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THE ANALYSIS OF THE INFLUENCE OF VARYING TYPES OF SHAPE GROOVES ON THE BEHAVIOUR OF INTERNAL MATERIAL DISCONTINUITIES DURING ROLLING

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The article discusses problems related to the influence of rolling processes on the process of closing of internal discontinuities in continuous castings during rolling in two types of shape grooves. Numerical modelling of the process of rolling 160 x 160 mm continuous C45 steel billets using the Forge 2008® software program. Variations in deformed strip temperature, as well as in the shape of holes simulating material discontinuities were examined.

Key words: hot plastic working, continuous casting, discontinuity, defects, numerical simulation

INTRODUCTION

The primary objective of plastic working is to impart the appropriate shape to finished products, but also to assure their proper internal quality. Often, mill feedstock in the form of continuous castings has internal discontinuities that impair the mechanical and plastic properties of finished products. The removal of such metal defects is very hard to accomplish in a Shape Mill and should be done at the time of deformation in initial passes during plastic working. By varying the strip deformation conditions during grooved rolling, the effect of partial or even complete closure of internal material discontinuities can be achieved [1]. The research results reported in studies [1,2] indicate that the rate at which rolled strip discontinuities are closed or welded is determined by the shape and order of the grooves used. The closing of discontinuities is substantially influenced by the following factors: the location of the discontinuity in the feedstock, the duration of compressive stress action on the surfaces around the discontinuity, and the temperature of the strip being deformed. At higher strip rolling temperatures, the magnitude of the deformed material yield stress is relatively low, and the rate of diffusion of steel constituent elements between the surfaces surrounding the discontinuities increases, which facilitates their bonding [3]. Research has been conducted at the Institute for the Automation of Plastic Working Processes on the improvement of internal material quality through rolling in grooves of varying shape and thereby closing any internal material discontinuities. For example, preliminary rolling in so called slitting grooves is proposed to replace box groove rolling. Rolling of rectangular cross-section feedstock is effected in bent slitting grooves, and then in bending grooves. The shape of finished product of acceptance dimensions is imparted in the last pass. This process allows finished product to be obtained in smaller number of passes due to increased deformations applied in individual passes.

PURPOSE AND SCOPE OF THE STUDY

The feedstock for testing the bent slitting groove rolling process were 160 x 160 mm continuous cast billets of C45 steel, whose chemical composition conformed to the requirements of EN 10083 standard (Figure 1). The arrangement of holes simulating feedstock discontinuities is shown in Figure 1. In order to obtain 250 x 21 mm flat bar from this feedstock, a four-pass rolling process was designed (Figure 2), which included rolling in two slitting grooves (Figure 2a, a' and 2b, b') in one bending groove (Figure 2c) and in a finishing pass, where the shape was imparted to the finished strip (Figure 2d). These grooves were arranged in four rolling stands of a continuous rolling train. The tests were conducted for two technological variants differing in groove type. These groves are illustrated in Figure 2 (Variant I – Figure 2a,b,c,d and Variant II – Figure 2a',b',c,d). The tests were aimed at determining the effect of groove shapes in the first two passes on the closure of internal material discontinuities. For numerical computation, the Forge 2008® software program was employed. The selection of groove shapes was guided by their ability to close internal material discontinuities during rolling.

For the computer simulation of rolling flat bars on the continuous rolling mill, the following rolling conditions were assumed: feedstock temperature, 1 200 °C; roll tem-

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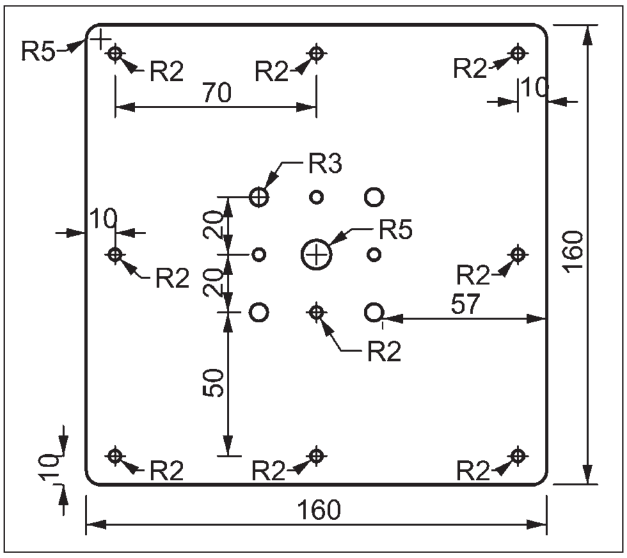

