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ScienceDirect

Procedia Engineering 207 (2017) 7–12

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

Al-Li Alloys – The Analysis of Material Behaviour during Industrial Hot Forging

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Abstract

Al-Li alloys are a promising class of aerospace materials that combine light weight with high strength, comparable to those of steels. In the case of critical components, it is well known that providing the required reliability is impossible without tailoring the output microstructure of the material. This, in turn, requires a clear understanding of the logic behind microstructure formation depending on the total processing history (especially temperature and strain-rate history). However, uniaxial isothermal laboratory tests provide very limited information about the material behaviour. Real forging processes, especially involving complex geometries, sometimes develop quite complicated temperature-strain-rate paths that vary across the deformed part. A proper analysis of the microstructural transformations taking place in the material under these conditions is therefore very important. In this paper, the correlation between the loading history and microstructural transformations was analysed for AA2099 alloy using the hot forging of a disk-shaped component at selected forging temperatures and strain rates. The obtained results were compared to industrial processing maps based on uniaxial tests.

Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.

Keywords: AA2099; Hot-forging; Flow Stability; Microstructure

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Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.
10.1016/j.proeng.2017.10.729

1. Introduction

AA2099 is a third generation Al-Li alloy developed primarily for aerospace applications. This generation has better density savings, corrosion resistance, fatigue crack growth resistance, and general strength and toughness in comparison to the performance of second generation alloys such as AA 2090 [1]. In addition, they also have a lower intensity of "brass" crystallographic texture. This reduces property anisotropy - one of the chief shortcomings of the second generation Al-Li alloys [2]. However, the risk of delamination fracture remains in all Al-Li alloys. Fig. 1 shows the initial microstructure of a AA2099 sample in the form of extruded rod and an example of delamination cracks obtained during attempts at cold forming this material. From this viewpoint, hot deformation remains the preferred route for the manufacturing of this alloy. It gives the ability to change the direction of grain flow and control the tendency for texture formation. However, the achievement of these aims requires a careful selection of forging conditions. This is hardly possible via blind trial and error methods, rather a deep understanding of both the mechanics of metal flow as well as microstructural behaviour of the material is necessary.

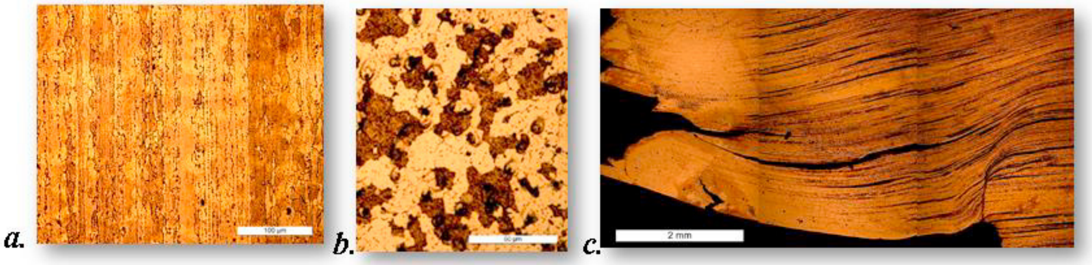

Fig. 1. Initial microstructure of AA2099: a) axial (extrusion) direction, b) transverse direction, c) example of delamination fracture during cold forming.

There are a number of works devoted to metallographic aspects of hot deformation of AA2099, e.g. [3–5] and a few investigations focused on the mechanical behavior of this alloy at elevated temperatures. Zhang *et al.* suggest the use of processing maps (first suggested by Y.V.R.K Prasad [6]) as a basis for the selection of the optimal forging regime. Processing maps consist of a superimposition of the power dissipation efficiency and the instability maps, the first framing the "safe" domain of process parameters and the second enclosing the parameters for avoiding undesirable microstructures [4]. Corresponding processing maps are shown in Fig. 2a for reference, while Fig. 2b shows the metal flow observed during hot forging of a disk geometry (more details in the next section) under different temperatures. It is readily observable that the material demonstrates different levels of flow instability. Based on what may be seen in Fig. 2b, the temperature of 400°C looks to be the best i.e. minimizes the zones of high shear, though this could hardly be deduced from the available processing maps. The aim of this paper is to analyze the specifics of material behavior under the conditions of industrial hot forging and to assess the applicability of the processing maps for process development and optimization.

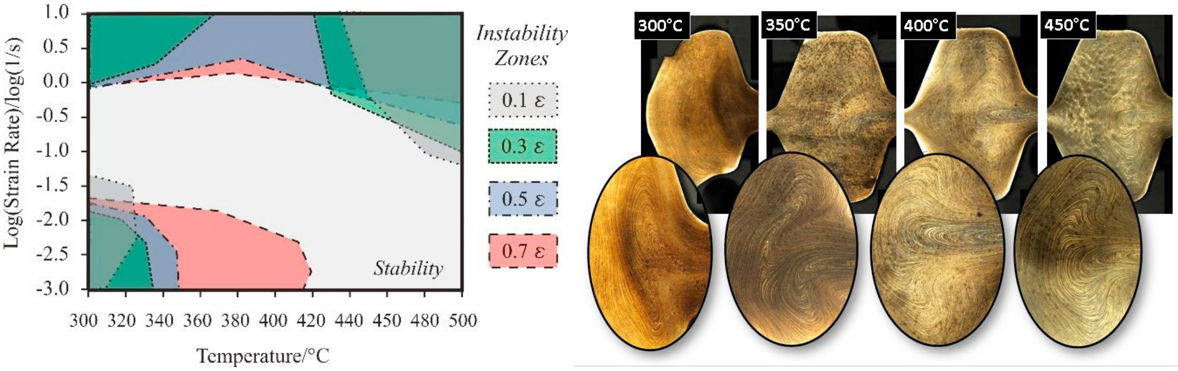

Fig. 2. (a) Processing maps for AA2099 at strains of 0.1, 0.3, 0.5 and 0.7 (summary of data taken from [4]); (b) the etched flow lines in disks forged at different temperatures.