DETERMINATION OF THE STRAIN VALUE DURING SEVERE FORMING ON THE MULTI-AXIS DEFORMATION UNIT MAXSTRAIN II

[1]Horymír NAVRÁTIL, [1]Ivo SCHINDLER, [1]Petr KAWULOK, [1]Petr OPĚLA, [1]Rostislav KAWULOK

[1]VSB – Technical University of Ostrava, Faculty of Materials Science and Technology, Ostrava, Czech Republic, EU, horymir.navratil@vsb.cz

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Abstract

Severe hot forming methods are effective in grain refinement and controlled development of microstructure. One of these methods is the cumulative deformation on the MAXStrain simulation module. The current state of the issue is briefly discussed in the literary analysis. In the presented research, the basic parameters of the simulation module MAXStrain II cooperating with the Gleeble 3800 hot deformation simulator as well as a new methodology for calculating the equivalent strain value during the cyclic multi-pass multi-axis deformation are introduced. The procedure for development of a unique computational model is presented in the individual steps.

Keywords: Gleeble simulator, MAXStrain module, severe forming, multi-axis deformation, equivalent strain

INTRODUCTION

The issue addressed in this article concerns the special method of severe plastic deformation. This is a method in which compressive passes are repeated in two directions while the sample is rotating – see **Figure 1** [1]. MAXStrain system which enables such processing is one of the modules compatible with the Gleeble 3800 hot deformation simulator. It is suitable for physical simulations of bulk forming processes with great cumulative strain. Using the MAXStrain module, samples can be subjected to almost unlimited strain with precise strain and temperature controls. It is a new-generation thermo-mechanical simulator with a proven ability to produce materials with ultra-fine-grained microstructure [2,3].

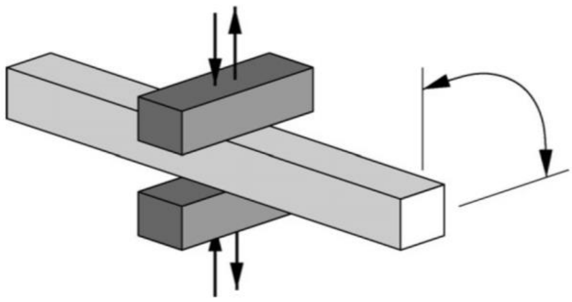

Figure 1 Deformation scheme for the MAXStrain system [1]

The main purpose of the MAXStrain simulation module is to verify the experimental possibilities of grain refinement of the tested materials through severe plastic deformation [4]. The aim is to achieve the controlled development of the microstructure and the smallest possible average grain size by a suitable choice of test parameters and deformation conditions. Various technical metallic materials were processed in this way, starting with aluminium [2,5] through titanium alloys [6,7], steels and another special alloys [8-11]. The phenomenon of the "first stress peak" in microalloyed austenitic and ferritic steels was also studied within the MAXStrain issue [12].

1. MULTI-AXIS DEFORMATION UNIT MAXSTRAIN II

This device is a mobile conversion unit compatible with the Gleeble 3800 simulator to which it is connected. It is designed to achieve extremely large strain with precise temperature control during high-speed multi-axis deformation. Photograph of this facility installed and operated at VŠB – Technical University of Ostrava, can be seen in **Figure 2**.

Figure 2 Multi-axis deformation unit MAXStrain II in the laboratory of VŠB-TUO

The heating and cooling rates of the test sample are automatically controlled, but the maximum rates are limited by the dimensions and design of the sample. The MAXStrain II system allows up to 80 compressive strokes (hits) over 10 mm distance in one program. The maximum sample size is 25 mm x 25 mm x 195 mm. Rotating manipulator can turn the specimen in increments of 90° based on computer command. Under all test conditions, the material flow is caused by the required compressive strain without any torsion of the sample. The servo-motor and rotary assembly holds the specimen with a maximum torque of 500 N·m to prevent the sample from twisting during multiple deformation. The inter-pass time between two consecutive deformations, defined as the time from the end of one pass to the beginning of another one, can be less than 1 s. Compressive deformation of the sample is ensured by two hydraulic pistons. Each of them is controlled independently. One of the hydraulic pistons is guided from a Gleeble 3800 simulator with a force of 196 kN and a maximum ram speed of 2 $m \cdot s^{-1}$. The second piston belongs directly to the MCU MAXStrain II and is designed for a maximum stroke rate of 0.7 $m \cdot s^{-1}$, maximum static load of 196 kN and dynamic force up to 80 kN. Thanks to this additional force, the conditions are created for achieving a very large compression [13].

Temperature control can be provided by the thermocouples or optical pyrometer. The thermocouple is inserted into a drilled hole that extends into the deformed part of the test sample. Thanks to this, it is possible to measure the temperature in the deformation zone even during great cumulative deformation. Non-contact optical measurement may be associated by difficulties due to changing surface properties and oxidation in the course of testing [13].

