PHYSICAL MODELLING OF THE MULTI-PASS FORGING OF ZIRCONIUM ALLOY BLANKS

H.DYJA[a], A.KAWAŁEK[a], A.M. GALKIN[b], K.V. OZHMEGOV[b], S.SAWICKI[a]

[a] *Czestochowa University of Technology, Czestochowa, Poland, EU, ippiibt@wip.pcz.pl*

[b] *National University of Science and Technology "MISIS" (MISIS), Moscow, Russia, pdss@misis.ru*

Abstract

This paper presents the results of plastometric modelling of the Zr-Nb-Sn zirconium alloy blank forging process. The results were obtained by performing a test on the “Gleeble 3800” plastometric simulator in hot conditions.

Keywords: Plastometric modelling, forging, hot deformation, Zr-Nb-Sn alloy

1. INTRODUCTION

When designing the technological processes of zirconium alloy blank manufacture increasing consideration is given to the issue of the rational distribution of single reductions under the conditions of multi-pass (intermittent) deformation on hydraulic presses, hammers, radial forging machines and HPT type pilger mills.

This problem is related not only to seeking the optical loading schemes and reducing the consumption of energy for technological purposes, but also to the issue of enhancing the quality indices and structural characteristics of finished products. Numerous theoretical and experimental studies of the rheology of plastically deformed materials, carried out in recent years, have found a relatively complex dependence of the yield stress σ_p of metal alloys being worked on the thermomechanical parameters of deformation and thus on the conditions of conducting the deformation process in time. At the same time, the value of σ_p is not only determined by presetting the deformation at a given moment; it depends also on previous deformations ("metal memory").

The complexity of the analysis and physical modelling of intermittent deformation stems also from the fact that the distribution and behaviour of the flow curves with multi-pass loading are influenced by a number of interrelated factors and parameters, such as:

- distribution of strain rate and metal temperature in successive passes;
- the magnitude of reductions in single passes and of the total reduction;
- the length of breaks between set loads and metal cooling conditions after deformation;
- the interaction between the processes of strain hardening and dynamic and static (metadynamic) softening of metal.

Solving this complicated problem within the framework of the theory of plasticity seems to be impossible, because according to this theory the stress deviator is related either to the strain deviator or the strain rate deviator. Therefore, the loading history could be most accurately considered by using the approach based on the equivalent creeping theory [1, 2].

The verification of the results of analytical calculations made according to the equivalent creeping theory model is best performed using modern plastometric equipment, such as in particular the "Gleeble" simulator of metallurgical processes [2, 3].

2. MATERIAL AND RESEARCH METHODOLOGY

Plastometric tests were carried out on cylindrical-shaped specimens made of a zirconium alloy of the Zr-Nb-Sn type (Zr-0,9%Nb-0,9%Sn-0,35%Fe), having a working portion diameter of 10 mm and a height of 12 mm, and being in an as-crystallized condition (a grain size of 9 - 10 Class). The tests were completed on the "Gleeble 3800" metallurgical process physical modelling device available at the Institute of Plastic Working and Safety Engineering of the Czestochowa University of Technology, using the "Pocket Jaw" multi-functional module [2, 4].

For controlling the deformation process in the "Gleeble 3800" device, the „Gleeble System Language” special programming language was used, which enables all operation parameters to be programmed for the preset conditions of tests to be conducted. For processing the experimental test results, the "Origin" software was used, which allows the high accuracy of output parameter measurements to be achieved with the use of one or two specimens per specified point of the testing programme.

The aim of the tests was to determine the plastic flow curves in the physical modelling of the process of hot forging of a 450 mm-diameter Zr-Nb-Sn zirconium alloy ingot into a 190×190 mm square cross-section blank on a hydraulic press with a rated pressure force of 12 MN.

The modelling covered the forging conditions occurring under real industrial conditions prevailing in an example industrial plant, while considering the technological scheme of forging with the changed distribution of single reductions and the deformed metal temperature in individual forging passes.

