Determining the Critical Value of Damage for C45 Grade Steel with Rotary Compression in a Channel

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Extended Abstract

Ductile fracture is one of the most commonly occurring limiting aspects to plastic forming of metals and their alloys. It can be determined using the so-called damage criteria, the most popular of which is the Cockroft-Latham criterion (CL), described by the following dependency:

$$\int^{\varepsilon_f} \frac{\sigma_1}{\sigma_i} d\varepsilon = C, \tag{1}$$

where: ε_f – critical plastic strain at fracture, -; σ_i – equivalent stress, MPa; σ_1 – maximal principal stress, MPa; *C* - the critical value of damage function. In order to apply this dependency, the value of constant *C* must be given. This value is obtained by calibration test, comprising of compression, tension and twisting. The closer the stress state is to the stress state in the real process, the higher the effectiveness of estimating the cracking of material.

Ductile fracture of material is very important in the case of analysing the processes of cross and skew rolling, where the so-called Mannessmann effect, causing cracking, occurs in the axial area of the specimen. In this case it is caused by cyclically changing (along with the rotation of the specimen) stress, alternately compressive and tensile. Such state of stress cannot be obtained with any of the currently implemented calibration tests. Therefore, a new test – rotary compression in a channel was designed in Lublin University of Technology.

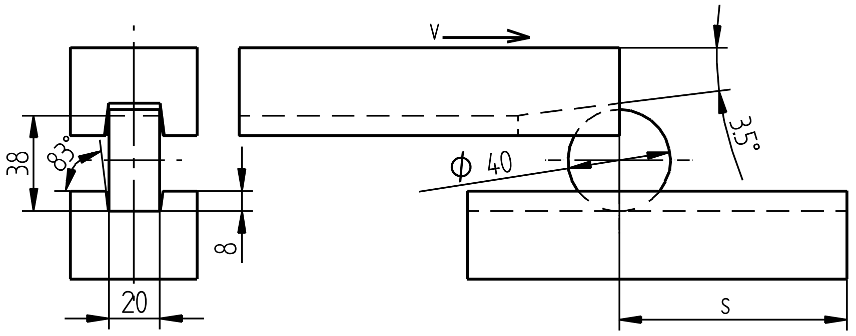

Figure 1. Scheme of the process of rotary compression in a channel, with significant dimensions given.

Figure 1 presents a scheme of the process of rotary compression in a channel, along with significant parameters assumed during its conducting. Within this test, a cylindrical sample is rotated in an impression created by the channels of two tools working together. One of those tools is fixed, whereas the other one moves in a plane motion. The height of the impression is smaller than the diameter of the billet, which ensures its compression in the *s* path, and if the length of the path is sufficient, results in a crack. The test aims to experimentally determine the critical length s at which the material cracking occurs, and subsequently, modelling the test using the finite element method in order to determine the value of the damage function in the axis of the sample at the moment of cracking. This value is assumed to be the critical value.

This calibration method was applied to determine the critical value of the damage of C45 grade hot-formed steel. Experimental testing was conducted using a wedge rolling mill located in the Lublin University of Technology, which allowed for rolling using flat tools with the length up to 1000 mm. The tools used in the process are in compliance with the scheme shown in figure 1, whereas the shifting velocity was equal 300 mm/s. Before forming, the samples were heated to 950 °C, 1000 °C, 1050 °C, 1100 °C and 1150 °C. Further on, the rotary compression test was conducted with various values of the s parameter (fig. 2), in order to determine the critical path. It was assumed the biggest value of the s parameter (for each billet temperature), where no cracks were observed after three repetitions of the forming process. It was established that the critical path is equal: 220 mm for T=950 °C, 230 mm for T=1000 °C, 350 mm for T=1050 °C, 430 mm for T=1100 °C and 675 mm for T=1150 °C.

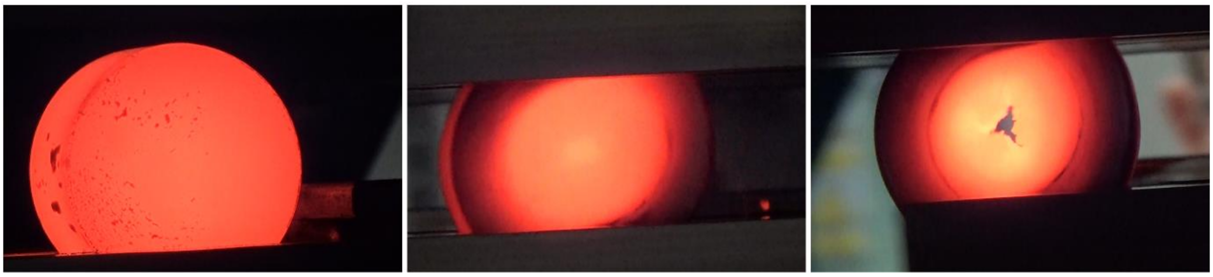

Figure 2. The process of rotary compression in a channel of a sample heated to 1000 °C and formed at the path of 275 mm.

The process of rotary compression in a channel was modelled using Forge NxT v.1.1 software. Figure 3 presents a geometrical model of a test in which parameters similar to those in experimental testing were used. For the simulation it was assumed that the material model of the formed C45 grade steel is described by Hensel-Spittel equation

$$\sigma_f = 1521.3 e^{-0.00269T} \varepsilon^{-0.12651} e^{-0.05957/\varepsilon} \dot{\varepsilon}^{0.14542}, \qquad (2)$$

where: σ_f – flow stress, MPa; ε – effective strain, -; $\dot{\varepsilon}$ – strain rate, s^{-1}; T – temperature, °C.

