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CONSTITUTIVE MODEL CONSTANTS FOR Al7075-T651 and Al7075-T6

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Abstract. Aluminum 7075-T651 and 7075-T6 are characterized at quasi-static and high strain rates to determine Johnson-Cook (J-C) strength and fracture model constants. Constitutive model constants are required as input to computer codes to simulate projectile (fragment) impact or similar impact events on structural components made of these materials. Although the two tempers show similar elongation at breakage, the ultimate tensile strength of T651 temper is generally lower than the T6 temper. Johnson-Cook strength model constants (A, B, n, C, and m) for the two alloys are determined from high strain rate tension stress-strain data at room and high temperature to 250°C. The Johnson-Cook fracture model constants are determined from quasi-static and medium strain rate as well as high temperature tests on notched and smooth tension specimens. Although the J-C strength model constants are similar, the fracture model constants show wide variations. Details of the experimental method used and the results for the two alloys are presented.

Keywords: Aluminum, projectile impact simulation, rate sensitivity, Johnson-Cook constitutive model.
PACS: 62.20 .Dc, 62.20..Fe, D 62.50. +p, 83.60.La

INTRODUCTION

Aluminum 7075 alloys are candidate materials for cold formable shapes used as containment for ordnance applications. Over the last few years, a number of alloys have been characterized to determine their suitability for impact mitigation. Numerical simulations of structures to study impact scenarios are being performed. In order to simulate projectile (fragment) impact on structural components made of aluminum 7075 alloys, accurate constitutive model constants (e.g., Johnson Cook strength and fracture model) based on high strain rate/temperature are required as input for computer codes (DYNA3D, EPIC).

Stress-strain data at various strain rates and temperatures are obtained using both quasi-static and high strain rate techniques. An extensive literature search on Aluminum 7075 alloy revealed wide differences in the J-C model constants [1]. The objective of present research is to accurately determine the Johnson-Cook strength and fracture model constants for Aluminum 7075-T651 and Aluminum 7075-T6 alloys.

J-C Strength Model

According to the Johnson-Cook model, the equivalent Von Mises flow stress **σ** is given by [2],

$$\sigma = \left[\mathrm{A} + \mathrm{B}\varepsilon_p{}^{\mathrm{n}}\right]\left[1 + \mathrm{C}\ln\dot{\varepsilon}^*\right]\left[1 - \mathrm{T}^{*^m}\right]$$

where ε, the equivalent plastic strain, $\dot{\varepsilon}^* = \dot{\varepsilon} / \dot{\varepsilon}_o$ is the dimensionless plastic strain rate for $\dot{\varepsilon}_o = 1/\mathrm{s}$. Constant A is the yield stress corresponding to a 0.2% offset strain; constant B and exponent "n" represent the strain hardening effects of the material. The expression in the second set of brackets represents the strain rate effect through constant C. Exponent “m” in the third set of brackets represents temperature softening of the material through homologous temperature T^*

$$T^*=(T_{test}-T_{room})/(T_{melt}-T_{room})$$

EXPERIMENTAL METHOD

Materials and Specimen Specifications

Tension specimens in the sub-size ASTM E8 configuration were fabricated from 12.7 mm diameter aluminum rods. The chemical composition of the two temper materials was similar, but omitted here for brevity.

Quasi-Static Strain Rate Test Technique

Quasi-static (~1/s) tests were performed at ambient conditions on a MTS Servo hydraulic machine equipped with an 11 kip actuator. Load was measured with a load cell calibrated over an appropriate range. A slack adapter allowed the actuator to attain test speed before applying load to the specimen. Strain was measured using back-to-back strain gauges bonded on the specimen. Post-yield strain was measured using a lightweight mechanical extensometer.

Tension Split Hopkinson Bar Technique

The schematic of the Tension Split Hopkinson Bar at the University of Dayton Research Institute is shown in Figure 1. The apparatus consists of a striker bar and two pressure bars, 0.5 in. (12.7 mm) in diameter and made of Inconel 718. The striker bar is launched in a compressed air gun. It strikes the incident bar end to end and produces a compressive stress pulse in incident bar. A collar is inserted around the specimen and the specimen is tightened until the pressure bars are snug against the collar.

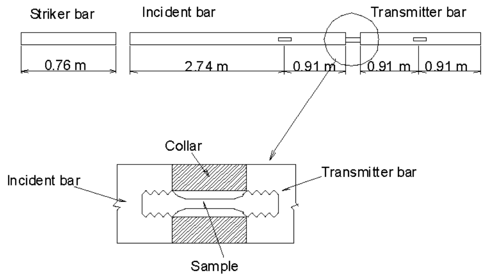

Figure 1. Schematic of the Tension Split Hopkinson Bar.