Industrial technological scheme of forging the Zr-Nb-Sn zirconium alloy

The tests were performed after heating the specimens up to a temperature of 950 °C, holding them at this temperature for 5 minutes, and then cooling them down to a temperature of 918 °C (allowing for the duration of transporting the ingot to the press). The distribution of reductions and deformed metal temperature in individual passes (in a total of 21 forging passes) is shown below:

The magnitudes of single reductions ε_i in individual passes: 0.12 - 0.12 - 0.12 - 0.12 - 0.12 - 0.12 - 0.12 - 0.11 - 0.11 - 0.11 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 - 0.1 ($\Sigma\varepsilon$ =2.27).

Deformed specimen temperature in a successive pass, T_{bad}, °C: 918 - 917 - 915 - 912 - 909 - 905 - 901 - 897 - 892 - 886 - 880 - 874 - 868 - 862 - 856 - 848 - 840 - 832 - 822 - 811 - 800.

Metal cooling rate between passes was 0.2 °C/s. The average strain rate in each forging pass was assumed at $\dot{\varepsilon}$ =0.5 s^{-1}. Breaks between passes were as follows: 5 - 10 - 15 - 15 - 20 - 20 - 20 - 25 - 30 - 30 - 30 - 30 - 30 - 30 - 40 - 40 - 40 - 50 - 55 - 55 s.

The experimental technological forging scheme after application of larger reductions in passes (in total, 17 forging passes)

The magnitudes of single reductions in successive passes ε_i : 0.16 - 0.16 - 0.15 - 0.15 - 0.14 - 0.14 - 0.13 - 0.12 - 0.14 - 0.14 - 0.13 - 0.13 - 0.12 - 0.12 - 0.12 - 0.11 - 0.11 ($\Sigma\varepsilon$ =2.27).

Deformed specimen temperature in a successive pass, T_{bad}, °C: 918 - 917 - 915 - 912 - 909 - 905 - 901 - 897 - 892 - 887 - 881 - 875 - 869 - 961 - 852 - 842 - 832.

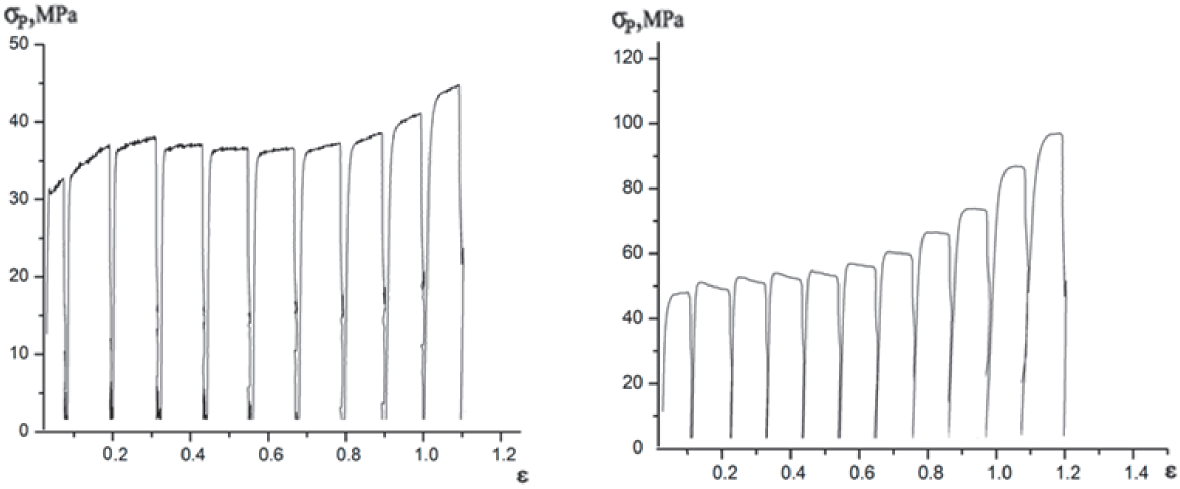
The rate of metal cooling between passes and the average strain rate in passes were preset according to the conditions prevailing in the selected industrial plant, while the breaks between passes were as follows: 5 - 10 - 15 - 15 - 20 - 20 - 20 - 25 - 25 - 30 - 30 - 30 - 40 - 45 - 50 - 50 s. The magnitude of the total deformation for both forging variants was identical, amounting to $\Sigma\varepsilon$ =2.27.