Moreover, it was assumed that friction is described by the Tresca model, determined by the friction factor equal 0.8. It was also stated that the temperature of the tools was 50 °C and the heat transfer coefficient was equal 10000 W/m^2K.

The calculations conducted using FEM aimed to determine the value of the damage function in the axis of the samples. Figure 4 shows an exemplary distribution of this function, determined for the sample heated to 1100 °C and formed on the critical path s=430 mm. The aforementioned scheme illustrates the phenomenon of damage concentration occurring in the axis of the sample, which is caused by the Mannessmann effect. In order to determine the quantitative value of the material damage in the axis of the sample 11 sensors were fixed (placed 2 mm from each other), where the damage function during the process was registered (fig. 5). The final value of the material damage in the given temperature was determined by averaging the final values of the damage function registered in each sensor. The critical damage values of C45 grade steel are shown in fig. 6. The listing of values shows that the value of this parameter is inextricably linked to the temperature, the increase of which causes the growth of the critical value of damage (from 1.005 for T=950 °C, to 5.280 for T=1150 °C).

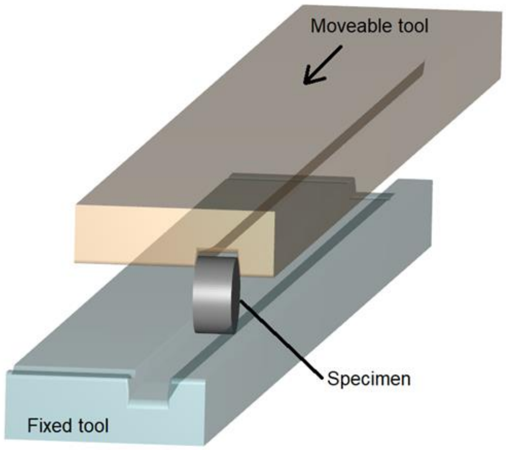

Figure 3. Geometrical model of the process of rotary compression in a channel, created in Forge NxT v.1.1 software.

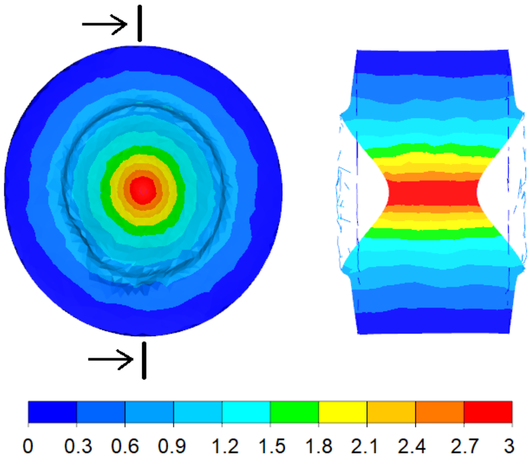

Figure 4. The distribution of the damage function in the sample, calculated in compliance with the CL criterion, heated to 1100 °C and subjected to compression in the critical path.

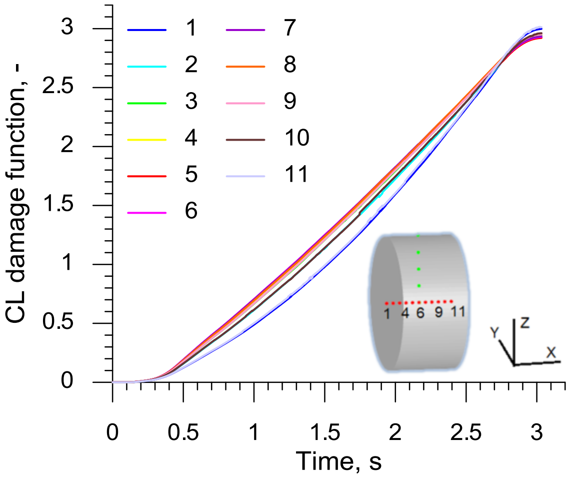

Figure 5. Change to the CL damage function in sensors located in the axis of the sample heated to 1100 °C and formed in the critical path.

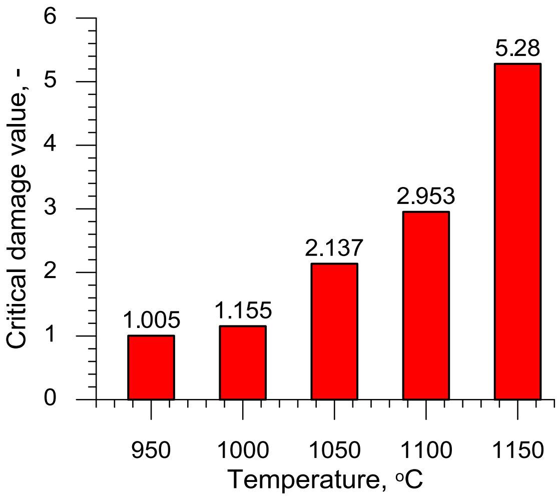

Figure 6. Critical values of the damage of C45 grade steel, depending on the temperature, obtained during the process of rotary compression in a channel.

Keywords: Damage, Calibration test, Rotary compression, FEM, Experiment.

Acknowledgment

The research has been conducted under the project No. 2017/25/B/ST8/00294 financed by the National Science Centre, Poland.