Determination of the Johnson-Cook constitutive model parameters for high strain rate deformation

GIGI-IONUȚ NICOLĂESCU[1], *GEORGE AMADO ȘTEFAN*[1], *ALEXANDRU PARASCHIV*[2], *CONSTANTIN ENACHE*[1], *EUGEN TRANĂ*[1]

Abstract: *The objective of the paper is to determine the Johnson-Cook material parameters A, B, n, m and C for CW614N brass using data obtained from quasi-static tensile and high strain rate torsion tests. The quasi-static tensile tests were performed on cylindrical specimens at different strain rates (0.00025 s^{-1}, 0.001 s^{-1} , 0.01 s^{-1} and 0.02 s^{-1}). The dynamic tests were performed on a Torsional Split-Hopkinson Bar at room temperature. Equivalent plastic tensile stress-strain data are obtained from torsion data using von Mises yield criterion.*

***Key Words**: Johnson-Cook constitutive model, high strain rate, Torsional Split-Hopkinson Bar, CW614N brass.*

The dynamical behavior of materials is very important in many applications such as forming operations or impact problems. Obtaining of a constitutive law for material that takes into account the stress, strain and strain rate involve many experiments performed at different strain rates.

The constitutive laws are empirical or semi-empirical and they are integrated into advanced computer programs, such as finite element codes, to perform numerical simulations of forming processes or impact problems that involving high strain rates.

---

[1] Military Technical Academy 39-49 George Coşbuc Avenue, Bucharest, Romania, nicolaescu_ionut@yahoo.com;
[2] National Research and Development Institute for Gas Turbines COMOTI 220D Iuliu Maniu Bd., sector 6, 061126, OP 76, CP174, Bucharest, Romania alexandru.paraschiv@comoti.ro.

In the past 30 years several material models were imposed, hereinafter constitutive material or flow stress models, the most widespread being the Zerilli-Amstrong, Steinberg–Cochran–Guinan–Lund and Johnson-Cook models.

The Johnson–Cook constitutive material model is purely empirical and establishes a stress – strain - strain rate - temperature relation given by following equation:

$$\sigma = [A + B\varepsilon^n][1 + C ln\dot{\varepsilon}^*][1 - T^{*m}] \quad (1)$$

where the constant A is the yield stress corresponding to a 0.2% offset strain, B is the strain hardening coefficient, n is the strain hardening exponent, $\dot{\varepsilon}^* = \frac{\dot{\varepsilon}}{\dot{\varepsilon_0}}$ is the dimensionless plastic strain for a reference strain rate, usually $\dot{\varepsilon_0} = 1s^{-1}$, ε is the equivalent plastic strain, and C represents strain rate sensitivity.

The last bracket take into account the thermal softening behavior of material:

$$T^* = \frac{T - T_0}{T_m - T_0} \quad (2)$$

where T_0 is the room temperature, T_m is the melting temperature of the material, and constant m is the thermal sensitivity parameter.

The Johnson-Cook model assumes that the constitutive law is independently affected by strain hardening, strain rate sensitivity and thermal softening behavior.

All tests have been performed at room temperature, without taking into consideration the effect of temperature. The Johnson-Cook constitutive material model that will be used is:

$$\sigma = [A + B\varepsilon^n][1 + C ln\dot{\varepsilon}^*] \quad (3)$$

Quasi-static tensile strain rate tests were performed on cylindrical specimens at different strain rates (table 1) at room temperature on a INSTRON 8802 servo-hydraulic testing machine from COMOTI institute. Specimens with circular cross-section were used (figure 1).

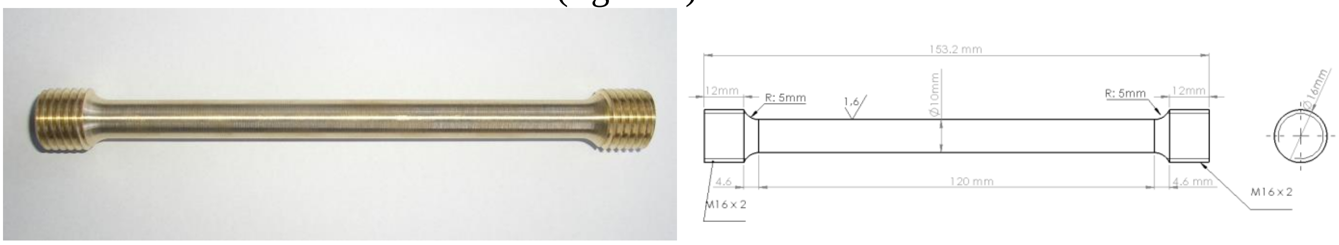


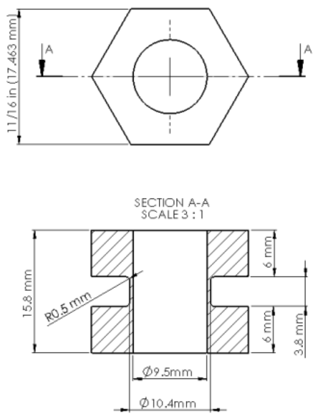
Figure 1 *. Quasi-static tensile specimen.*

