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COMPUTER PROCESSING OF RESULTS OF THE WEDGE ROLLING TEST

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Abstract

A simple laboratory test, performed by rolling of the wedge-shaped sample on plain rolls, enables to investigate the structure-forming processes and formability of metallic materials effectively, thanks to its ability to implement a wide range of height reductions in a single sample. The formed material's spread induces tensile stresses at the sample's lateral faces, which can yield in cracking. This method is very suitable for comparison of rollability of some materials with lower formability. Mathematical processing of the wedge rolling test's results is complicated due to an irregular shape of the rolled stock. Hence the developed software represents an universal instrument for mathematical processing of results of the discussed test, which works reliably and independently on complexity of shape of the final rolled product. It is valid also in the case when the initial sample for the wedge rolling test is provided with notches of V shape, milled in the vertical direction on a lateral surface. These notches function as initiators of cracks and make it possible to better compare plastic properties of miscellaneous metallic materials. Deformation behaviour of the material close to these notches was subjected to FEM analysis by means of program FORGE 2005. The simulation confirmed an increased share of tensile stresses on the face of the notch and susceptibility to crack formation. At the same time the formation of laps during drawing the notch into the roll gap was confirmed. Knowledge gained by calculation are in full accordance with behaviour of the samples rolled in a laboratory rolling mill.

Key words: rolling, formability, cracking, equivalent strain, strain rate, computer analysis

1. INTRODUCTION

A simple laboratory test performed by rolling of the wedge-shaped sample on plain rolls enables to investigate both the hot and cold deformation behaviour and above all formability of metallic materials effectively, thanks to its ability to implement a wide range of height reductions (commonly from 0 up to ca 80 %) in a single sample. The formed material's spread induces tensile stresses at the sample's lateral faces, which can yield in cracking. Formability (or more exactly rollability) of the actual material can thus be evaluated as a function of temperature and strain. It is necessary to note that this experimental method cannot give the exactly defined results comparable e.g. with the results of plastometric tests because of the markedly changing conditions along the rolled sample's length (states of stresses, strain rate, etc.). On the other hand, this method is very suitable for comparison of rollability of some materials with lower plasticity – e.g. those containing some subsurface flaws in as-cast state.

To increase accuracy and comfort of this method the special software was developed for calculation of

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equivalent strain and strain rate in whatever cross section along the length of the resulting rolling stock (Heger et al., 2003a). Calculations are based on comparison of corresponding partial volumes of the wedge-shaped initial sample and resulting rolling stock. The latter has approximately constant thickness but due to spread strongly irregular planar shape and size. This factor considerably complicates principle application of the law of volume preservation, when necessary calculations of partial strain components are carried out. The outlined particular problem was successfully solved by applying methods of computer analysis of a bitmap picture gained by scanning the planar shape of the sample after its rolling and straightening (Turoňová, 2005).

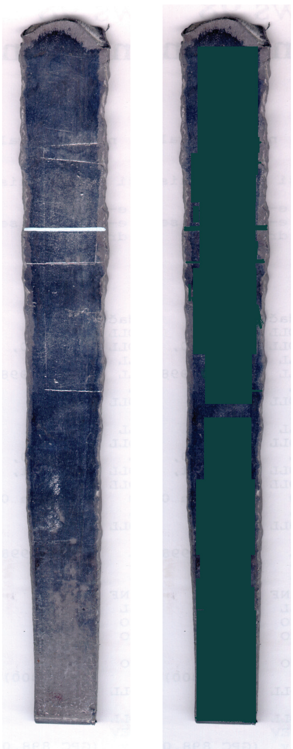

Fig. 1. Rolled out sample (right - retouched picture).

2. OBTAINING OF PICTURE OF THE ROLLED OUT SAMPLE AND ITS COMPUTER PROCESSING

Accuracy in obtaining of dimensions of the rolled out sample has decisive influence on accuracy of values computation which represent plastic features of the material, of which the sample is made. In general a mechanical deduction of dimensions in several cross-sections is made and the obtained values are averaged. However, the values obtained in such a way do not allow to acquire continuous values of the monitored parameters and are loaded with a statistical discrepancy. Computer techniques open new possibilities of acquiring precise dimensions of the samples with exploitation of picture analysis. There are several possibilities how to acquire a first-rate two-dimensional picture of the plan area projection of the rolled out sample that is crucial for its volume determination (Heger et al., 2003b).

