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DETERMINATION OF THE FLOW CURVE OF ALZn5MG3 ALLOY USING THE MODIFIED RASTEGAEV TEST

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Abstract: The application of a modified Rastegaev test for determining flow curves is presented in this paper, as these curves are essential for accurate modeling and simulation of metal forming processes. First, a comprehensive overview of conventional flow curve determination methods is provided, including tensile, compression and tensile testing techniques. The modified Rastegaev test is then described in detail, with particular emphasis on its ability to evaluate material behavior across a wide range of plastic strains. The experimental part focuses on characterizing the flow behavior of an AlZn5Mg3 aluminum alloy using the modified Rastegaev test. The resulting data were used to construct the flow curve of the tested alloy, which was subsequently approximated using the Ludwik equation.

Keywords: flow curve, modified Rastegaev test, Ludwik equation, Hollomon equation

1. INTRODUCTION

Reliable flow curve data is indispensable for the design, simulation, and optimization of metal forming processes. By quantifying the relationship between stress and plastic strain, flow curves provide the necessary input for accurately predicting material behavior under different loading conditions. Traditionally, flow curves have been obtained through conventional testing methods such as tensile, compression, and torsion tests [1]. While these approaches are widely used, each of them has certain limitations, particularly in their ability to cover a wide range of plastic strains or to

reproduce the complex stress states encountered in industrial forming operations. As a result, there is a continued need for alternative testing techniques that can extend the applicability and accuracy of flow curve determination [2, 3].

One such approach is the Rastegaev test [4], originally designed to account for the effects of inhomogeneous deformation in compression testing. In a standard compression test, friction between the specimen and the tool surfaces often leads to inhomogeneous deformation, barreling of the specimen, and deviations in the measured stress-strain response. These

effects restrict the accuracy of the derived flow curve, particularly at higher plastic strains. To address this problem, Rastegaev [4] proposed a modified specimen geometry that significantly reduces frictional influences. The conventional Rastegaev specimen (Fig. 1a) is a cylindrical sample with cylindrical recesses on its surfaces. These recesses are filled with lubricant (Fig.1b) prior to testing to minimize friction and prevent the extreme barreling (a bulging shape) typical of standard upsetting tests. Building on this concept, the Rastegaev test allows the determination of flow curves over an extended range of plastic strains ($\varphi_{\max} \approx 1.4$) [5], making it especially suitable for materials used in large plastic deformation processes such as bulk metal forming

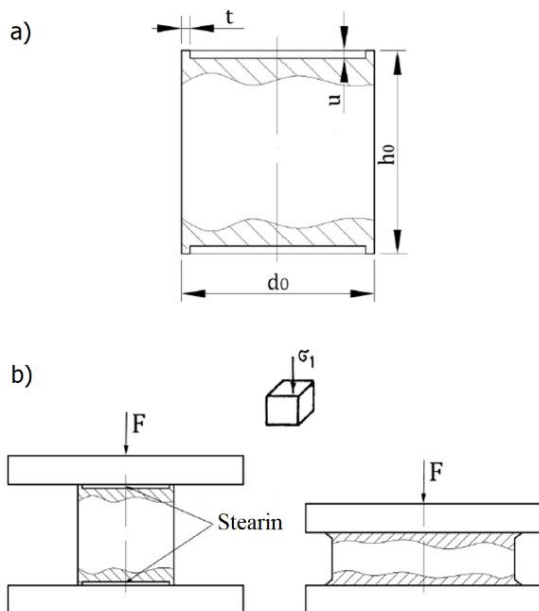


Figure 1. Conventional Rastegaev specimen (a) and corresponding testing procedure (b)

In addition to specimens with cylindrical recesses, the Rastegaev test can also be performed using specimens with different geometrical features (Fig. 2). Although these specimens are less commonly used in practice due to manufacturing challenges, they offer certain advantages. In particular, specimens with conical recesses exhibit greater stability during testing, allowing better control of the deformation pattern at large strains and enabling the determination of flow curves over a wider range of plastic strains ($\varphi_{\max} \approx 2$) [6].

In this work, the modified Rastegaev test is applied to an AlZn5Mg3 aluminum alloy. The experimental results were used to construct the material's flow curve, which was subsequently analyzed and approximated using the Ludwik empirical equation, also known as the power-law hardening model. The study aims to demonstrate the effectiveness of the modified Rastegaev test in determining flow behavior and to provide insight into its advantages compared to conventional testing techniques.

