J MATER RES TECHNOL. 2016;5(2):190–197

Available online at www.sciencedirect.com

jmr&t
Journal of Materials Research and Technology
www.jmrt.com.br

Short Communication

Tensile behaviour of aluminium 7017 alloy at various temperatures and strain rates

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ARTICLE INFO

Article history:
Received 2 May 2015
Accepted 7 December 2015
Available online 21 January 2016

Keywords:
Aluminium 7017
J-C model
Strain rate

ABSTRACT

The objective of the present study is to carry out high strain rate tensile tests on 7017 aluminium alloy under different strain rates ranging from 0.01, 500, 1000 and 1500 s^{-1} and at temperatures of 25, 100, 200 and 300 °C. Quasi-Static tensile stress–strain curves were generated using INSTRON 8500 machine. Johnson-Cook (J-C) constitutive model was developed for 7017 aluminium alloy based on high strain rate tensile data generated from split Hopkinson tension bar (SHTB) at various temperatures. This study evidently showed an improvement in dynamic strength as the strain rate increases. The predictions of J-C model are observed to be in consistence with the experimental data for all strain rates and temperatures. The fracture surfaces of specimens tested were studied under SEM. The change in fracture mode has been observed at different strain rates. The shear mode of fracture is dominant at lower strain rates (0.01 and 500 s^{-1}); whereas cup- and cone-like surface representing dimple structure is found at the higher strain rates (1000 and 1500 s^{-1}). The numbers of dimples at high strain rates are more than the quasi-static and intermediate strain rates. It is also observed that the flow stress decreases with increase in temperature. The 7017 aluminium alloy demonstrates thermal softening at higher temperatures. So when the temperature is more than 200 °C at these strain rates, thermal softening is predominant mode of deformation mechanism. It is found that when the temperature increases to 200 °C, the number of dimples rises and the dimple size of 7017 aluminium alloy is larger than at lower temperatures.

1. Introduction

Aluminium alloys are widely employed in the automobile and armour applications to enhance crashworthiness and reduce weight of the components. The understanding of the strain rate sensitivity parameters and mechanism of deformation of these alloys is indispensable for the successful design of components. Aluminium alloys have found potential applications due to high strength to density ratio. Al 7017 alloy has got uses in armour applications. Many ballistic experiments were carried out on this alloy against 7.62AP projectiles in normal and oblique configurations [1,2]. Hence, it is important to investigate the material deformation characteristics under high

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http://dx.doi.org/10.1016/j.jmrt.2015.12.002

strain rate loading conditions. The data obtained will be helpful for incorporating in constitutive strength models. In order to develop more robust strength models and failure criteria under dynamic loading tensile and compression experimental data performed over wide range of strain rates is necessary [3,4].

The effect of strain rate on properties viz. flow stress, strain rate sensitivity, etc., varies for each material. High strain rate compressive deformation behaviour of AA 6082 and AA 7108 alloy under peak tempered and overaged condition shows low strain rate sensitivity. Also a trend of negative strain rate sensitivity was observed at strain rates higher than 2000 s^{-1} [5]. Smerd et al., have shown marked increase in elongation with increase in strain rate [6]. Similar increase in ductility has also been reported in Al 7075 alloy by El Magd et al. [7]. Metallographic investigations of the material showed ductile shear failure. Existence of two regions of strain rate sensitivity in Al 7075 over a range of strain rates has been explained by Lee et al. [8]. It has been reported that in the strain rate regime of 10^2–10^3 s^{-1}, the strain rate has only slight effect on flow stress, whereas at strain rates higher than 10^3 s^{-1}, the flow stress increases more rapidly with strain rate having an approximate linear relationship.

Lin et al. [9] studied the compressive behaviour of aluminium 2124-T851 alloy under the strain rates of 0.01–10 s^{-1} and temperature range of 653–743 °C. A modified constitutive model accommodating the effects of material behaviour was proposed.

Haghdadi et al. [10] predicted the high temperature flow behaviour of a cast A356 aluminium alloy to optimize the design of forming process. An artificial neural network (ANN) was adopted to determine the flow stress characteristics under different loading conditions. A series of isothermal compression tests was performed in the temperature range of 400–540 °C and strain rates of 0.001–0.1 s^{-1}. Lee et al. [11] investigated the high temperature impact properties and microstructural evolution of 6061-T6 aluminium alloy at temperatures ranging from 100 to 350 °C and strain rates ranging from 1000 to 5000 s^{-1} using a compressive split-Hopkinson pressure bar (SHPB) system. The experimental results revealed that the flow stress and strain rate sensitivity increased with increasing strain rate or decreasing temperature. The flow stress–strain response of the 6061-T6 alloy was effectively described by the Zerilli–Armstrong fcc model. Pérez-Bergquist et al. [12] studied the mechanical response of aluminium alloys 5083, 5059 and 7039 in compression and shear, in both the quasi-static (0.001 s^{-1}) and dynamic (2000 s^{-1}) strain rate regimes. The mechanical responses in shear were found to be strain-rate sensitive. To evaluate the thermo mechanical response of these alloys, both dynamic and quasi-static tests were performed at temperatures ranging from 20 to 300 °C. The 7039 alloy exhibited the highest strength in compression at room temperature followed by alloys 5059 and 5083 respectively.

So far no attempt has been made to study the effect of strain rate and temperature on dynamic tensile flow stress of 7017 aluminium alloy. The objective of the present study is to develop constitutive models for predicting the dynamic tensile flow stress of 7017 aluminium alloy during high strain rate deformation. The fracture surfaces of specimens tested under various strain rates and temperatures were studied by under SEM.

Fig. 1 – Photo of the quasi static tensile specimen of aluminium 7017 alloy.

2. Experimental methods

2.1. *Materials and test setup*

The present alloy under study is Al–4.5Zn–2.5Mg–0.3Si–0.40Fe, commercially named as 7017 aluminium alloy (peak aged). Tensile testing was performed at various temperatures on tensile specimens (Fig. 1) using INSTRON 8500 testing machine at a crosshead speed of 1.0 mm/min. Specimens have been tested according to ASTM E8 M11 standard in a temperature range between 20 and 300 °C, at strain rate of 0.01 s^{-1}. Three specimens were tested at each set of conditions. The quasi static yield and ultimate tensile strengths of the alloy are 458 MPa and 508 MPa, respectively. Ductility measured as percentage elongation is 13%. The authors have also performed high strain rate compression tests of various strain rates at room temperature.

High strain rate tensile testing of 7017 aluminium alloy samples of length 45 mm and diameter 10 mm (ASTM E8) was carried out using SHTB apparatus. Fig. 2 shows the SHTB equipment with heating system, specification of the specimen used and arrangement for testing. The resistance wire heating method is used to elevated temperature dynamic experiment. The specimens are heated by the resistance-heated furnace. Thermocouple wire is connected on the specimen, which can measure the specimen temperature variation. Fig. 3 shows the tensile fractured specimens at different strain rates and temperatures.

The pressure wave was generated by impacting a striker bar (projectile) to input (incident) pressure bar. The striker bar was propelled by a gas gun system attached at one end. The strain gages in conjunction with amplifiers and associated instrumentation record these wave pulses. Since the specimen deforms uniformly, the strain rate within the specimen are directly proportional to the amplitude of the reflected wave (ε_r).

Strain-rate generated in the specimen

$$\dot{\varepsilon} = \frac{-2c\varepsilon_r}{l} \tag{1}$$

Hence strain in the specimen is

$$\varepsilon = \frac{-2c}{l\int_0^t \varepsilon_r dt} \tag{2}$$