Repeatability of measurements and accessibility of the suitable technique may be obtained by use of the scanner. While preserving the optimal differentiation ability in DPI, the acquiring of precise absolute values of picture dimensions is assured (see figure 1). In the process of rolling, the original sample is deformed and the edges of the sample are irregular with dome-shaped concavity. Also various forms of surface roughness (notches, cracks and so on) result in local changes of colour of the sample. These defects have to be retouched because they could have unfavourable consequences in the process of computer analysis of the picture. In figure 1 the picture of the rolled out sample is shown before (left) and after (right) picture hand retouching. After the picture is retouched, it can be analyzed and a set of values about the sample width along its length may be obtained. Now an additional program was created, which enables easy and quality retouching of the picture of the sample in such a way so that errors during transfer of the picture to dimensions of the sample could be minimized.

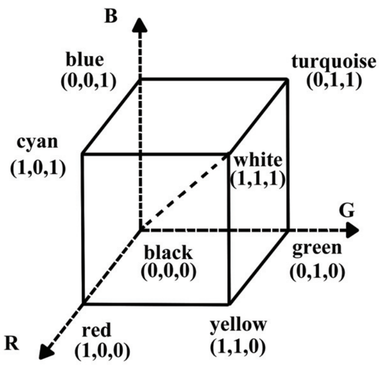

Fig. 2. RGB model.

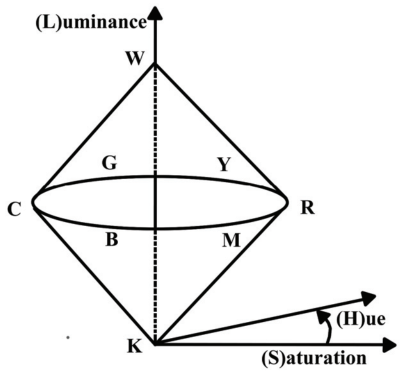

Fig. 3. HLS model.

The program will read the file of the required picture of the sample and will screen this picture. The corrector will make the brush wet in a place of the sample that corresponds with its colour to the corrected area. The correction itself is performed by drawing a circular correction mark with selected diameter in places of the picture which may be different in colour and where possible errors of transfer to dimension could occur. The retouched picture is stored in a new file and it is ready for computer processing of results of the wedge rolling test.

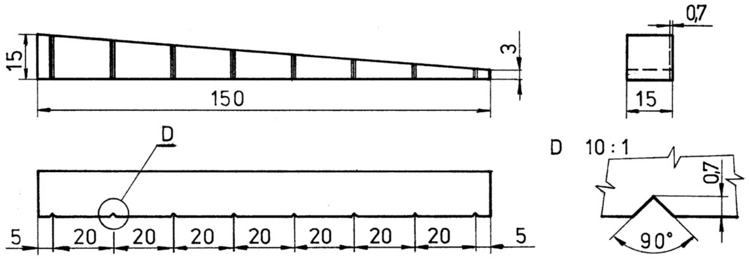

Fig. 4. Initial shape of a wedge-shaped sample (side wall and ground plan).

Every pixel of the picture is defined by ordered triad of colour components RGB (see figure 2). The RGB arrangement is suitable for colour displaying on the computer monitor, but for dimension analysis of the sample's pictures the RGB values have to be converted to an arrangement that is divided into three components which define Hue, Saturation and Luminance.