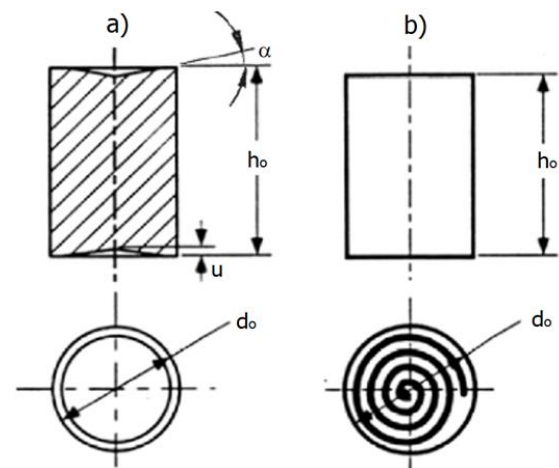


Figure 2. Specimens for the modified Rastegaev test: (a) with conical recesses and (b) with spiral grooves

2. MATERIAL AND EXPERIMENT

The modified Rastegaev test was performed using cylindrical specimens with conical recesses (Fig.3), made from AlZn5Mg3 aluminum alloy. Three specimens were prepared for the purposes of experimental testing [7].

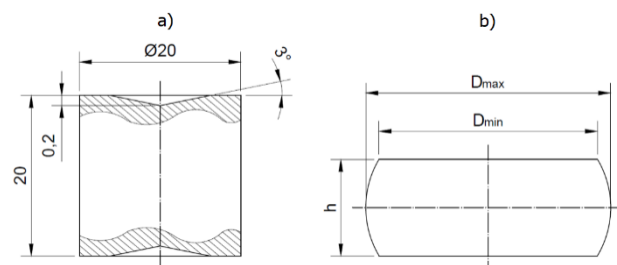


Figure 3. Specimens before and after compression

The upsetting tests were carried out in multiple stages (specimens 1 and 2) on a Sack &

Kiesselbach 630 t hydraulic press using flat plates (Fig.4), with each stage corresponding to a 10% reduction in height. After each stage, the sample's height (h), as well as its maximum (D_{max}) and minimum diameter (D_{min}), were measured. The third specimen was compressed in a continuous (single-stage) manner. Fig.5 shows the load (F) plotted as a function of die stroke (s) for all three specimens. The comparison of specimens before and after compression (Fig.6) shows minimal barreling, indicating effective suppression of frictional effects and deformation under near-uniaxial stress conditions. It should be noted that visible cracks were observed in specimen 3, most likely resulting from lubricant layer failure under high contact pressures. This can be attributed to the experimental procedure—unlike the first two specimens, where the lubricant layer was renewed after each deformation stage, specimen 3 (due to continuous upsetting) was lubricated only at the beginning of the process.

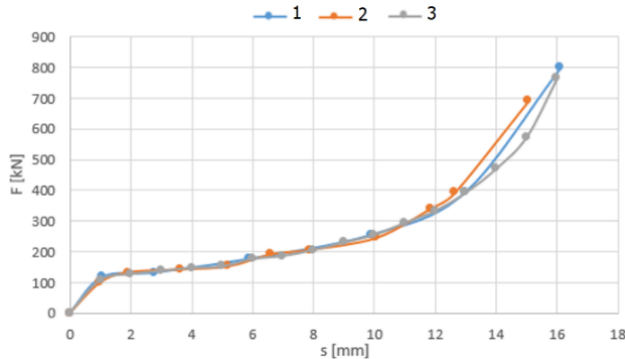


Figure 4. Load –stroke diagram

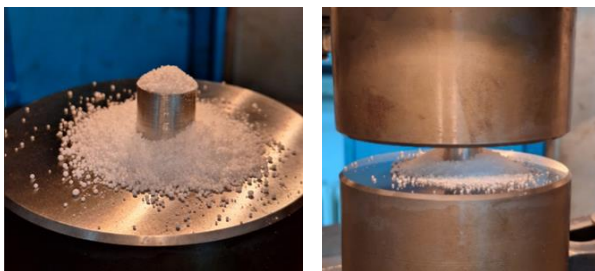


Figure 5. Preparation (lubrication) of a specimen (left), and upsetting with flat plates (right)



Figure 6. Specimens before and after compression

3. EXPERIMENTAL RESULTS

True stress (K) and true strain (φ) necessary for obtaining the flow curve, were determined using the following equations:

$$K = \frac{F}{A}, \quad \varphi = \ln \frac{h_0}{h} \quad (1)$$

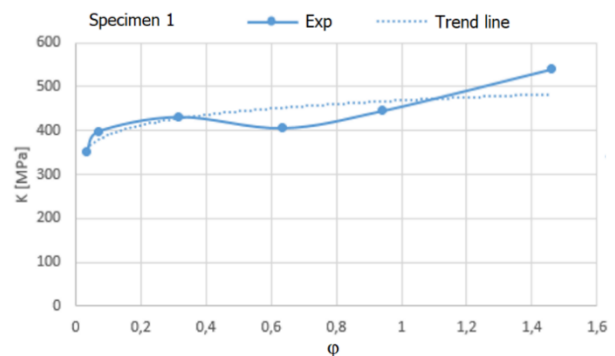
where the average diameter (D) and cross-sectional area (A) are calculated as follows:

$$D = \frac{D_{max} - D_{min}}{2}, \quad A = \frac{D^2 \cdot \pi}{4} \quad (2)$$

Since the third specimen was upset continuously, D_{min} , D_{max} , and h could not be measured. Therefore, the average diameter (D) was calculated based on volume constancy ($V_0 = V$), while the height (h) was determined as the difference between the initial specimen height and the achieved stroke (s).

