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ACCURACY OF PURE COPPER FLOW CURVES DETERMINATION IN COMPRESSION TESTS

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Abstract: Comparison of experimental results obtained in two main compression test methods are presented in this paper. First method is so called Schofman procedure. Second method is near friction free compression test so called Rastegaev procedure, and there is used as referent. Schofman method is attractive with his bright idea of non-experimental grapho–analytical elimination of friction, but experimental part is demanding and often problematic. Performed were Schofman compression test using pure copper samples, and proposed two variation of basic method. In second part of the experiment performed was Rastegaev compression test known as reliable and accurate, and classic compression test with existing of friction. After experimental results comparison and analysis, conclusions made about Schofman method, and especially about proposed corrections of basic procedure.
Keywords: flow curves, compression tests, pure copper

INTRODUCTION

Strain hardening curves or flow curves are the most significant characteristics of metal materials behaviour in the field of plastic deformation. One of the main reasons for that significance is flow curves usage in numerical simulations of forming processes. The accuracy of material data (including flow curves) is an important factor determining the accuracy of simulations.

Strain hardening curves are most often obtained by a tensile test. At the point of onset of necking strain intensity is relatively small. Data after necking is generally obtained by analytical approximation or by simple extrapolation. But, there is another solution – compression tests, suitable especially for bulk forming processes. Exist different methods [1, 2], and unique problem: how minimize influence of friction. One of the classic methods is so called Schofman compression test which is not sufficiently known in the western literature [1]. Essential postulate is inventive idea of friction elimination not by lubrication and experimental procedures but by mathematical extrapolation of proper functions curves. All the other tests are based on different experimental modifications and result corrections [1,2,3,4]. In research centers in Serbia (and former Yugoslavia) well–known is so called Rastegaev compression test [1] (also not sufficiently known in the West), which provide good and usable results.

There are many investigations of compression tests in literature. Some of them are given here. In the paper [3] presented was lead and tin samples compression test without lubrication. Idea was independently determine friction coefficient in ring test and afterwards make corrections of stress–strain curves in appropriate mathematical procedure. In the paper [4] was shown compression test performed with a dumbbell–shaped specimen and closed contact areas. Authors conclude that it's possible in the tests to estimate large strains (up to 1.5) by suppressing the effects of friction. In the paper [5] given are implementation of numerical procedure called inverse analysis to correct experimentally obtained stress–strain flow curves. Paper [6] gives extensive experimental analysis of 26NiCrMoV 14–5 steel behaviour at higher temperature range (850–1150°C). Beside other techniques, applied was compression test, reached 0.7 strain and determined flow curves, but without experimental and other details. In the paper [7] authors presented was analysis similar to the one gives in paper 6, but with other material (2050 Al–Li alloy) and other temperature range (340–500°C). Used was classic compression test and than made was relatively complicated correction procedure for friction influence elimination.

In this investigation authors was applied classic compression Schofman method on the pure copper samples, with appropriate corrections. Correction effects were estimated by comparing results with separately made reliable Rastegaev test.

EXPERIMENT AND ANALYSIS

Material used in experiment was pure copper (Cu – PHC or CW020A according to EN 13601:2013). It is deoxidated copper intended to electrical industry, process equipment manufacture and other purposes. It has very good formability and high electrical conductivity. Main mechanical properties are given in Table 1.

Table 1. Cu–PHC Mechanical properties

Sign	Temper	Mechanical properties				
		R_M	R_{p02}	A		HV
		N/mm²	N/mm²	A5, %	A10, %	
Cu–PHC	R240	240÷300	>180	>14	≥8	65–90

Series of cylindrical samples was prepared for the experimental part of Schofman method (Figure 1). There is in Figure 1 geometry of six samples, but sample with height of 20 mm was abandoned because of unstable compression process. Compression was performed on classic mechanical laboratory testing machine with maximal force of 100 kN. Velocity was 5 mm/min. View of samples and testing machine are given at Figure 1 and Figure 2.

According to Schofman method [1] compression test without lubrication was conducted to strain about 0.7. Force capacity of machine was only limit. After that, collected experimental data were presented in diagram witch give dependence of compression stress on strain (Figure 3).