As the most suitable HLS arrangement was chosen, the basic expression of colour information of which is apparent in figure 3. By choosing an appropriate interval of single components of HLS arrangement (Žára et al, 1998), the monitored object can be "picked up" from the whole picture and converted to a contrast projection, where the sample has black and its surroundings white attributes of colours. The pre-processed picture can be now further compiled in order to acquire precise layout dimensions of the deformed sample. Dome-shaped concavity of the sample sides after rolling results in problems with definition of accurate width and length of the sample, respectively. In the process of dimensions determination by mechanical measurement (e.g. with a slide rule), the diameter between maximum (outer relief) and minimum (inception of dome-shaped concavity) value is usually taken. Computer analysis enables to increase the precision of this operation. Because of illuminating of the sample by the scanner, the dome-shaped concavities are distinguished by the change of the colour hue and luminance compared to the rest of the sample. By changing the parameters that define the dividing line between the sample and its surroundings and in agreement with the law of the volume preservation, the agreement between the known volume of the wedged sample (see figure 4) before rolling and computed volume of the rolled out sample can be reached; hence, the high precision of the width and length of the sample is assured.

3. COMPUTATION OF DEFORMATION FEATURES OF ROLLED MATERIAL

Knowing the geometry dimensions of the initial as well as rolled sample, the developed program is ready for computation of actual deformation features. Its intention is not only the improvement of computation but also maximum simplicity, comfort and automation for acquiring and computation of information about the rolled material.

When calculating equivalent strain, it is necessary to determine the real roll bite length l_d (see figure 5) in any place of the rolled sample and assign the selected cross section of the rolling stock to the relevant cross section of the input wedge-shape sample (by comparing the partial volumes of the sample before and after its forming). Equivalent strain e is calculated according to equation

$$e = \sqrt{\frac{2}{3}} \cdot \sqrt{e_h^2 + e_w^2 + e_l^2} \tag{1}$$

where strain in the height direction $e_h = \ln(h_s/h_x)$, strain in the width direction $e_w = \ln(b_s/b_x)$, and strain in the length direction is calculated according to the law of conservation of volume as $e_l = -e_h - e_w$. Equivalent strain rate é [s^{-1}] has been simply defined as

$$é = e \cdot \frac{v}{l_d} \tag{2}$$

where v [mm/s] is output velocity of the rolling stock.

Figure 6 shows an example of information obtained after the complex computer processing described above – data concerning shredding strain as well as strain rate along the hot rolled wedge-shaped sample made from the Cr-Ni-Cu-S free-cutting austenitic steel 17247CuS (temperature 1000°C). Before the test itself this steel was heat treated by annealing at 1200°C / 0.5 hours and water cooled (Rusz et al., 2006). Length of the wedge-shaped sample was 150 mm with eight notches (see figure 4). Evident cracks were observed starting from the notch No. 3, i.e. from ca 60 % of the height reduction of the sample. Research of steel formability is usually made at large interval of rolling temperatures. For presentation of posibility the new original software, which evaluated of wedge tests by procedures described in chapter 2 and 3, we selected only one specimen and their results.

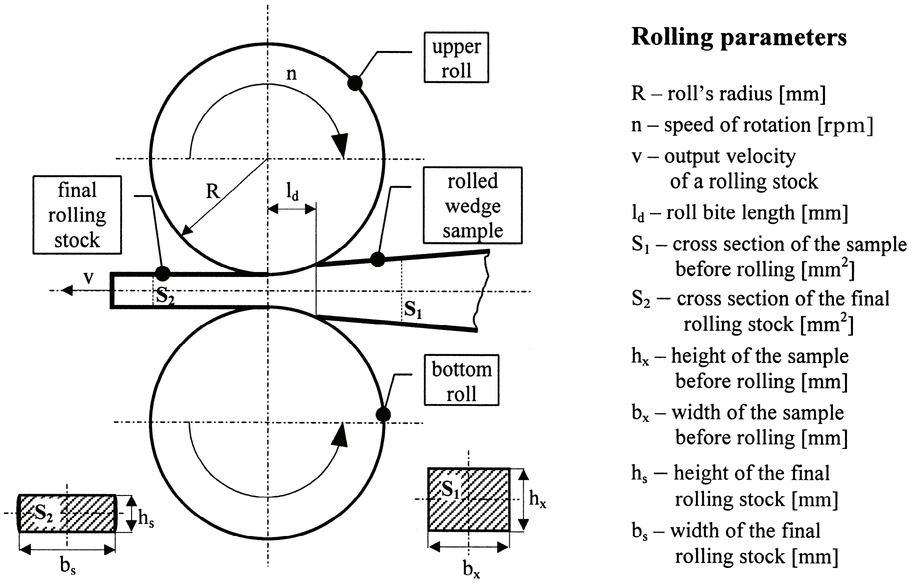

Fig. 5. Simplified schema of rolling of the wedge-shaped sample.

