CONSTITUTIVE MODEL CONSTANTS FOR LOW CARBON STEELS FROM TENSION AND TORSION DATA

N. S. Brar, V. S. Joshi, and B. W. Harris

Citation: AIP Conf. Proc. 955, 627 (2007); doi: 10.1063/1.2833171

View online: http://dx.doi.org/10.1063/1.2833171

View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=955&Issue=1

Published by the American Institute of Physics.

Related Articles

Novel temperature dependent tensile test of freestanding copper thin film structures

Sample size effects on the large strain bursts in submicron aluminum pillars

High-strength titanium alloy nanopillars with stacking faults and enhanced plastic flow

Note: Bending compliances of generalized symmetric notch flexure hinges

Repetitive impact loading causes local plastic deformation in wood

Additional information on AIP Conf. Proc.

Journal Homepage: http://proceedings.aip.org/
Journal Information: http://proceedings.aip.org/about/about_the_proceedings
Top downloads: http://proceedings.aip.org/dbt/most_downloaded.jsp?KEY=APCPCS
Information for Authors: http://proceedings.aip.org/authors/information_for_authors
CONSTITUTIVE MODEL CONSTANTS FOR LOW CARBON STEELS FROM TENSION AND TORSION DATA

N. S. Brar\textsuperscript{1}, V. S. Joshi\textsuperscript{2}, and B. W. Harris\textsuperscript{1}
\textsuperscript{1}University of Dayton Research Institute, University of Dayton, Dayton, OH 45469-0182
\textsuperscript{2}Naval Surface Warfare Center, Indian Head, MD 20640

Abstract. Low carbon C1010 steel is characterized under tension and torsion to determine Johnson-Cook (J-C) strength model constants. Constitutive model constants are required as input to computer codes to simulate projectile (fragment) impact on structural components made of this material. J-C model constants (A, B, n, C, and m) for the alloy are determined from tension and torsion stress-strain data. Reference tension tests are performed at a strain rate of ~1/s at room temperature. Tests at high strain rates are performed at temperatures to 750°C. Torsion tests at quasi-static and high strain rates are performed at both room and high temperatures. Equivalent plastic tensile stress-strain data are obtained from torsion data using von Mises flow rule and compared directly to measured tensile data. J-C strength model constants are determined from these data. Similar low carbon steels (1006, 1008, and 1020) have their J-C constants compared.

Keywords: Low carbon steels, projectile impact simulation, strain rate sensitivity, Johnson-Cook, constitutive model.
PACS: 62.20.De, 62.20.Fe, S 62.50. +p, 83.60.La

INTRODUCTION

Low carbon steels are candidate materials for cold formable shapes that act as containment for ordnance applications. Over the last few years, a number of alloys have been characterized to determine their suitability for impact mitigation of different types of ordnance explosions. The studies involve numerical simulations of structures to impact scenarios. In order to simulate projectile (fragment) impact on structural components made of low carbon steels, accurate constitutive model constants are required as input for computer codes (DYNA3D). These simulations require high strain rate data, as input, into constitutive material models (e.g., Johnson Cook strength model). Traditionally stress-strain data at various strain rates and temperatures are obtained using both quasi static (split Hopkinson bar) and high strain rate techniques [1]. The objective of present research is to accurately determine the J-C strength model constants A, B, n, m and C for low carbon steels and compare the results with similar steels that have only a small variation in chemical composition.

EXPERIMENTAL METHOD

Materials and Specimen Specifications

Tension specimens in the sub-size ASTM E8 configuration were fabricated from 8 mm diameter C1010 steel rods containing 0.10% carbon and 0.38% manganese.

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. Data from the extensometer and strain gauge were averaged to compensate for bending.
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 mounted and aligned longitudinally in bearings rigidly supported in a horizontal plane. The bars are 0.5 in. (12.7 mm) in diameter and made of Inconel 718. The striker bar (0.76-m long) is launched in a compressed air gun. It strikes the incident bar (3.65-m long) end to end and produces a compressive stress pulse in incident bar.

Two strain gages (1000Ω) are bonded on each bar 0.81-m away from the specimen to monitor strains in the pressure bars. The tensile test specimen is placed into the threaded holes in the two pressure bars. A collar is inserted around the specimen and the specimen is tightened in until the pressure bars are snug against the collar. The collar is made of the same material as the pressure bars and has the same outer diameter of 12.7-mm. The stress wave generated by the impact of the striker bar on incident bar is transmitted through the collar into the transmitter bar without affecting the specimen. It reflects back from the free end of the transmitting bar as a tensile wave and subjects the specimen to a tensile load. A part of the incident (tensile) stress pulse, $\varepsilon_T$, is transmitted through the specimen $\varepsilon_T$ and the rest is reflected back through the incident bar $\varepsilon_T$. Incident, reflected, and transmitted stress pulses are analyzed following the procedure described by Nicholas [2].