$$D = D_0 \sqrt{\frac{h_0}{h}}, \quad h = h_0 - s \quad (3)$$

Figure 7. presents the flow curves derived from the experimental results.



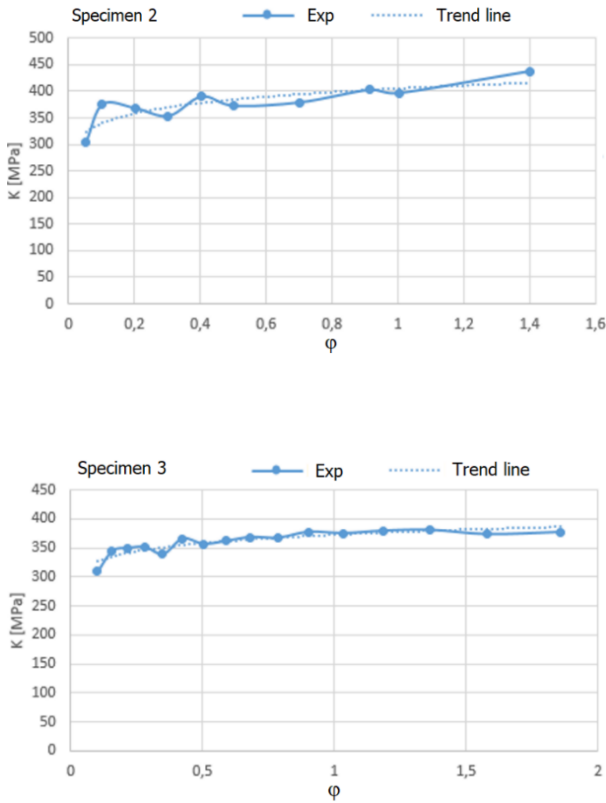


Figure 7. Flow curves determined experimentally

Analytical flow curves for all three specimens were obtained by approximation using the Ludwik equation (5)

$$K = K_0 + C \cdot \varphi^n \quad (4)$$

where:

K_0 – yield stress

C, n - material-dependent constants

The analytical forms of the Ludwik flow curve equations for all three specimens are given in Eq.6, with the corresponding graphs shown in Fig. 7:

$$\begin{aligned} K_{(1)} &= 260 + 223.13 \cdot \varphi^{0.24} \\ K_{(2)} &= 260 + 145.95 \cdot \varphi^{0.268} \\ K_{(3)} &= 260 + 113.35 \cdot \varphi^{0.209} \end{aligned} \quad (7)$$

The yield stress (K_0) for aluminum AlZn5Mg3 is 260 MPa [7].

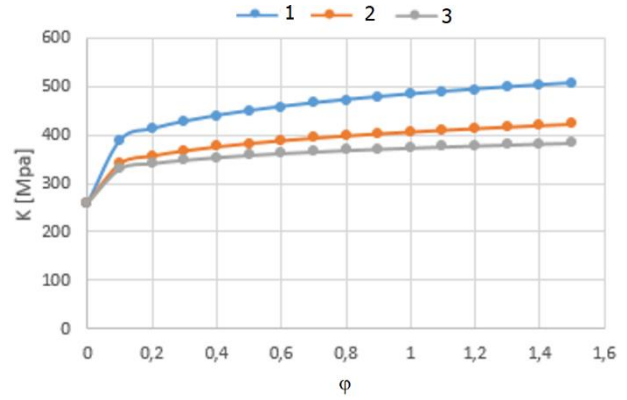


Figure 8. Flow curves approximated using Ludwik's equations

4. CONCLUSION

The study demonstrated the effectiveness of the modified Rastegaev test, which employs cylindrical specimens with conical recesses, in determining the flow curve of the AlZn5Mg3 aluminum alloy. Compared to the conventional Rastegaev test using cylindrical specimens with cylindrical recesses, this modification further reduces frictional effects, allowing accurate characterization of material behavior over a wide range of plastic strains. Results from the tests indicate that large plastic strains ($\varphi=1.4-1.6$) can be achieved without notable process instability or barreling, demonstrating the method's robustness and reliability. This stability under high deformation conditions highlights its suitability for its for accurate flow curve determination and its potential for advanced metal forming applications.

ACKNOWLEDGEMENT

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