3. INVESTIGATION RESULTS AND THEIR DISCUSSION

The data represented in **Fig. 1** shows that the distribution of the magnitudes of the yield stress σ_p of the investigated alloy in passes, and thus also the forging force, following to the industrial technology, is non-uniform. In the initial passes, the value of σ_p lies in the range of 30-37 MPa, but starting from the eighth forging pass it begins to increase monotonically, reaching a value of 80-90 MPa in the last passes.

At the same time, the behaviour of variation of the yield stress of the examined alloy in the initial passes (up to 7-8) resembles the classic flow curves $\sigma_P - \varepsilon$, characteristic of the dynamic recrystallization process [2, 5-7]. At the initial stage of deformation (in the range of ε = 0.2-0.3), a distinct maximum was observed to have occurred for the magnitude of σ_p , followed by passing to the steady flow stage ($\sigma_p = \sigma_{pu}$).

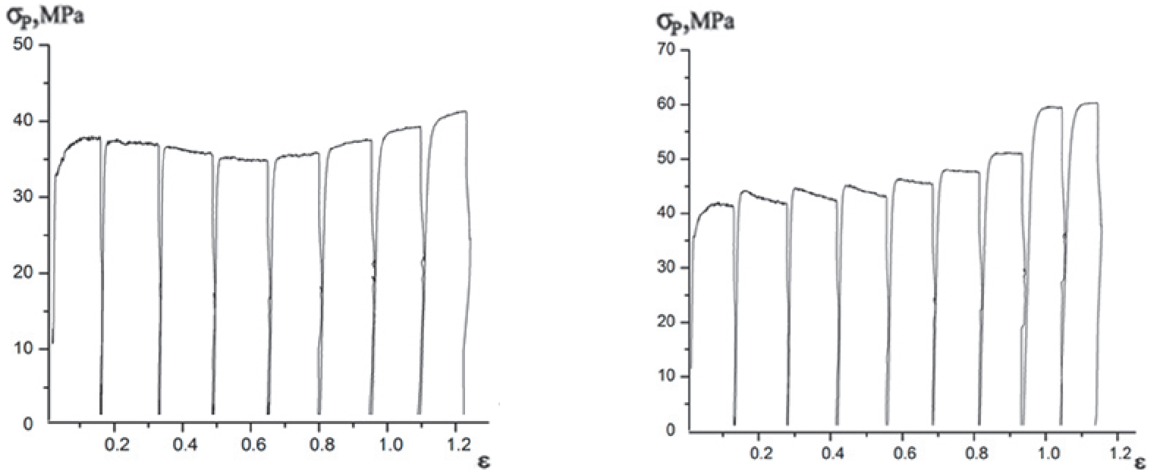
Further on, after exceeding the value of ε = 0.7-0.8, a monotonic increase in yield stress magnitude takes place, which is related to the drop in forging process end temperature (T_{bad} = 800 °C). The behaviour of the yield stress distribution curve displayed in **Fig. 1** shows that in forging according to the industrial variant, the permissible loads are not used in the initial passes, but only at the end of the forging cycle the magnitude of the strain σ_p rapidly increases, resulting in an increase in deformation non-uniformity in the last passes. This was the reason for making the correction to the scheme of forging ingots of the investigated alloy by introducing a more uniform distribution of single reductions throughout the deformation cycle.



a) b)

Fig. 1 Distributions of the values of σ_p in the successive passes of the process of forging the 190×190 [mm x mm] square cross-section Zr-Nb-Sn zirconium alloy blank from the 445 mm-diameter ingot; a) in passes 1÷10, b) in passes 11÷21; according to the industrial technology

