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ISSN 0543-5846
METABK 53(4) 501-504 (2014)
UDC – UDK 621.771:669.14.620.19=111

THE INFLUENCE OF THE SHAPE OF GROOVES ON THE BEHAVIOR OF INTERNAL MATERIAL DISCONTINUITIES IN CONTINUOUS S355J2G3 STEEL STRANDS DURING ROLLING

Received – Prispjelo: 2013-12-31
Accepted – Prihvaćeno: 2014-04-30
Original Scientific Paper – Izvorni znanstveni rad

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 shape grooves. Numerical modelling of the process of rolling 160 × 160 mm continuous S355J2G3 steel strands was carried out using the Forge 2008® software program. The experimental studies were conducted in a D150 laboratory rolling mill. Holes simulating material discontinuities were examined. In numerical and experimental studies, in steel samples after rolling in the third rolling stand, the defects were closing in 100 % on average. It was stated that the speed of closing of material discontinuities in feedstock is strongly influenced by the shape of the rolling groove.

Key words: rolling, continuous casting, defects, discontinuity, numerical simulation

INTRODUCTION

The issues related to material discontinuities closure and welding in plastically deformed material were the subject of many studies conducted in the Institute of Metal Forming and Safety Engineering at Czestochowa University of Technology [1]. On the basis of these studies, it was confirmed that the intensity of closure and welding of discontinuities in a rolled strand is influenced by the shape and order of the rolling grooves, as well as the temperature of the deformed strand and the location of the defect [2÷7]. At higher strand 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 [7]. 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 shaping grooves is proposed to replace box groove rolling. 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 study analyses the influence of the shape of initial shaping grooves on closure of defects. Numerical and experimental studies of rolling process of flat bars for feedstock with material discontinuities simulating internal defects were conducted. For the sake of comparison, rolling in a traditional system was analysed as well. Calibration was designed in a way that allows maintaining the same final measurements for both processes. The numerical simulations were carried out using the Forge 2008® software programme. The experimental studies were conducted in a D150 laboratory rolling mill. A rolling process of 200 × 20 mm flat bars from a 160 × 160 mm feedstock in eight rolling passes was designed, using shaping grooves, while in case of traditional rolling, there were 14 passes. In the new calibration, only two edge grooves were used, whereas in the traditional rolling there were five of them. In the new calibration, the first edge groove was applied only in the fifth pass, because introducing edge grooves in the initial stage of the rolling process can lead to re-opening a freshly welded defect [6]. In the research, the S355J2G3 structural steel was used. The steal was heated up to 1 150 °C. The temperature, deformation and stress distributions in a cross-section of a strand located in the consecutive shaping grooves were analysed. Surface areas of the defects after rolling were examined. Figure 1 presents the first three shaping grooves designed for rolling flat bars.

Feedstock with defects simulating internal and subsurface bubbles was designed. Figure 2 presents an actual ingot with internal discontinuities (Figure 2a), a designed sample (Figure 2b), a steel sample (Figure 2c) prepared for experimental studies.

RESULTS AND DISCUSSION

Temperature distributions during rolling in a cross-section of a strand in shaping and traditional grooves (Figure 3) were analysed.

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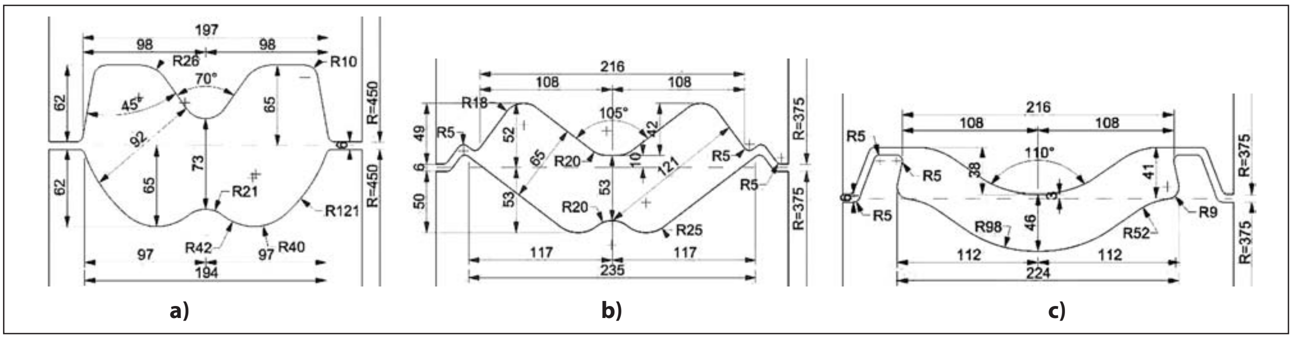

