta. Mat.* Vol.47 (8), 1999, PP. 2376-2376.
- [6] S. Spigarelli, F. Bardi and E. Evangelista, The 7th Inte. Conf. Aluminum Alloys Charlottesville, USA, 2000, pp. 449-454.
- [7] E. Evangelista, A. Forcellese, F. Gabrielli and P. Mengucci, conf. proc., "Hot Deformation of Al Alloys", Ed., T.G. Langdon et al, TMS, Warrendale, PA, 1991, pp. 121-139.
- [8] R. Kaibyshev, O. Sitdikov, A. Goloborodko, T. Sakai, *Mat. Sci. Eng.A*, Vol. A344, 2003, pp. 348-356.
- [9] G. R. Ebrahimi, A. Zarei-Hanzaki, and Sh. Khoddam, The 5th National Surface Engineering & Heat Treatment Cong., Iran, 2003, pp. 692-701.
- [10] F. J. Humphreys, M. Hatherly, Pergamon, Oxford, UK, 1995.
- [11] P. J. Apps, J. R. Bowen and P. B. Prangnell, *Acta. Mat.* Vol.51, 2003, PP. 2811-2822.
- [12] H. Mughrabi, *Mat. Sci. Eng.A*, Vol.A319, 2001, pp. 139-143
- [13] P. Cizek, B.P. Wynne, and B.A. Parker, *Script. Mat.*, Vol.35, No.10, 1996, pp. 1129-1134