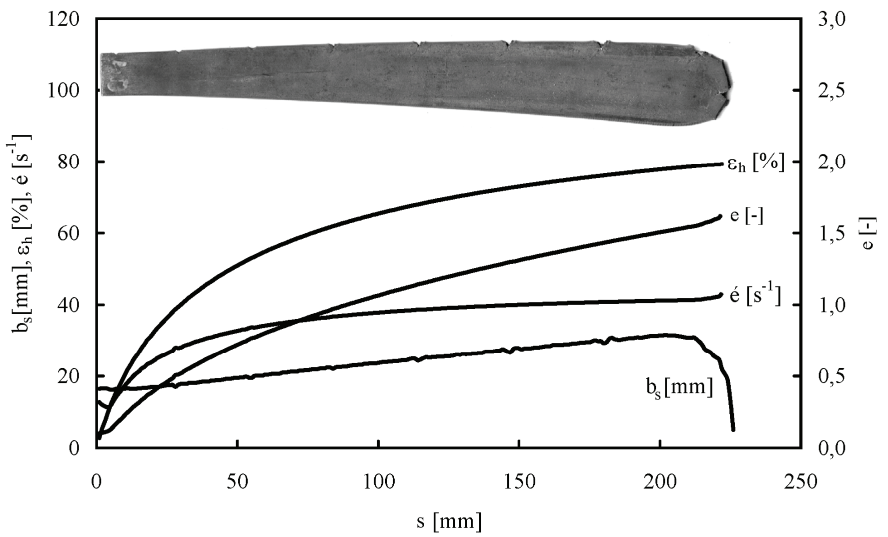

***Fig. 6.** Plan shape of the rolled out wedge and strain/speed relations along the rolling stock (steel 17247CuS, temperature 1000 °C).*

4. MATHEMATICAL SIMULATION OF ROLLING OF THE WEDGE-SHAPED SAMPLE

To add knowledge of deformation behaviour of tested materials a mathematical simulation by means of FEM was carried out on the basis of the program FORGE 2005 of the company Transvalor. For comparison with samples rolled on real conditions, simulations of rolling of wedge-shaped samples with notches were computed. A model for austenitic steel corresponding to steel grade 17247CuS was chosen from the material database, i.e. the same material that is used for exhibition of evaluation of the wedge rolling test in figure 6 (Schindler & Bořuta, 1995). It was most difficult to select an appropriate friction coefficient μ from boundary conditions; an optimum value seems to be $\mu = 0.4$. The initial conditions were defined according to actual conditions of rolling (roll diameter, geometry of the sample, rotational speed of rolls, roll temperature, wedge temperature).

An obvious contradiction results from the direct comparison of the obtained shapes. The result of mathematical simulation does not take into account springback of rolls, forming tools are here defined as rolls rotating around the axis that is in a constant position during computation. In real conditions this cannot be maintained due to clearances in bearings of rolls and rigidity of the rolling mill stand.

It is obvious from the obtained results that a lap in the top of the notch will arise at the entry of the formed material into rolls. Size and location of laps formed in this way may be seen in figure 7 by means of criterion of lap formation c_f. Criterion for folds detection is not specially described in manual for Forge (Forge, 2005), and is only remark that is related to overlapped triangles. In this figure also status of the end of the wedge-shaped sample with last three notches can be seen. These results are in accordance with observations of the surface of the rolled out wedge-shaped sample.