In accordance with the new technological scheme (**Fig. 2**), the magnitude of single reductions in the initial forging passes was increased to the value of ε = 0.14-0.16, and in the subsequent deformation cycle the magnitude of strain ε was monotonically reduced as low as to 0.1 in the last pass. This made it possible to reduce the number of reductions from 21 according to the industrial technology to 17 in accordance with the experimental conditions. At the same time, the forging cycle duration decreased and the blank metal temperature drop was reduced. Due to the proposed changes, the magnitude of the stress σ_p of the investigated alloy, deformed according to the proposed experimental forging scheme conditions, was contained in the range of 40-50 MPa (**Fig. 2**) up to pass no. 15. Only in the last two forging passes did the magnitude of σ_p increase up to σ_p = 60 MPa. It is worth noting that, according to the experimental forging scheme, the minimum magnitude of σ_p occurred during forging in passes 3-5 (σ_p = 0.4-0.8), where the dynamic recrystallization process occurs most intensively. This process affected the behaviour of the curve of intermittent deformation in the subsequent passes. Starting from pass 9 through to pass 14, a maximum of the σ_p magnitude occurs in the $\sigma_p - \varepsilon$ curves for the initial loading stage.



a) b)

Fig. 2 Distributions of the magnitude of σ_p in successive passes in the process of forging the 190×190 [mm x mm] square cross-section Zr-Nb-Sn zirconium alloy blank from the 445 mm diameter ingot; a) in passes 1÷8, b) in passes 9÷17; according to the experimental scheme

The behaviour of the flow curves obtained for the experimental forging conditions (**Fig. 2**) indicates that it is possible to achieve even a more uniform distribution of the magnitudes of σ_p in the entire forging cycle. It has been recommended to reduce the magnitude of single reductions in the first two passes and in final passes 16 and 17. At the same time, it is necessary to respectively increase the magnitudes of single reductions in passes 4 and 5 and in passes 9-14.

CONCLUSION

It can be stated that for the fractional loading of the Zr-Nb-Sn alloy within the range of investigated parameters the most important factor is the temperature so to decrease values for fractional loading, the value of single draft should be increased and number of passes should be reduced.

Based on the investigation of the process of multi-stage forging of Zr-Nb-Sn alloy blanks it can be concluded that there exist wide possibilities of physical modelling and optimizing the technology of real complex loading processes using the "Gleeble 3800" metallurgical process simulator.

The analysis of the results presented in the paper allow to further research which could be helpful to design the optimal technology of metal forming for such alloys

REFERENCES

[1] Pozdeev, A.A., Tarnovskij, V.I., Eremeev, V.I. *Primenene teori polzuchesti pri obrabotke metallov davlenem.* M.: Metallurgya, 1973, 192 p.

[2] Dyja, H., Gałkin, A., Knapiński, M. *The Rheology of Plastically Deformed Metals*, Publishing House of the Czestochowa University of Technology, Czestochowa, 2010, p. 371.

[3] Gałkin, A., Ozhmegov, K., Dyja, H., Kawałek, A. *Rudy Metale*, 2011, year 56, nr. 1, pp.29-31.

[4] Dyja, H*. Advanced Technologies in Metal Working Processes*. Study guide. IRIAS Moscow, 2009, pp. 189-207.

[5] Dyja, H., Galkin, A.M., Knapiński, M., Ozhmegov, K.V. *Hutnik-Wiadomości Hutnicze,* 2010, nr. 5, pp. 207-209.

[6] Galkin, A.M., Kawałek, A., Kiselev, O.A., Ozhmegov, K.V. *Hutnik-Wiadomości Hutnicze*, 2010, nr. 5, pp. 212-214.

[7] Ozhmegov, K.V., Kawalek, A., Galkin, A.M. Knapiński, M. *Hutnik-Wiadomosci Hutnicze*, 2012, nr. 5, pp. 353-357.