The stress wave generated by the impact of the striker bar on incident bar is transmitted through the collar into the transmitter bar without plastic deformation. It reflects back from the free end of the transmitting bar as a tensile wave and subjects the specimen to a tensile pulse. Incident, reflected, and transmitted pulses are analyzed following the procedure described by Nicholas [3].

RESULTS AND DISCUSSION

Quasi-static tension stress-strain data for Al7075-T651 and Al7075-T6 at a strain rate of ~1/s are shown in Figure 2. J-C Model constants A, B, and n are determined from these data.

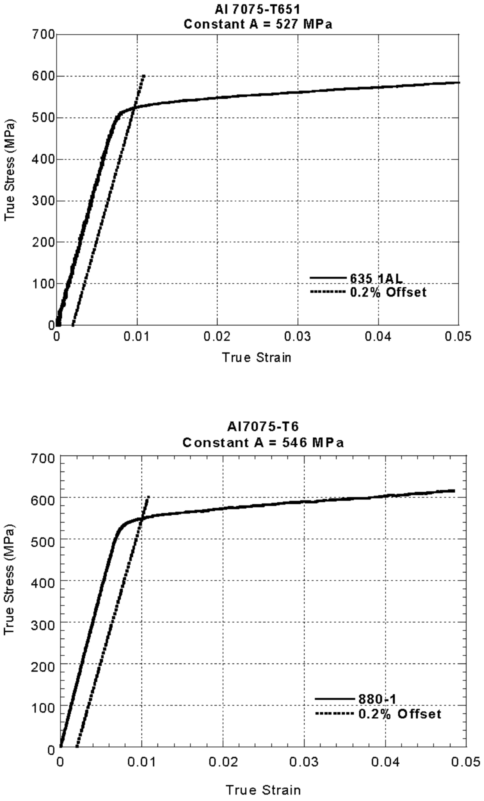

Figure 2. Stress – Strain Data for Al7075-T651 and Al7075-T6 at a strain rate of ~1/s.

Model constants B and n are evaluated from the plastic portion of the quasi-static data (Figure 2). Data from high strain rate tests (to ~1700/s) are analyzed to determine strain rate sensitivity constant C for the two alloys, as shown in Figure 3.

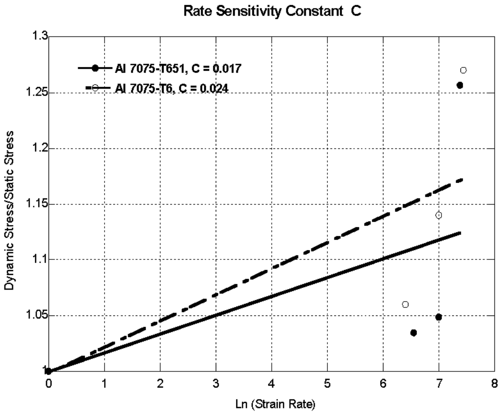

Figure 3. Rate sensitivity constant C.

Ambient and high temperature data at different strain rates are plotted in Figure 4 to evaluate temperature softening constant m.

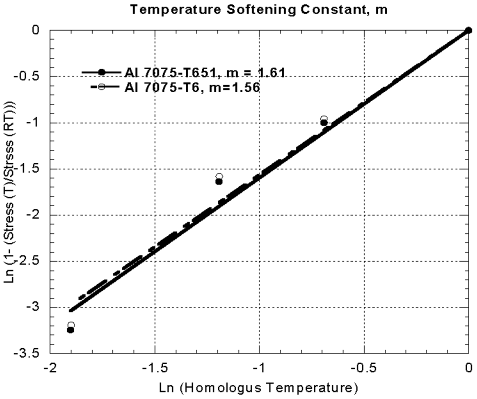

Figure 4.Temperature softening constant m.

J-C Fracture (Damage) Model

The J-C Fracture model is defined as

$$\varepsilon_f = \left[D_1 + D_2 e^{D_3\sigma^*}\right]\left[1 + D_4 \ln\dot{\varepsilon}^*\right]\left[1 + D_5 T^*\right]$$

where ε_f is the equivalent plastic fracture strain, σ^* is the stress triaxiality factor (STR), and D_1, D_2, D_3, D_4, and D_5 are fracture model constants [4]. Constants D_1, D_2, and D_3 were determined by performing quasi-static tension tests at a strain rate of ~1/s on notched specimens (notch radii, 0.4-mm, 0.8-mm, 2.0-mm) to vary STR (= 1/3 + Ln $(1+a_o/2R_o)$), where a_o and R_o are the original specimen radius at the notch center and notch radius, respectively [5]. Similar tests on un-notched (smooth, ASTM E8) specimens, (STR = 1/3) were performed. Equivalent fracture strain at failure, ε_f, is determined as

$$\varepsilon_f = \mathrm{Ln}\,(A_o/A_f)$$

where A_o and A_f are the specimen cross-section area before and after the test. Specimen areas were measured using a traveling microscope. Data on ε_f and STR for the two materials were plotted as shown in Figure 5 (a) and (b) to determine constants D_1, D_2, and D_3 using the Levenberg-Marquardt optimization method [6].

