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Research Progress on Rheological Behavior of AA7075 Aluminum Alloy During Hot Deformation

Muhammed O.H Amuda, Materials Development and Processing Research Group (MADEPREG), Department of Metallurgical and Materials Engineering, Faculty of Engineering, University of Lagos, Lagos, Nigeria

Taiwo F. Lawal, Materials Development and Processing Research Group (MADEPREG), Department of Metallurgical and Materials Engineering, Faculty of Engineering, University of Lagos, Lagos, Nigeria

Esther T Akinlabi, Department of Mechanical Engineering Science, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

ABSTRACT

The current characterization of the rheological behavior during high temperature deformation in AA7075 is presented. The prevailing understanding in the literature is limited to the consideration of process parameters in isolation of microstructural features and the dynamics at the deformation zone in relation to geometry of the die tool and frictional conditions. Multiplicity of phenomena such as dynamic recovery (DRV), discontinuous dynamic recrystallization (DDRX), continuous dynamic recrystallization (CDRX), and geometric dynamic recrystallization (GDRX); are reported to dictates the dynamics in play during high temperature deformation of the alloy. Therefore, a need to appropriately characterize the flow behavior in AA7075 alloy during high temperature thermo mechanical processing that would involve an integrative study of concerned process parameters, metallurgical features and conditions at the deformation zone is imperative in order to achieve wholesome understanding of the flow behavior in AA7075 aluminum alloy during high temperature deformation.

KEYWORDS

Constitutive Equations, Dynamic Softening, Dynamic Strengthening, Hot Extrusion, Inverse Analysis, Micro Textural Analysis, Microstructural Features, Process Parameter, Tooling Geometry

INTRODUCTION

AA7075 is a structural grade aluminum alloy containing Al-Zn-Mg-Cu in the range of 5.6-6.1wt% Zn, 2.1-2.9wt% Mg, 1.2-2.0wt% Cu and it exists in many temper conditions. Wang et al. (2012) reported that it possess specific strength greater than the 5xxx and 6xxx series and comparable to many steels. The alloy superior stress corrosion cracking resistance relative to the 2xxx series makes it suitable for most critical applications; and as such finds extensive use in the aerospace and ordinance industries. But, in spite of these attractive attributes of the AA7075 alloy, it is considered that its response to plastic deformation over a wide range of temperature and strain rates is poor, particularly at deformation temperature beyond 0.4Tm. Therefore, its application is limited to simple shapes. Thus, the high temperature deformation of the alloy is associated with several challenges such as dynamic softening which reduces the ductility of the alloy.

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Ashtiani et al. (2012) in their work expressed hot temperature deformation to be plastic deformation processing conducted at temperature above 0.4Tm which is accompanied by both recrystallization and the development of new stress free grains such that the dislocation density is at equilibrium. In another instance, Humphrey and Hatherly (2004) referred to hot temperature deformation as high temperature thermo mechanical processing, and may be accompanied by grain refinement. Doherty et al. (1997) had previously considered hot working as thermomechanical processing in the temperature range $0.6T_{m,}$ and this was dictated by dislocation substructures of low density including sub grain migration which was further characterized by subgrain diameter, interior dislocation spacing and wall spacing related to angle of misorientation.

The challenges of thermo mechanical processing such as increased productivity, reducing scrap rate, production of almost perfect microstructures, and improving the quality of manufactured parts during processes like rolling, forging and specifically extrusion require enhanced scientific understanding of the flow characteristics in the candidate materials in relation to stress, strain, temperature, microstructural evolution and geometry of deformation during such processes.

Tilak (2005) employed Liquid aluminum refining system to improve the extrudability of aluminum alloy and reported that the flow behavior during thermo mechanical processes such as high temperature extrusion is influenced by multiplicity of variables involving both technical and metallurgical process parameters. This expression is supported by Humphreys and Hatherly (1996) in their literature on recrystallization and related annealing phenomena.

Altan (1983) identified the technical parameters to include deformation temperature, strain, strain rate, shear rate, friction, ram speed, tool geometry; while metallurgical parameters include chemical composition, degree of prior strain, initial grain size, metallurgical structure and phases. Yang et al. (2014) associated deformation direction as another significant technical parameter influencing the flow behavior of AA7075 during hot deformation. It must be stated that initial grain size, metallurgical structure and phases are further influenced by type of grain refiner, degree of dispersion, solute content, size and distribution, inter-particle spacing, and coherency of second phase particles. Sun et al. (2014) for instance, reported the presence of η phase ($MgZn_2$), ή phase (MgZn), T phase ($Al_2Mg_2Zn_3$) and S phase (Al_2CuMg) in AA7075 alloy. This is reinforced by Abolhasani et al. (2012) of the evidence of presence and distribution of Mg(Zn_2, AlCu) M (or η) hexagonal phase, S (Al_2CuMg) orthorhombic phase, $Al_{32}(MgZn)_{49}$ T phase and Fe rich phases such as Al_7Cu_2Fe and Al_3Fe second phase particles in the grain interior and along the grain boundaries of a AA7075 alloy.

Zhou (2009) extruded AA7075 alloy using double packet dies under different combinations of technical and metallurgical conditions. The work established that the complex changes in microstructures and properties of the alloy are dictated by the interaction of technical and metallurgical parameters; but that the level of interaction is moderated by a balance between the alloy constitution and its incipient melting temperature. The significance of this interaction mechanism on flow behavior was equally reported for a similar high strength aluminum alloy by Arabshahi (2009) in their investigation of dynamic and static softening behaviour in AA2024 alloy under high temperature deformation.

Yang et al. (2014) identified flow stress as the most significant parameter for characterizing the flow behavior during deformation of metallic materials. Vazquez and Altan (2000), described it as the instantaneous yield stress or true stress of a metal which determines the load and energy required for plastic deformation.

Sun et al. (2014) employed extruded AA7075 bar to investigate significance of thermo-mechanical processing parameters and second phase particles on the softening mechanism and microstructural evolution during high temperature deformation. They postulated that the flow behavior of AA7075 during high temperature is characterized by an increase in flow stress at the onset of deformation signifying dynamic strengthening. This is followed by a regime of flow stress saturation signifying a balance between dynamic strengthening and flow softening; and finally, a trend of decrease in flow stress to the end of straining signifying dynamic flow softening. Yang et al. (2014) studied the importance of the technical parameters of strain, strain rate, deformation temperature and deformation