Figure 1 New grooves for rolling of 200 × 20 mm flat bars: a) slitting grooves; b, c) bending grooves

On account of the shape of the first three shaping grooves, high temperature (about 1 170 ° C) in the central part of the strand is maintained longer, and because of that better closure of internal material discontinuities occurred there, compared to rolling in traditional grooves.

Distribution of the intensity of deformation ε_i and stress σ_i was analysed, and the analysis indicated that the values increased during rolling in shaping grooves, due to the shape of the grooves. Consequently, it caused better closure of the discontinuities, compared to traditional rolling.

Then, distribution of average stress σ_m during rolling of flat bas in shaping grooves was analysed (Figure 4).

High values of average stress σ_m (about 70 MPa) in the places where the defects occurred, allowed closing them already in the first pass. While average stress σ_m of about -40 MPa in the specific zone made welding the void occurring there more difficult. In order to level discontinuities located in the central part of the feedstock, high average stress must be forced there, which is difficult to obtain during rolling in traditional grooves. Using shaping grooves made it possible.

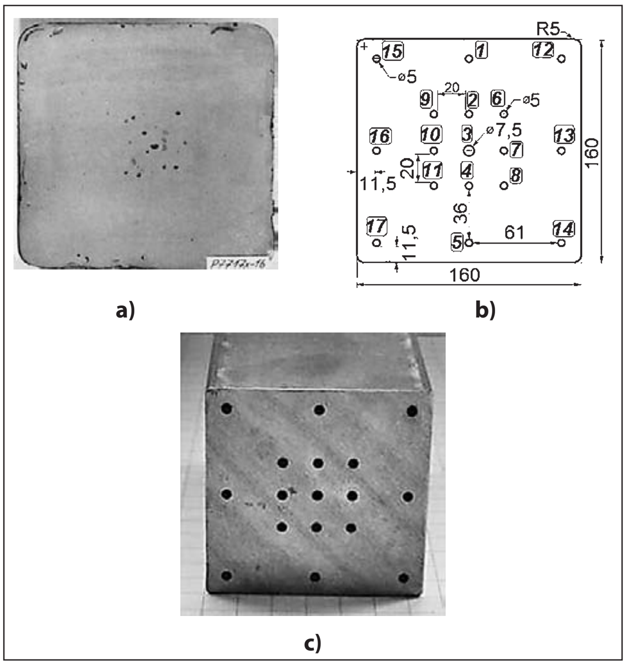

Figure 2 An image of a sample with placed defects simulating internal and subsurface bubbles: a) actual defects; b) designed defects; c) steel sample

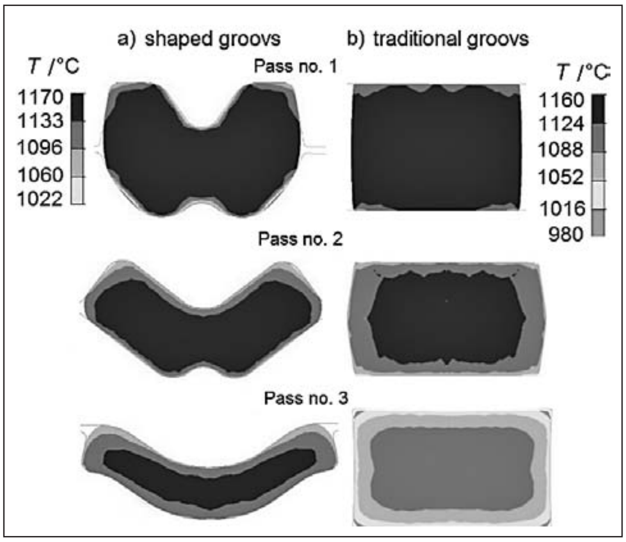

Figure 3 Temperature distributions in cross-sections of strands during rolling in three shaping (a) and traditional grooves (b)