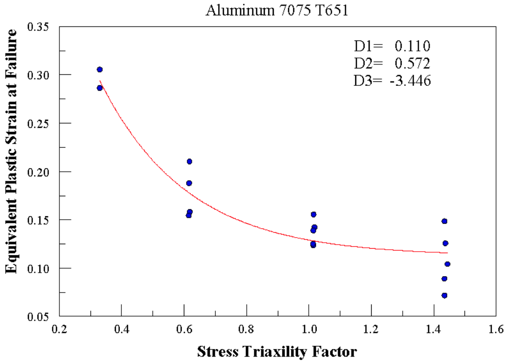

Figure 5(a). J-C Fracture Model Constants D_1, D_2, and D_3 for Al7075-T651.

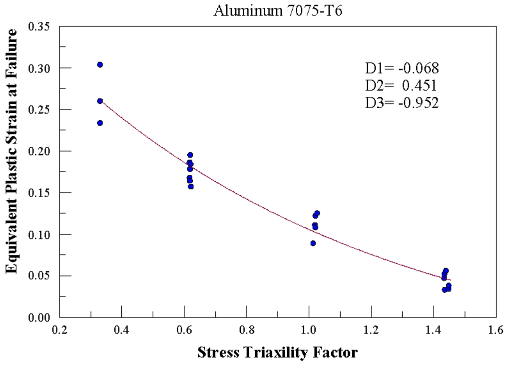

Figure 5(b). J-C Fracture Model Constants D_1, D_2, and D_3 for Al7075-T6.

Tension tests on smooth tensile specimens were performed at high strain rates to 1700/s at ambient temperature. Equivalent fracture strain at failure versus strain rate for specimens of Al7075-T651 and Al7075-T6 are plotted in Figure 6 to determine constant D_4.

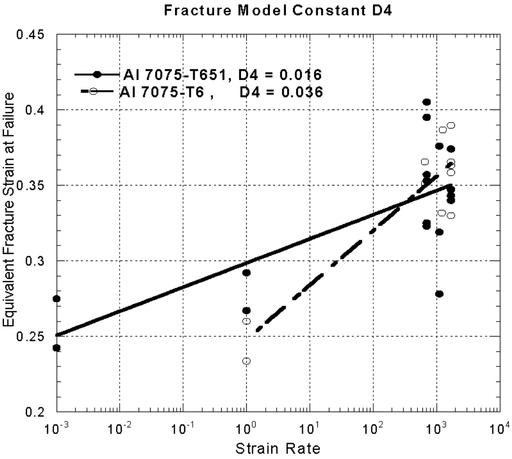

Figure 6. J-C Fracture Model Constants D_4 for Al7075-T651 and Al7075-T6.

High temperature tests to 250°C were conducted on smooth tensile specimens of the two alloys at a strain rate of ~1100/s. Equivalent fracture strain versus homologous temperature is shown in Figure 7 to determine constant D_5.

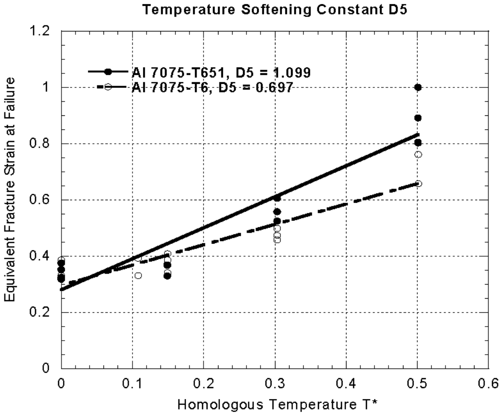

Figure 7. J-C Fracture Model Constants D_5 for Al7075-T651 and Al7075-T6.

The compiled strength and fracture model constants are summarized below for both the alloy tempers.

J-C strength model constants for Al7075

Constant	A	B	n	C	m
Al7075-T651	527	575	0.72	0.017	1.61
Al7075-T6	546	678	0.71	0.024	1.56

J-C fracture model constants for Al7075

Constant	D1	D2	D3	D4	D5
Al7075-T651	0.110	0.572	-3.446	0.016	1.099
Al7075-T6	-0.068	0.451	-0.952	0.036	0.697

It is interesting to note that the strength model constants do not show much variation, but the fracture model shows large variation, which is also reflected in the plots of plastic strain versus triaxiality. This is significant for modelers. Making a general assumption of model constants based on similarities of composition and strength can not be extended to fracture (failure).

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