Figure 1 Arrangement of holes in the 160 x 160 mm sample examined

perature, 60 °C; ambient temperature, 20 °C; last stand rolling speed, 1,31 m/s; friction coefficient, μ = 0,45; friction factor, m = 0,85; coefficient of heat transfer between the material and the tool, α = 3000 W/Km^2; coefficient of heat transfer between the material and the air, α_{air} = 100 W/Km^2. For the computation of the yield stress, the values of the coefficients were taken from the material database of the Forge2008® program.

RESULTS AND DISCUSSION

From the performed numerical simulations, distributions of stress intensities (Figure 3) and strain intensities on the strip cross-section in the deformation zone, as well as temperature distributions in the strip after rolling in individual grooves were obtained.

The analysis of the strain intensity distribution in the strip in the roll gap was made in the study. The uneven stress distribution is caused primarily by geometrical factors (the shape of the feedstock and the groove), but also by the inhomogeneous chemical and structural composition of the rolled metal and the different external friction conditions [4,5].

Strip elements that first contact the rolls undergo the greatest deformations. The highest strain intensity areas lie immediately at the surface of strip contact with the rolls and in the top strip part. The lowest strain intensity areas occur in the lateral strip edge regions, where the strip moves freely. The largest deformations for Variant I amount to approx. 1,5 for the strip in the first groove; 1,65 in the second groove; 2,7 in the third groove; and 3,0 in the fourth groove. Whereas, for Variant II, they amount to approx. 2,7 for the strip in the first stand; 1,8 in the second stand; 2,6 in the third stand; and 3,0 in the fourth stand. While the lowest intensity of strains in the strip occurs in regions subjected to tension in the central and bottom parts of the sample, where a relatively small deformation is preset. For Variant I, the least strain for the strip in the first groove was approx. 0,06; in the second groove, 0,9; in the third groove, 2,0; in the fourth groove, 2,6. For Variant II, on the other hand, the least strain for the strip in the first stand was approx. 0,2; in the second