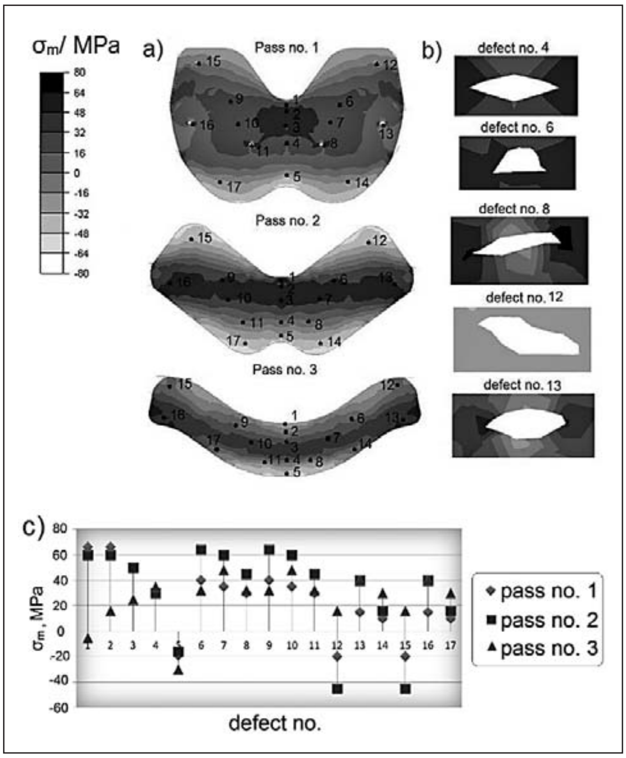

Figure 4 Average stress σ_m distribution: a) in cross-sections of rolled strands in three shaping grooves; b) around discontinuities; c) σ_m change where particular defects were located

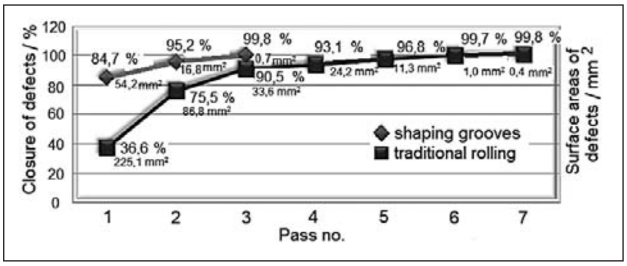

Figure 5 Relative changes in surface areas of defects in strand during rolling in shaping and traditional grooves

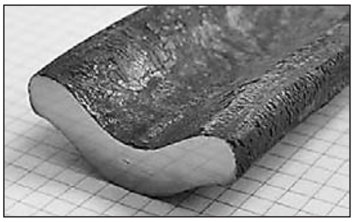

Figure 6 The view strands after rolling in a steel sample after the third groove

The next stage of the study was measuring surface areas of the discontinuities during numerical simulations. Figure 5 presents relative changes in the surface areas of the defects in strand during rolling in shaping and traditional grooves.