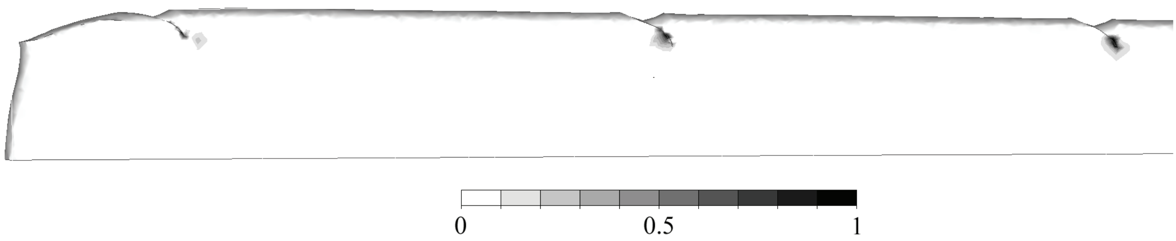

Fig. 7. *Results for criterion of lap formation c_f at simulation of rolling of wedge-shaped sample made from steel 17247CuS (heating temperature 1000°C).*

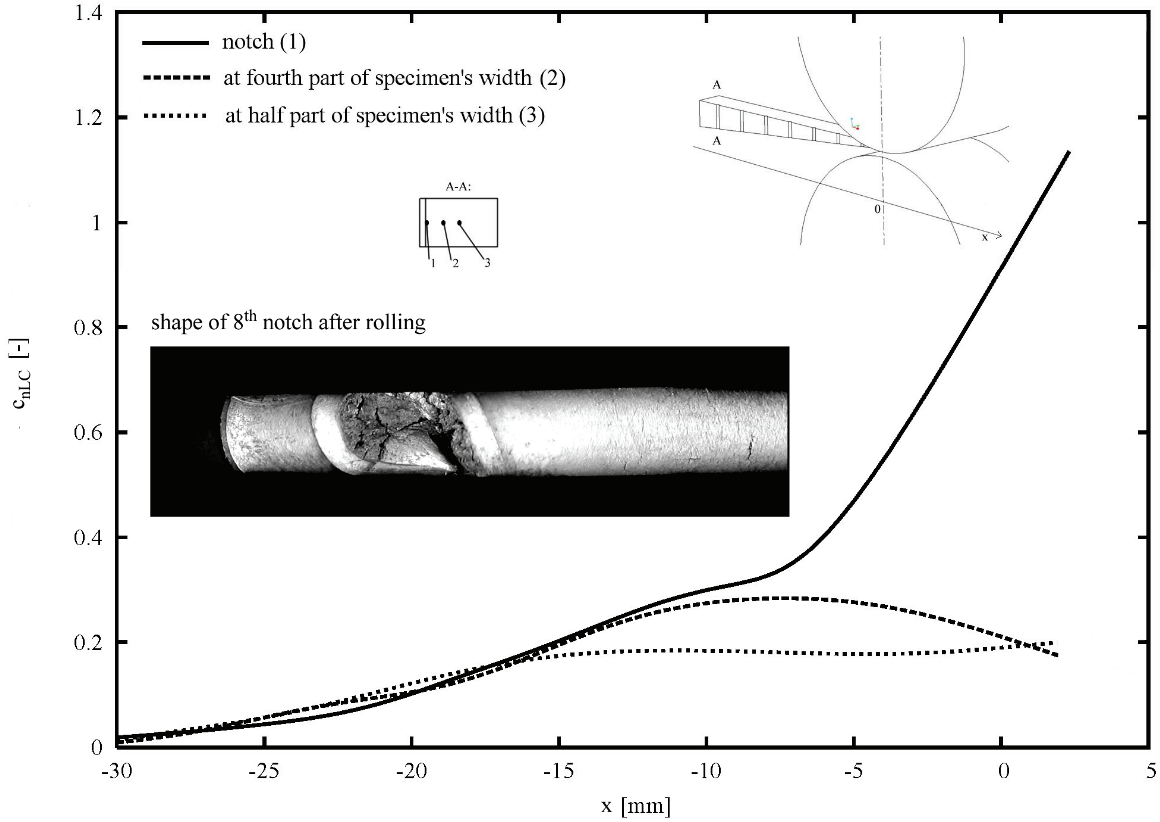

Fig. 8. *Course of the normalized Latham and Cockroft variable c_{nLC} at the level of last 8^{th} notch and specific places related to width of the sample from steel 17247CuS (heating temperature 1000°C).*