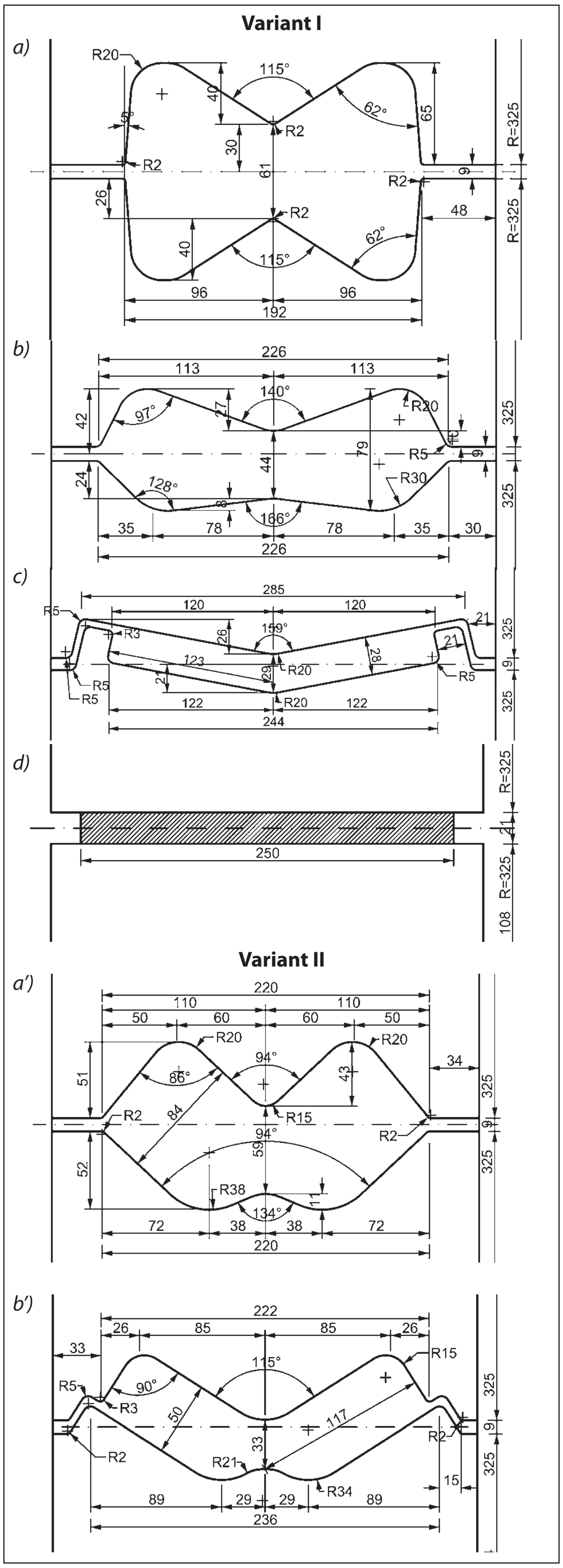

Figure 2 Grooves for rolling of 250 x 21 mm flat bar: a,a',b,b') slitting grooves; c) bending grooves; d) shaping grooves

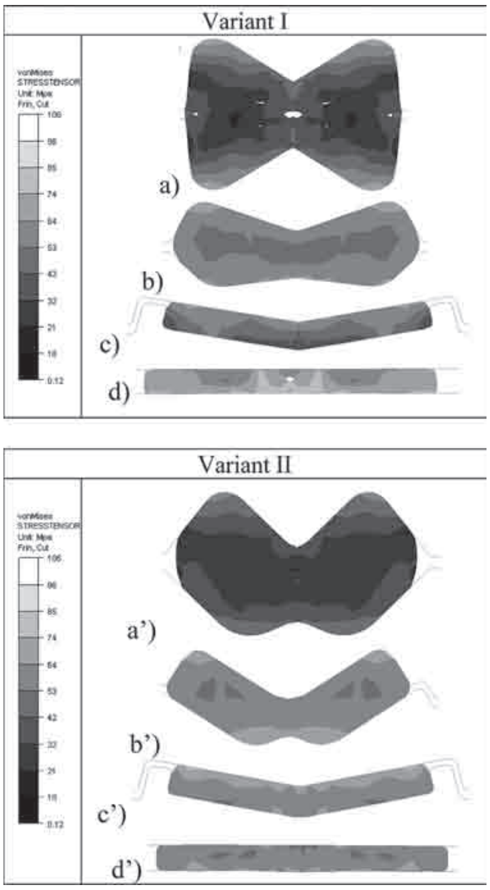

Figure 3 Distributions of stress intensities on the strip cross-sections during rolling in: a,a',b,b') slitting grooves; c,c') bending grooves; d,d') shaping grooves

stand, 1,3; in the third stand, 2,2; and in the fourth stand, 2,6. The uneven strain intensity distribution in the rolled strip formed due to the varying rolling reduction occurring on the strip width, which was caused by the shape of the grooves used. In contrast to Variant II, smaller deformations were preset in the first stands in Variant I, which resulted in a poorer closure of discontinuities. Strains decreased with increasing distance from the strip surface; the similar was true for the reduced stresses. As a result, in the zones deformed with a larger rolling reduction compressive stresses form, while in the strip parts deformed with a smaller rolling reduction, tensile stresses occur [4]. Consequently, the occurrence of larger compressive stresses resulted in better reuniting of discontinuities in the strip being deformed (Variant II).

The distributions of reduced stress intensities in strips during rolling were also compared (Figure 3).

The data in Figure 3 indicates that the highest stress intensity zones are located in the surface layers of strips being deformed and on their edges, whereas the lowest stress intensity zones, in the central strip part. In rolling according to Variant I, the highest stress intensity values in the strip being in the first stand amounted to about 75 MPa; in the second stand, 76 MPa; in the third stand, 93 MPa; and in the fourth stand, 88 MPa. Whereas, when rolling was conducted following to Variant II, the highest stress intensity values in the strip being in the first stand amounted to approx. 78 MPa; in the second stand, 78 MPa; in the third stand, 93 MPa; and in the fourth stand, 91 MPa. It was observed that what deformed in the first place was the metal layer being at some distance from the strip contact with the rolls, but also at a certain distance from the strip centre; therefore, discontinuities were found to close fastest in that particular location (Variant II). This deformed layer induces longitudinal and lateral tensile stresses in its neighbouring layers, which cause the deformation of the entire metal volume in the roll gap. Thus, discontinuities in the subsequent, i.e. middle and sub-surface, strip layers are reunited next [5,6].