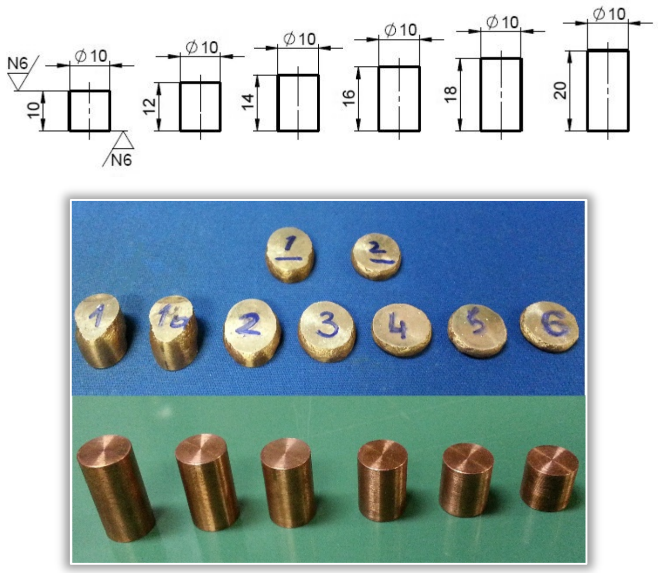

Figure1. Samples for Schofman test

Figure 2. Testing machine

Diagram stress – sample diameter, sample height ratio need to form based on the data from diagram in Figure 3, at the second stage of Schofman method. Note that in Figure 4 on x–axis given is d_0/h_0 – ratio before deformation, i.e. type of sample.

Through obtained points for strains 0.1 to 0.6 (step 0.1) calculated and drew were extrapolation exponential functions, according to appropriate mathematical procedure. Points in sections of y–axis and extrapolation curves gives true stress in theoretically low friction condition, i.e. equivalent stress. Note that points for d_0/h_0 – ratio of 0.55 were abandoned (except for minimal 0.1 strain e1) because of unstable forming (see Figure 1 above).

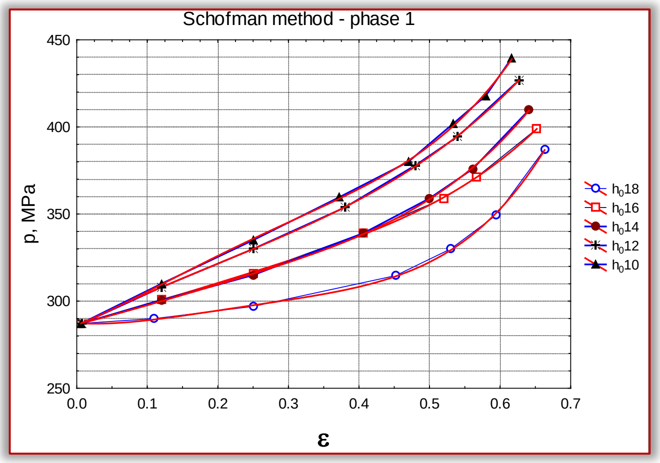

Figure 3. Compression stress – strain diagram

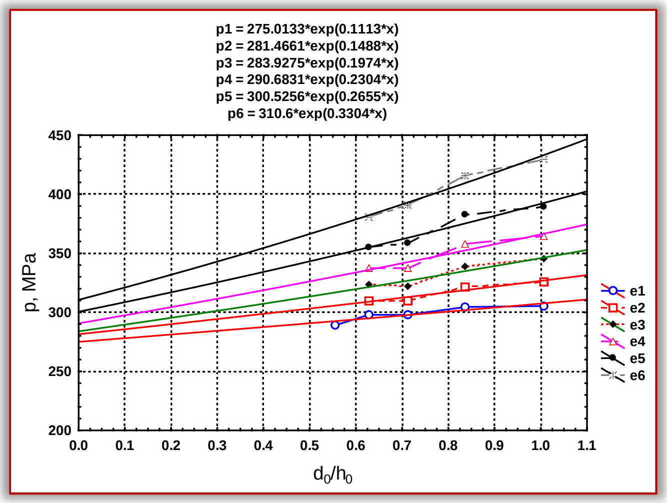

Figure 4. True stress–diameter to height ratio diagram

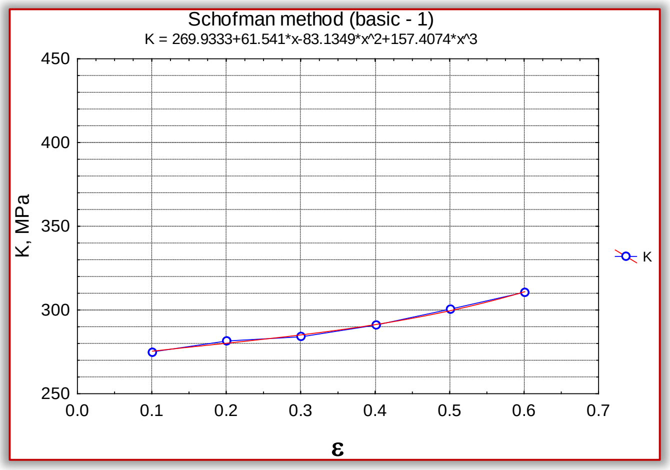

Figure 5. Flow curve–variant 1

Obtained curve (Figure 5) have lower position than can be expected. That was the reason to propose corrected extrapolation, Figure 6. Points for smallest strain of 0,1 (e1) are most reliable, and for these points calculated was extrapolation function, the same as at Figure 4. Functions for the next strains are equidistant. Flow curve are given in diagram Figure 7, variant 2. Position of the curve K2 is more realistic.

