MATEC Web of Conferences **12**, 03001 (2014)
DOI: 10.1051/matecconf/20141203001
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Fatigue characterization of flowformed A356-T6

Matthew J. Roy[1,a], Daan M. Maijer[2] and Jianbin Zhao[2]

[1]University of Manchester, School of Mechanical, Aerospace and Civil Engineering. Sackville Street Building, Manchester, UK M13 9PL

[2]University of British Columbia, Department of Materials Engineering. 6350 Stores Road, Vancouver, Canada V6T 1Z4

Abstract. Flowforming is an incremental rotary forming technology consisting of deforming a cylindrical workpiece through contact between a roller and a rotating mandrel. This process delivers significant local compressive plastic strain to the workpiece. The effects on fatigue resilience of a common aluminum foundry alloy (A356) processed in this manner at an elevated temperature has been shown to improve post heat treatment. Fatigue properties of material processed with a standard heat treatment following casting is compared to material which has been cast and flowformed to varying degrees and then heat treated. Flowformed material with varying degrees of rotary deformation have been tested. Endurance limits have been found to be generally governed by porosity and maximum principal stress for high cycle fatigue on undeformed material. Fatigue properties have been quantified employing stress-life relationships derived from uniaxial fatigue tests. A 30% increase in the high-cycle endurance limits of flowformed compared to non-deformed material has been observed and is linked to the extent of deformation. Fractographic examination shows that this increase in endurance limit can be attributed primarily to the mitigation of porosity. Microstructural changes due to processing appear to be a secondary factor.

1. Introduction

Forging cast aluminium components is a relatively expensive manufacturing process that can improve mechanical properties. A lower cost alternative for axisymmetric components is flowforming. In this process, a small portion of a rotating workpiece is impinged between a roller and a mandrel, such that only a small amount of material is compressively deformed at a time. Forming cast A356 must be carried out at elevated temperature to garner additional ductility. This type of processing mitigates porosity and causes microstructural changes that lead to improved fatigue resilience.

2. Experimental overview

Two sources of flowformed A356 were employed in the current study. A quantity of material in the as-formed condition was received from a North American automotive wheel manufacturer with a high

[a] Corresponding author: matthew.roy@manchester.ac.uk

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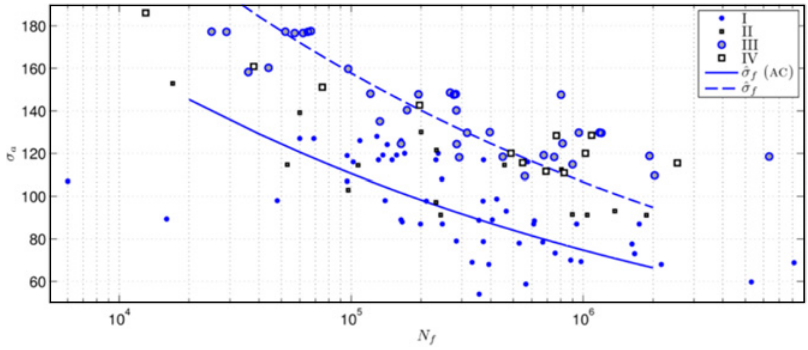

Figure 1. *S*–*N* data for undeformed (I commercial & II experimental) versus flowformed (III commercial & IV experimental). Lines indicate Basquin fitting to infer fatigue limits.

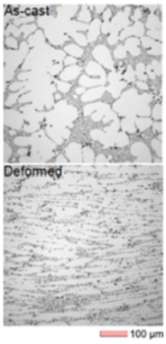

Figure 2. As cast vs. deformed microstructure.

amount of deformation (>50% thickness reduction). Material with a lower amount of deformation (∼10% thickness reduction) was processed with an experimental forming apparatus located at the University of British Columbia. This material, in addition to material drawn from undeformed blanks from both the commercial and experimental materials was heat-treated to the T6 condition (3 hours at 540 °C, 60 °C water quench, immediate artificial ageing at 150 °C for 3 hours) and had uniaxial fatigue specimens extracted. These uniaxial fatigue specimens were run-out tested on a Sonntag eccentric fatigue machine under fully reversed ($R = -1$) loading conditions, targeting the high-cycle regime. See Ref. [1] for further experimental details regarding the flow forming process.

3. Results and discussion

The results of the fatigue testing show that there is an appreciable improvement in flowformed material over undeformed post-heat treatment. The improvement was quantified by fitting Basquin relationships ($b = 0.17$) through data from both commercially and experimentally formed material. The Basquin relationship resulted in a fatigue limit at 10^6 cycles of 75 MPa for as-cast and 107 MPa for flow formed material.

The principal cause for the increase in fatigue limit is the mitigation of porosity. The main indicator that porosity has been diminished is the overall range of fatigue limits found with undeformed material as compared to formed. Furthermore, higher fatigue limits were found with specimens having a greater extent of deformation, which increases the chance of closing pores. Fatigue crack initiation was found at very small pores or inclusions, which implies that porosity was not completely eliminated. Examination of the fracture surfaces of some of the commercially flowformed specimens showed generally a more ductile material, with striations easily observable as compared to undeformed material with the same temper [2]. Fracture surfaces of the formed material were also found to be more irregular than the undeformed, which indicates that crack path deflection was more prominent. This latter observation is likely due to eutectic particle refinement as smaller particles have been found to increase fatigue limits in this alloy system [3].

Changes to the microstructure imparted by flowforming, such as recrystallization and eutectic particle refinement, coupled with porosity mitigation are deemed to be the principal reasons for the 30% increase in fatigue limit in the high-cycle regime.

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