Temperature distributions in the strip cross-section during rolling in individual grooves were also examined.

It was found that the highest temperatures occurred in the middle part of the strip, as well as in the free strip areas that do not contact with the rolls. In contrast, the lower strip temperatures were observed in locations where the strip contacts with the rolls. Overcooling of the material layer on the external sample surfaces had the effect of accelerating the closing of discontinuities occurring in the axial zone [6]. For Variant I, the average temperature of strip in the first grove is 1 155 °C; in the second groove, 1 130 °C; in the third groove, 1 124 °C; and in the fourth groove, 1 056 °C. Whereas, for Variant II, the average temperature of strip in the first groove is 1 165 °C; in the second groove, 1 135 °C; in the third groove, 1 030 °C; and in the fourth groove, 1 080 °C. The higher average temperatures of strip rolled according to Variant II resulted in better closing of discontinuities.

Figure 4 shows distributions of discontinuities on the strip cross-section during rolling in individual grooves.

It follows from Figure 4 that in rolling according to Variant I discontinuities are transferred as far as to the last stand, in contrast to rolling according to Variant II, where there are no discontinuities already in the third stand. It can be stated that the groove shape used in Variant II is much better in terms of closing of internal material discontinuities.

SUMMARY

The theoretical examinations carried out within this study found the following:

- The best closing reuniting of discontinuities occurred for holes situated in the side parts of the feedstock (in the both variants, already in the second pass). This was caused by relatively high stresses of approx. 78 MPa that occurred there. In rolling following to Variant I, discontinuities located in the middle strip part closed slower, because of the lower stresses occurring there (approx. 75 MPa in the first stand), compared to the strip rolled according to Variant II (approx. 78 MPa). The determined strain intensity values were greater in strips deformed following Variant II (ap-

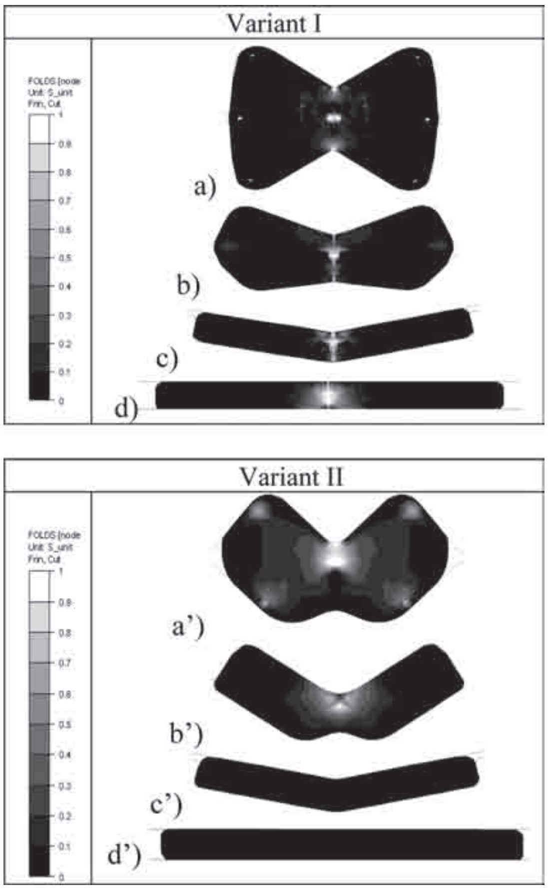

Figure 4 Distributions of discontinuities on the strip cross-sections after rolling in: a,a',b,b') slitting grooves; c,c') bending grooves; d,d') shaping grooves

prox. 2,7 in the first stand), as compared to strips rolled according to Variant I (approx. 1,5). The greater strains caused by the groove shape used resulted in an increase in the magnitudes of maximum stresses in the metal deformed following to Variant II, which contributed to the acceleration of the discontinuity closing process.

– The process of discontinuity closing is largely affected by deformed metal temperature and strip cooling rate in the rolling process. The higher rolled strip temperature, the better internal discontinuities are welded. As a result of strip overcooling in surface regions, the yield stress value increases there (the surface becomes less plastic). This results in an increase in strains within the sample and, as a consequence, an accelerated process of closing of discontinuities is observed in those regions.

– The groove shape used for rolling flat bars following to Variant II caused better closing of internal material discontinuities compared to the shapes made according to Variant I.

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Note: The responsible translator for English language is Czesław Grochowina, Poland