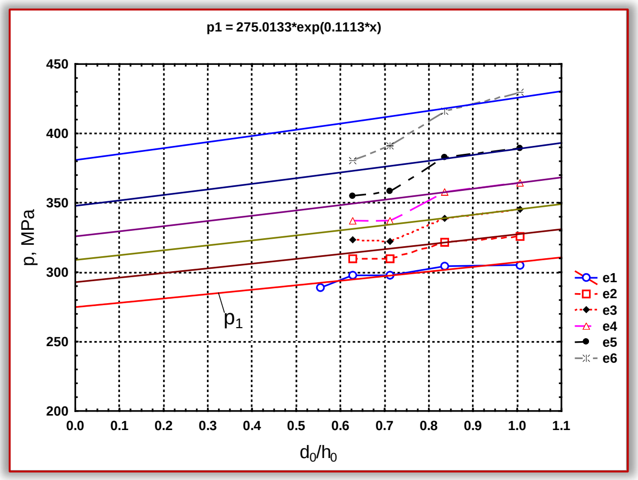

Figure 6. Corrected extrapolation (var. 2)

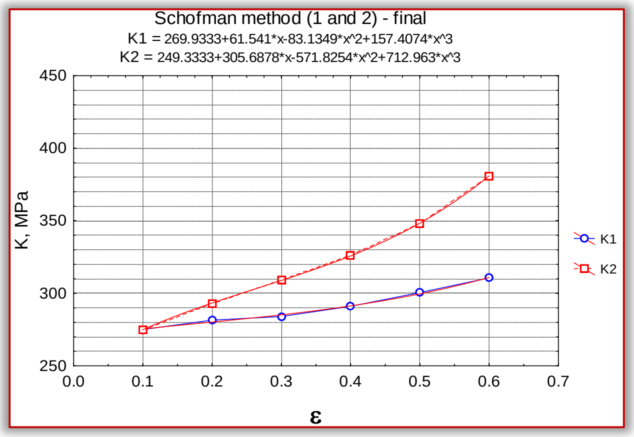

Figure 7. Flow curves (variant 1 and 2)

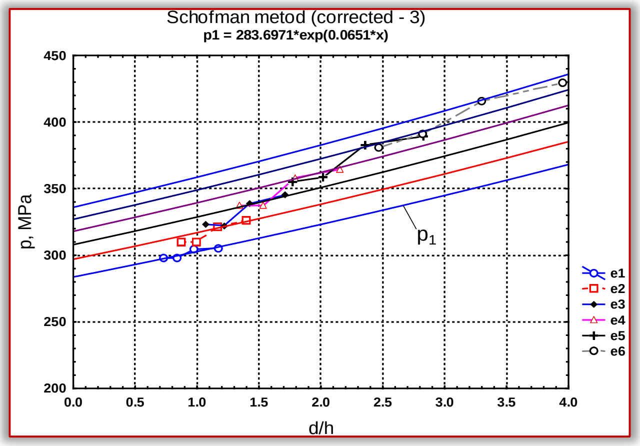

Figure 8. Corrected extrapolation (var. 3)

Variant 3 is second correction and principle is given in Figure 8. Instead of d_0/h_0 there is used value d/h corrected according to realized deformation [1]. Extrapolation functions calculated in the same way as in Figure 6. Flow curve can be seen in Figure 9. Disregarding corrected ratio d/h position of flow curve is relatively low.

For the estimation of obtained flow curves chosen was reliable Rastegaev method [1, 2]. Geometry of special specimen is given at Figure 10, and view at Figure 11. Diameter d=10 mm, height h=12 mm, u=0.3 mm, t=0.7 mm. Lubrication was realized with molybdenum disulfide grease.