2. EXPERIMENTAL PROCEDURE

Sample made of plain-carbon steel was deformed at temperature set on 950 °C with a stroke rate of 50 $mm \cdot s^{-1}$. Its narrowed deformation zone has a length of 12 mm and a cross-section of square of 10 mm – see detail in **Figure 3** with slantwise drilled hole for thermocouple. The sample's height after each of 60 hits was set to 6 mm and the inter-pass time was 3.4 s. The sample was rotated 90 ° between successive passes. Evolution of the sample's shape during the forming procedure is demonstrated in **Figure 4**. The process was recorded on a camera. Photographs of the sample were obtained from the captured video recording after each hit.

Figure 3 Central part of the initial sample

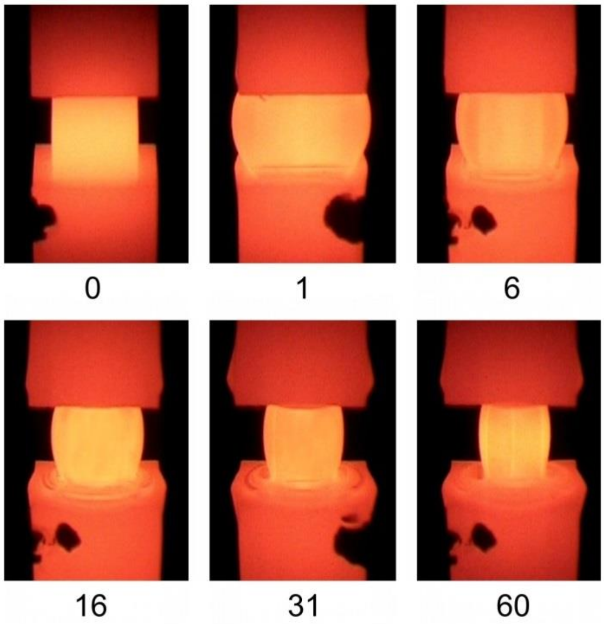

Figure 4 Development of the sample's shape depending on the pass number (0 = initial state)

3. RESULTS AND DISCUSSION

The snaps were used to determine the height and mean width of the deformed part of the sample, taking into account the uneven spreading. Based on these measured values, the true strain in the direction of height e_H (-) and width e_W (-) after each pass was calculated. The equivalent strain e_{Eq} (-) can be computed according to formula (1):

$$e_{Eq} = \sqrt{\frac{2}{3}(e_H^2 + e_W^2 + e_L^2)} \tag{1}$$

assuming that the true strain in the direction of length e_L = 0. It is clear from **Figure 5** how the value of e_{Eq} in each hit decreases gradually with increasing number of passes and how the strain accumulates more and more slowly.

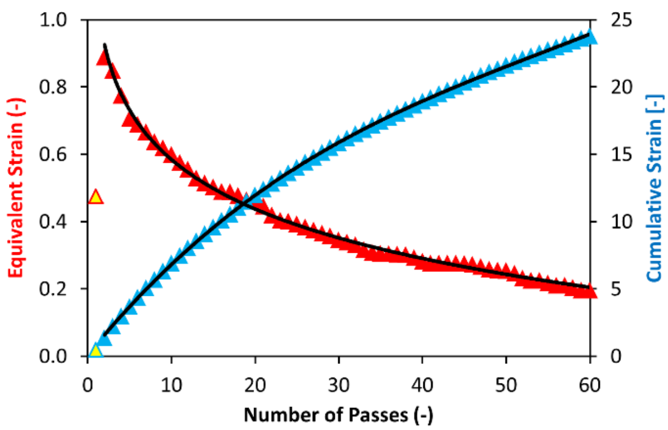

Figure 5 Influence of the number of reductions on deformation ratios

The reason is that the volume conservation law does not seem to apply in the deformation zone. In effect, the formed material escapes from this zone into the sample's heads because it also flows in the length direction.

As a result, the cross-sectional area of the sample gradually decreases from the initial value of 100 mm^2 - see **Figure 6**. The cumulative strain is the sum of partial equivalent strains.