RESULTS AND DISCUSSION

Quasi-static tension stress-strain data at a strain rate of $\sim1/s$ from two tests are shown in Figure 2. Stress-strain data at a strain rate of $\sim1000/s$ and various temperatures are shown in Figure 3.

FIGURE 2. Stress – Strain Data for 1010 Steel at a strain rate of $\sim1/s$ from two tests.

FIGURE 3. Stress – Strain Curves for 1010 steel at various temperatures.

JOHNSON-COOK STRENGTH MODEL

The J-C constitutive model is simple and primarily intended for use in computer codes. According to Johnson-Cook model, the equivalent Von Mises flow stress $\sigma$ is given by,
\[ \sigma = \left[ A + B \varepsilon^* \right] \left[ 1 + C \ln \dot{\varepsilon}^* \right] \left[ 1 - T^\prime \right] \]

Where \( \varepsilon \), the equivalent plastic strain, \( \varepsilon^* = \varepsilon / \dot{\varepsilon}_0 \) is the dimensionless plastic strain for \( \dot{\varepsilon}_0 = 1/s \). 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 \( T^\prime \).

**J-C Strength Model for C1010 Steel**

Constant \( A \) is determined from the true stress–true strain data at a strain rate of \( \sim 1/s \). Constants \( B \) and \( n \) are \( 10^{(\text{intercept})} \) and the slope of the log (Plastic Stress) Vs log (Plastic Strain) plot for the plastic region of the quasi static data (\( \sim 1/s \)) respectively. An offset of 0.2% strain is plotted on the true stress-strain plot at a strain rate of \( \sim 1/s \) to determine constant \( A \), as shown in Figure 4 (a). The value of constant \( A \) is 367 MPa. Constants \( B \) and \( n \) for mild steel are determined from the plastic stress-strain data shown in Figure 4(b).

**FIGURE 4(a).** Constant \( A \) for C1010 Steel.

The slope of Figure 4b’s linear fit identifies \( n \) as equals 0.935 and \( B \) to be 700 MPa. Strain rate sensitivity constant is identified with constant \( C \). It is determined as the slope of the linear fit of Log (Strain Rate) Vs (dynamic stress/static stress) using the high strain rate data corresponding to a strain of 10% as shown in Figure 4(c). A value of \( C \) is determined to be 0.045.

**FIGURE 4 (b).** Constants \( B \) and “\( n \)”.

The temperature softening constant \( m \) is determined by plotting the ratio of the flow stresses at high and room temperatures as shown in Figure 4 (d).

**FIGURE 4 (c).** Rate Sensitivity Constant \( C \).

Similar low carbon steels with their J-C strength model constants are given in Table 1 [1,3]. Data
comparison suggest that temperature softening constant m decreases with increased carbon content.

Similar disagreement has been reported by Johnson and Cook for a number of materials [1].

**FIGURE 4 (d).** Constant “m” for C1010 Steel.

**Table 1.** J-C Strength Model Constants for Low Carbon Steels

<table>
<thead>
<tr>
<th>Steel</th>
<th>A (MPa)</th>
<th>B (MPa)</th>
<th>n</th>
<th>C</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1006</td>
<td>350</td>
<td>275</td>
<td>0.36</td>
<td>0.022</td>
<td>1.00</td>
</tr>
<tr>
<td>1008</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.787</td>
</tr>
<tr>
<td>1010</td>
<td>367</td>
<td>700</td>
<td>0.935</td>
<td>0.045</td>
<td>0.643</td>
</tr>
</tbody>
</table>

**EQUIVALENT TENSILE PLASTIC STRESS-STRAIN FROM SHEAR DATA**

Shear tests were performed on thin walled C1010 steel specimens at strain rates of 0.001/s, 0.1/s, and 5/s at room and temperatures to 775°C. Shear stress ( )-shear strain ( ) data at a strain rate of 5/s were converted to equivalent tensile stress ( )-plastic tensile strain ( ) using von Mises yield criterion as,

$$
\sigma = \sqrt{3} \quad \text{and} \quad \varepsilon = (1/\sqrt{3})
$$

Calculated equivalent tensile stress-strain data at equivalent strain rate of $\sqrt{5} = \sqrt{2}/5$ are compared to measured quasi-static data (Fig 2) at a strain rate of 1/s in Figure 5. There is a good agreement between equivalent stress-plastic strain data for $\varepsilon = 0.03$. For strains above 0.03, equivalent stresses are about 15% greater than the measured stress. We think this large disparity between the two sets of data is due to different origins of the bar stocks used for tension ( =0.25") and torsion ( =1") tests. Similar disagreement has been reported by Johnson and Cook for a number of materials [1].

**FIGURE 5.** Comparison of Equivalent tensile stress- strain with measured tensile data.

**CONCLUSIONS**

Johnson Cook constitutive model for C1010 steel required to simulate fragment impact were determined. Comparison with similar low carbon steels suggest that while A, B, n and C tend to increase with the percentage of carbon and m tends to decrease.

**ACKNOWLEDGMENTS**

This work was supported by the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV), Indian Head, MD.

**REFERENCES**