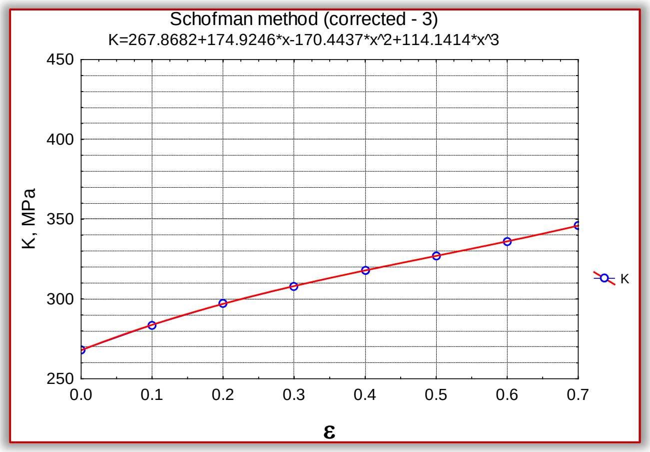

Figure 9. Flow curve–variant 3

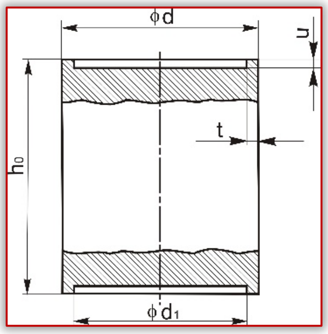

Figure 10. Sample for Rastegaev test

Figure 11. View of Figure 10 sample

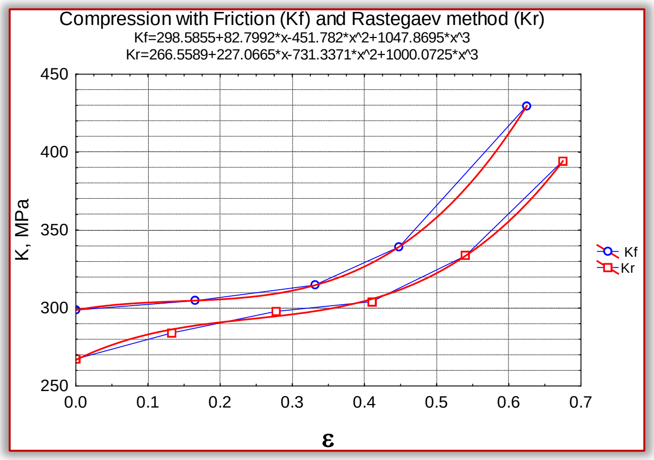

Figure 12. Stress–strain curve with friction (Kf) and Rastegaev flow curve (Kr)

Here, can been seen in Figure 12 effect of Rastegaev reduction of friction. Above stress–strain curve is with and below without friction. Obvious difference between the curves confirms efficiency of Rastegaev method.

Figure 13 shows results comparison of corrected Schofman method (variant 2 and 3) and Rastegaev method which is considered as referent here. Differences are not great and proposed curves are acceptable, but not ideal.

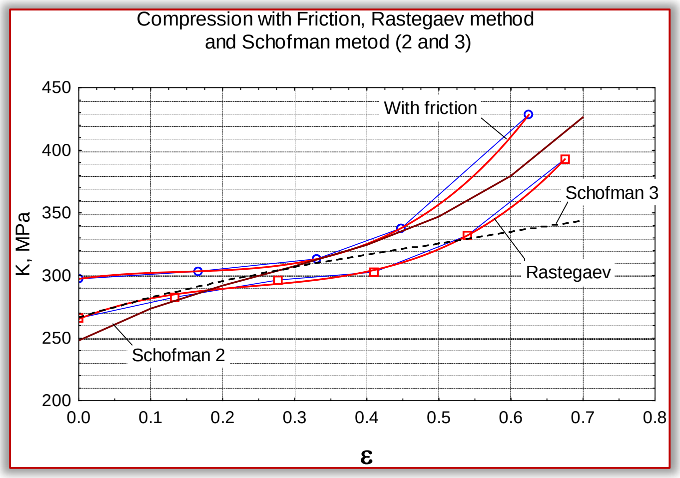

Figure 13. Different flow curves comparison

CONCLUSION

The appropriate corrections in classic Schofman method based on compression test were proposed. Conducted was compression experiment with samples of pure copper (Cu–PHC). Beside experiment for Schofman method, separately was performed compression test with friction, and according to Rastegaev method, with significantly reduced friction. Comparison of the curves with friction and Rastegaev reduction of friction clearly shows effect of that method.

Very sensitive Schofman method gives (in this experiment) lower position of flow curve than can be expected. After correction in grapho–analytical extrapolation procedure obtained more reasonable curves. Estimation of these flow curves were made by comparing with ones obtained in reliable Rastegaev test.

At the end, can be conclude that proposed correction gives acceptable results, but also there is a lot of space for further investigations.

Note:

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