Table 1. *Quasi-static tensile tests performed at different strain rates.*

No.	Type of test	Specimens	Strain rates	No. of tests	Temperature
1	*Tensile*	*Circular cross-section Φ10 mm, M16x2*	*0.00025* s^{-1}	*3*	*room*
2	*Tensile*	*Circular cross-section Φ10 mm,*	*0.001* s^{-1}	*3*	*room*

		M16x2			
3	*Tensile*	*Circular cross-section Φ10 mm, M16x2*	*0.01 s^{-1}*	*3*	*room*
4	*Tensile*	*Circular cross-section Φ10 mm, M16x2*	*0.02 s^{-1}*	*3*	*room*

High strain rate torsion tests were performed on short thin-wall tube with hexagonal flanges specimens (figure 2) at room temperature on a Torsional Split Hopkinson Bar (Torsional Kolsky Bar) from University of Cambridge, Cavendish Laboratory.



a. Specimen geometry for high strain rate torsion tests

b. Tested specimen

***Figure 2**. Specimen geometry.*

The Torsional Kolsky Bar is made up of two collinear bars (incident and transmitter bars) supported by bearings that allow them to rotate freely. Between them is placed a short specimen (figure 2). The bars are made of titanium and they have a diameter of about 25 mm.

To conduct a test, a torsional wave is generated in one of the bars (incident bar). The wave propagates toward the specimen, and, when it arrives, the specimen is loaded and the wave is partially reflected back to the incident bar and partially transmitted to the other bar (transmitter bar).

Shear stress pulses in the input and output bars are measured using a strain gage bridge. Each bridge consisting of two pairs, one pair attached diametrically opposite the other on the surface of the bar. The gages are oriented at a 45 deg. Angle to the axis of the bars; gages arranged this way will measure only shear strains by excluding both axial and bending strains.

The first strain gauge bridge is placed in region of stored torque between clamp and loading end and is used only to measure the magnitude of the applied (stored) torque to the input bar. The second strain gauge is located on input bar (incident bar) between clamp and specimen. This gauge will record the incident wave and the reflected wave. The third strain gauge is located on transmitter bar and it will record only the transmitted wave.

References

[1] **Cornel Bia, Vasile Ille, Mircea V. Soare.** *Rezistenţa materialelor şi teoria elasticităţii.* București : Editura Didactică şi Pedagogică, 1983.

[2] **Cristescu, Nicolae Dan.** *Dynamic Plasticity.* s.l. : World Scientific Publishing Co. Pte. Ltd., 2007. ISBN-13 978-981-256-747-5, ISBN-10 981-256-747-X.

[3] **GORDON JOHNSON, WILLIAM COOK.** *A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures.* Haga, Olanda : Proceedings of the seventh international symposium on ballistic, 1983.

[4] **International, ASM.** *ASM HandBook Volumen 8 Mechanical Testing and Evaluation.* 2000 : s.n.

[5] *On the Use of a Torsional Split Hopkinson Bar to Study Rate Effects in 1100-O Aluminum.* **J. Duffy, J.D. Campbell, R.H. Hawley.** 1, s.l. : Journal of Applied Mechanics, 1971, Vol. 38, p. p. 83.

[6] **Meyers, Marc Andre.** *Dynamic Behavior of Materials.* s.l. : John Wiley & Sons, 1994. 0-471-58262-X.

[7] **N. S. Brar, V. S. Joshi, B. W. Harris.** *Constitutive Model Constants for Low Carbon Steels from Tension and Torsion Data.* s.l. : American Institute of Physics, 2007.

[8] **Polyzois, Ioannis.** *Finite Element Modeling of the Behavior of Armor Materials Under High Strain Rates and Large Strains.* Winnipeg, Manitoba, Canada : Master of Science, 2010.

[9] **T. Holmquist, G. Johnson.** Determination of constants and comparison of results for various constitutive models. *Journal de Physique.* 1991, Vol. IV.

[10] **Weerasooriya, Tusit.** *The MTL torsional split Hopkinson bar.* s.l. : U.S. Army Materials Technology Laboratory, 1990.

[11] **Weinong Chen, Bo Song.** *Split Hopkinson (Kolsky) Bar. Design, Testing and Applications.* s.l. : Springer, 2011. ISBN: 978-1-4419-7981-0.

[12] **L.C Forde, W.G Proud, S.M Walley.** *Symmetrical Taylor impact studies of copper.* s.l. : PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES. pp. 769-790. Vol. 465. 1364-5021.