During rolling in shaping grooves, complete closure of discontinuities occurred already in the third rolling cage, while in case of traditional rolling no sooner than in the seventh pass. In shaping grooves, the defects in the first groove closed in 84 %, 95 % in the second

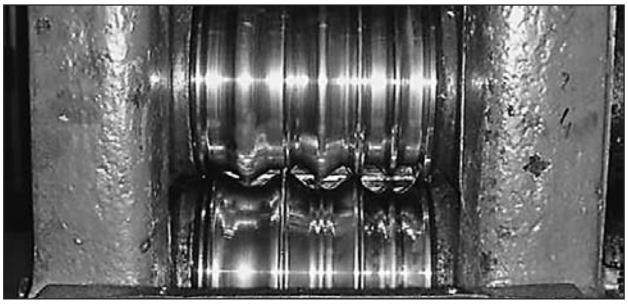

Figure 7 A Ø150 mm laboratory rolling mill with grooves placed on the barrel

groove, 100 % in the third one. In case of a traditional system, the defects in the first groove were closed on average only in 36 %, 75 % in the second groove, 90 % in the third one, 93 % in the fourth, 96 % in the fifth, 99 % in the sixth, and 100 % in the seventh. In shaping grooves, the defects in the central part were closing in 93 % in the first pass, and only in 34 % in traditional grooves. In shaping grooves, the defects were closed in 100 % in the second pass, while in case of a traditional system they were carried over even till the fifth pass.

During experimental studies, rolling of steel samples (Figure 6) with discontinuities was conducted in a D150 mm rolling mill with the designed grooves (Figure 7).

During studying steel samples, an optical microscope - Nikon Eclipse MA-200 - was used for observation. Figure 8 presents examples of traces of discontinuities located in samples after rolling, magnified about 200 ×. Then, there was an analysis of relative change of

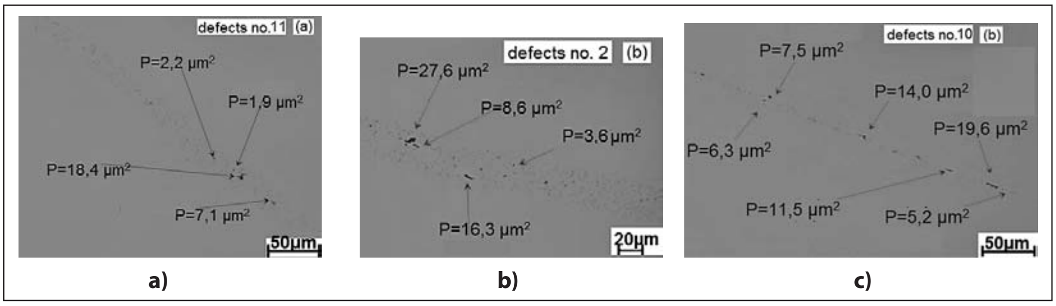

Figure 8 Residue of defects and surface areas of components of the defects in a sample after rolling in the 3rd groove; a) unprotected samples (a), b, c) protected samples (b)

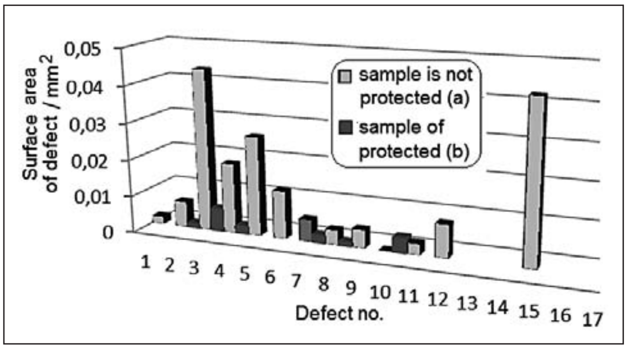

Figure 9 Surface areas of defects in particular batches with discontinuities after rolling in the 3rd groove, for protected (b) and unprotected (a) samples

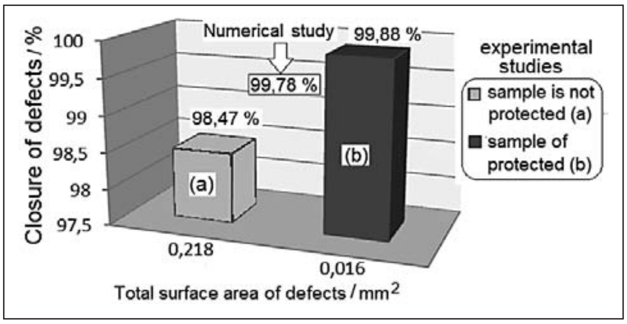

Figure 10 Relative change of total surface areas of defects in particular batches with discontinuities after rolling in the 3rd groove, for protected (b) and unprotected (a) samples, during experimental and numerical studies

total surface areas of the defects in particular batches with discontinuities after rolling in the third groove, for protected (b) and unprotected (a) samples (Figure 9 and Figure 10).