From viewpoint of stress state during forming itself we were interested in a distribution of stress in location of the notch. It was confirmed that in the notch location a formation of tensile stress occurs at lower deformation size than in case of tensile stress that occurs at the edge of the sample at the roll gap exit. The normalized Latham and Cockroft variable c_{nLC} was used for a more general expression. This criterion is defined as:

$$\frac{dc_{nLC}}{dt} = \frac{\sigma_1}{\sigma_{eq}} d\dot{\bar{\varepsilon}} \qquad (3)$$

where σ_1 is maximum principal stress [MPa]

σ_{eq} is equivalent stress [MPa]

$\dot{\bar{\varepsilon}}$ is strain rate [s^{-1}] (Forge, 2005)

In figure 8 one can see an approximately identical growth of this criterion for points in a half and in a fourth of width of the sample, at the level of the last notch when is moving through the roll bite. In the vicinity of the last notch a value of the normalized Latham and Cockroft variable increases above 0.45, which is considered to be an usual critical value for starting of crack formation in the material. This relationship is calculated again for steel 17247CuS and heating temperature 1000°C.

5. CONCLUSIONS

By exploitation of computer analysis of the rolled out material, the wedge test becomes very effective because assigning between particular corresponding cross sections of the wedge-shaped rolled out sample is very accurate, which allows to improve considerably even calculations of deformation parameters. Of course, for evaluation of the test the outlined procedure connected with picture evaluation of shape of the rolled out sample has to be followed. With only one sample it is possible to evaluate formability at the given temperature and to take the material necessary for metallographic observations with different, accurately defined, deformation parameters, as is show on selected example from steel 17247CuS.

In the case of materials with good formability it is possible to make the wedge test more sensitive by means of the V-shaped notch. Influence of these notches was investigated by means of FEM. Formation of laps on the surface of the material that is in contact with rolls was proved by calculation. This fact helped to differentiate laps from cracks that are formed at lateral sides of the rolled wedge-shaped samples with notches. By expression of the normalized Latham and Cockroft variable we confirmed correctness of the assumption of higher sensitivity of the material in the area of a notch to crack formation in rolling, which was also verified during laboratory tests.

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WSPOMAGANA KOMPUTEROWO ANALIZA PROCESU WALCOWANIA PRÓBEK KLINOWYCH

Streszczenie

Prosty test laboratoryjny walcowania próbek klinowych za pomocą walców płaskich umożliwia zbadanie procesu formowania struktury materiału oraz możliwości formowania metali. Płynięcie formowanego materiału indukuje naprężenia wywierane na powierzchnię próbki, które mogą skutkować pojawianiem się pęknięć. Matematyczne modelowanie procesu walcowania klinów jest skomplikowane ze względu na nieregularny kształt walcowanego wsadu. Dlatego też rozwijane oprogramowanie przedstawia uniwersalne narzędzie przetwarzania matematycznego dla wspomnianego testu, niezależnie od złożoności kształtu finalnego wyrobu. Aplikacja ta wykonuje również obliczenia dla próbek z wycięciami kształtu V. Wycięcia te funkcjonują jako miejsca inicjacji pęknięć, aby umożliwić lepsze porównanie właściwości plastycznych różnych materiałów metalicznych. Zachowanie materiału podczas formowania blisko wycięć jest przedmiotem analizy MES wykonanej przy użyciu programu Forge 2005. Przeprowadzona symulacja potwierdza zwiększony wpływ naprężeń rozciągających na formowanie pęknięć. Wiedza zgromadzona dzięki przeprowadzonym symulacjom została zweryfikowana z wynikami doświadczenia przemysłowego.

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