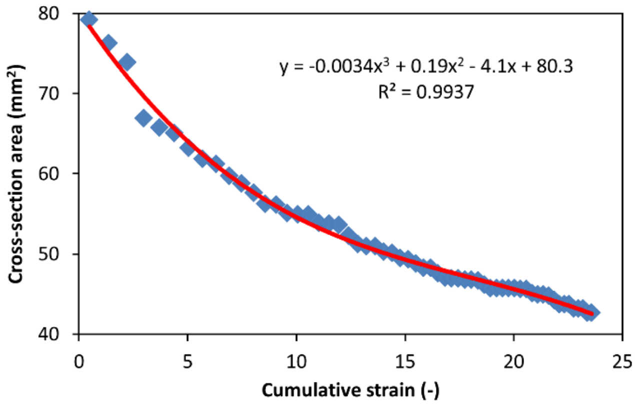

Figure 6 Decrease of cross-sectional area of the sample with increasing cumulative strain

When considering the volume conservation law and knowledge of e_H and e_W values, the theoretical strain e_L can be calculated for each pass. The calculation can be simplified if we obtain a regression dependence between the strain values e_H and e_B (see **Figure 7**), respectively between the cumulative strain and the quantity e_L (see **Figure 8**).

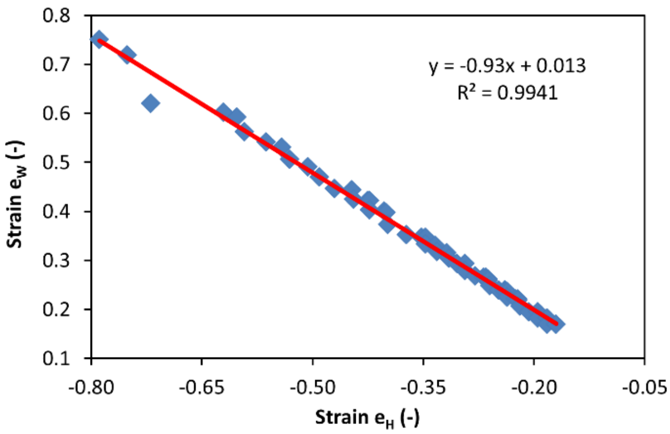

Figure 7 Dependence between height strain and spreading

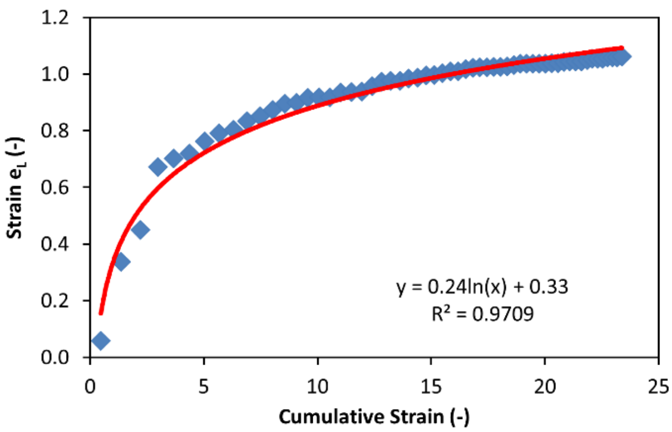

Figure 8 Influence of cumulative strain on the apparent value of strain in direction of the sample's longitudinal axis

The simple regression equation in **Figure 8** is not accurate enough and for further calculations and it had to be replaced by two polynomials with the limit value of the cumulative strain equal to 9.0.

Using the described procedure, it is possible to determine the real value of the equivalent strain in each pass (which is advantageous when simulating multi-pass forming processes on MCU MAXStrain), or gradually change the setting the movement limits of anvils (stroke) so that the same strain was achieved in each pass. Strain calculations based on regression functions are so simple that using of Excel spreadsheet is quite sufficient for this purpose. However, it should be noted that for other test conditions (e.g. forming of some non-ferrous metal alloys at different temperatures) or for samples of different initial shape and dimensions, the ratios between the strains e_H, e_W and e_L may be significantly different. Therefore, the proposed procedure is not completely universal and for other experimental conditions it would be appropriate to repeat and refine the given procedure of the sample's measurements and calculations of the true stress values.

The advantage of the presented computational model is its quite substantial simplicity and the possibility of precise adjustment of the stroke limits for individual hits. In contrast to the complex computational model of Bereczski [14-16], it allows the relatively simple calculation of strain in individual passes and is easily applicable during the implementation of the experiments themselves. On the other hand, the Bereczski's model seems to be more general. Other authors also dealt with the issue [1,17]. However, the published data do not enable to predict the equivalent strain value in individual compressive passes.

4. CONCLUSION

It is very difficult to determine the equivalent strain value during the cyclic multi-pass multi-axis deformation on the MAXStrain simulation module. The situation is complicated by the uneven flow of material out of the deformation zone of the sample. A new methodology for strain value calculation was developed which is simply applicable at real experiments on this thermomechanical simulator. Using the unique computational model, it is possible to adjust the movement of the anvils so that the required strain value is achieved in every pass. It allows us to physically simulate in laboratory conditions various processes with large cumulative strain. The presented studies can contribute to a controlled development of the microstructure and intensive grain refinement e.g. in the operating conditions of rolling mills and forges. They can also significantly enrich the issue of research into the deformation behaviour of metallic materials.

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