In the protected samples (b) no traces of the defects number 1, 5, 6, 9, 11, 17 were found, while in the unprotected samples (a) the defects number 13, 14, 16, 17 were not observed. After rolling in the 3rd groove, the sum of surface areas of discontinuities amounted to 0,218 mm^2 in the unprotected samples (a), and only 0,016 mm^2 in the protected samples (b).

On average, most of the defects were closed in 99,89 % in protected samples (b), while in samples exposed to oxidation of surface (a) the defects were closed in 98,47 %.

Residue of discontinuities that were left in a strand are only traces of closed defects, and most of them can be considered closed, because their appearance does not indicate further opening. On average, the difference in closure of the discontinuities, compared to numerical studies, equals only about 0,1 % for experimental studies on steel.

SUMMARY

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

- Closure of material discontinuities is mostly influenced by: the shape of a rolling gap, temperature of a rolled strand, speed of deformation and location of the discontinuities in feedstock. The shape of grooves enables almost 100 % closure of discontinuities located in the axis area of feedstock.
- Discontinuities occurring in feedstock as a result of rolling in a traditional system were being carried over even till the seventh pass, while during rolling in shaping grooves the discontinuities were closing already in the third groove.
- Thanks to introduction of forced widening, the shape of the three designed grooves has influenced the speed of closing internal material discontinuities and effective closure of defects in 99 %, on average (after the third groove).
- During rolling in shaping grooves the number of passes was reduced from 14 to 8, the productivity of the rolling mill was increased by reducing the duration of rolling.
- A smaller number of edge grooves was used during rolling in shaping grooves, and introducing them in the initial stage of the process can lead to opening a freshly welded defect. The first edge groove was used only in the fifth pass.
- The process of rolling in shaping grooves, which enables to close internal material discontinuities, can be used in industry, since it was designed specially for rolling 200 × 20 mm flat bars from 160 × 160 mm continuous ingots, that are being produced right now.
- A process of that kind will allow recycling of products meant for remelting, due to air bubbles inside the feedstock.

REFERENCES

[1] Dyja H., Sobczak K., Kawałek A., Knapiński M.: The analysis of the influence of varying types of shape grooves on the behaviour of internal material discontinuities during rolling. Metalurgija 52 (2013), 1, 35-38.
[2] Mamuzić I., Longauerova M., Ŝtrkalj A.: The Analysis Of Defects On Continuous Cast Billets. Metalurgija 44 (2005), 3, 201-207.
[3] Jovanović M., Kosec L., Zorc B.: Examination of weld defects by computed tomography. Metalurgija 51 (2012), 2, 233-236.
[4] Gojić M.: Current State and Development of Steelmaking processes. Metalurgija 43 (2004), 3,163-168.
[5] Skuza Z., Prusak R., Budzik R.: Contemporary elements of system of quality management in metallurgical enterprises. Metalurgija 50 (2011), 2, 137-140.
[6] Woźniak D.: Wpływ kształtu wykroju na stany naprężenia i odkształcenia w kotlinie walcowniczej oraz na intensywność zamykania osiowych nieciągłości materiałowych w układzie owal – kwadrat. The Institute for Ferrous Metallurgy in Gliwice, Rolling Engineering (2005), 82-90.
[7] Wang A., Thompson P. F., Hodgson P. D.: A study of Pore Closure and Welding in Hot Rolling Process, In: Proc. Metal Forming'96, eds, Pietrzyk M., Kusiak J., Hartley P., Pilinger I., Mat. Proc. Techn., Kraków 60 (1996), 95-102.

Note: The person responsible for the English translation is M. Sobczak, Czestochowa, Poland.