MULTISTAGE COMPRESSION MODELLING DURING HOT ROLLING OF STEEL PRODUCTS

DZIEDZIC Michał, TURCZYN Stanisław, KUŹMIŃSKI Zbigniew

AGH University of Science and Technology, Cracow, Poland, EU
dziedzic@agh.edu.pl, turczyn@metal.agh.edu.pl, kuzminsk@metal.agh.edu.pl

Abstract

The paper presents application of multistage compression test for modelling of hot rolling of various steel products. To carry out these experiments multifunctional deformation simulators Gleeble of different types have been used. Results of this work show that the flow stress data can be obtained for high strain values, much higher than can be acquired in torsional tests. Thus, conditions of Gleeble tests are more close to industrial condition and data (flow stresses) obtained from Gleeble simulation are more realistic. Apart from that, the compression tests realized in the investigation aimed at identification of grain size evolution and hardening or softening behaviour as function of temperature, strain, strain rate and idle time between deformations. Physical modelling using multistage compression tests provides basics for the analysing and designing of hot rolling processes of various products and allows to learn more about metal properties in deformation conditions.

Keywords: Gleeble simulator, thermo-mechanical rolling, hot workability, DP and MS steels, RB500W steel

1. INTRODUCTION

Physical modelling of the deformations proceeded in the rolling processes very often uses Gleeble simulators, where single stage or multistage compression tests are realized [1, 2, 3]. The main advantage of these tests is that the flow stress data can be obtained for high temperatures and high strain values, much higher than can be acquired in torsional tests. Thus, parameters of Gleeble tests are more close to industrial condition and data (flow stresses) obtained from Gleeble simulators are more realistic.

The paper presents application of multistage compression test for modelling of hot rolling of different steel products, which belong to the group of long and flat products. It was primary applied to simulate rolling of ribbed bars in slitting passes from steel having high value of yield stress, RB500W. Next two tests were used to model rolling of flat products in finishing stands from multiphase steel, namely dual phase (DP) and martensitic steel (MS) [3, 4, 5]. The test parameters, i.e. temperature of deformed metal, strain, strain rate and idle time between passes were selected to represent as precisely as possible the rolling condition occurring in real processes. Furthermore, obtained data of deformed metal have been applied in the other investigations, namely computer modelling of hot rolling using FEM. Apart from that, the multistage compression tests realized in the investigation aimed at identification of grain size evolution and hardening/softening behaviour as function of deformation parameters, namely temperature, strain, strain rate and idle time between deformations.

2. TESTED MATERIALS

For whole experimental investigations three steel grades have been chosen, namely Dual Phase (DP), Martensitic Steel (MS) and RB500W steel. The chemical composition of these steels is presented in **Table 1**. The own casts of DP and MS steels have been made, from which the samples for laboratory tests were prepared. The melts of the tested steels DP and MS having the weight of approximately 100 kg were performed in the vacuum induction furnace. The chemical composition of investigated steels has been optimized before casting in the aim of obtaining an optimal fraction of multiphase microstructure under conditions of hot rolling and multistage cooling.

Table 1 Chemical composition of investigated steels, mass fraction

Steel grade	C	Mn	Si	P	S	Cr	Ni	Mo	Ti	Nb	Al.
Dual Phase	0.10	1.49	0.52	0.01	0.009	0.04	0.02	0.01	-	-	0.06
Martensitic Steel	0.10	1.02	0.67	0.01	0.007	0.68	0.01	0.01	0.06	0.06	-
RB500W	0.22	1.60	0.60	0.05	0.05	-	-	-	-	-	-

The rough hot deformation was performed using open die forging operations and the hydraulic press. The ingots were reheated for forging in a gas furnace. Forging temperature ranged from 1200 °C to 900 °C with reheating between operations so that the materials were not cooled down below temperature 900 °C. Successively, the ingots were hot forged into flat bars of 160 mm in with and 60 in thickness, from which the specimens for experimental experiments were machined. Steel plant is acknowledged for providing the raw material of RB500W steel for testing. This steel is commonly used for thermo-mechanical rolling of ribbed bars.

3. SINGLE AND MULTISTAGE COMPRESSION TESTS OF RB500W STEEL

The modern technology of ribbed bar rolling in many cases is based on the application of single or multiple longitudinal slitting, so-called Slit Rolling (SR) [6, 7]. The essence of this method is the application of two or three consecutive cutting-in passes in the final stage of rolling process, **Figure 1**. In this passes the metal is subjected to deformations considerably differing from those occurring in conventional stretching or shaping passes. Furthermore, the metal is deformed in high temperature with application of high values of strain and strain rate. Hence, the process of deformation in slitting passes was carefully analysed applying Gleeble simulator, where the deformations parameters were close to the rolling condition occurring in real processes.

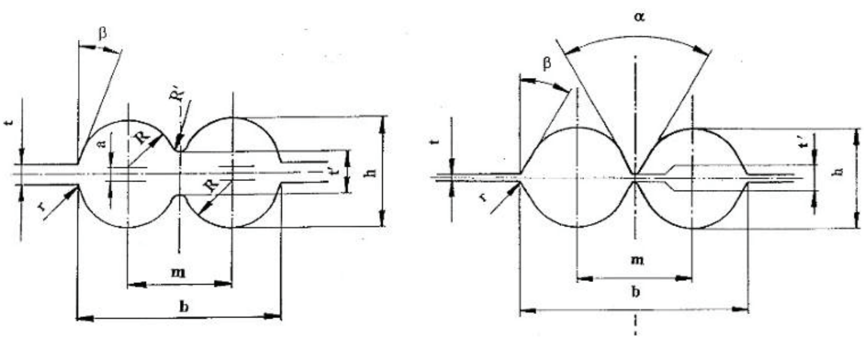


Figure 1 The design of slitting grooves

Set of specimens from RB500W steel have been made for single and multi-stage compression tests, which were performed on the simulator of the metallurgical processes DSI Gleeble 3800 being the equipment of the Institute of Ferrous Metallurgy in Gliwice. The simulator was equipped with a hydraulic mechanical system, which enables to apply pressure of 200 kN during pressing and to make tests with strain rate within the range from 0.0001 to 200 s^{-1}. Linear variable differential transformers and tensiometric sensors for pressure measurement were produced feedback securing the exact execution and repeatability of the mechanical values of the defined deformation process. Very thin graphite and tantalum foils have been inserted between the specimen surface and the die in order to reduce friction, and a nickel-based lubricant was applied onto the both surfaces. The stress - strain curves have been obtained using high temperature compression tests in the temperature of 1050 ºC and 1100 ºC with strain rate 50 s^{-1}, 100 s^{-1} and 150 s^{-1}. The example results of these test are presented on **Figure 2**.

Figure 2 show the flow stress vs. true strain curves obtained for three values of strain rates for steel RB500W. The similar shape of stress-strain curves suggests, the testing temperature does not have dramatic effect on the overall strain hardening behavior of RB500W steel, although all flow stress values are increasing with temperature decreasing, **Figure 2**. Decreasing of the temperature by around 50 °C results in increasing of flow stress by around 25 MPa.

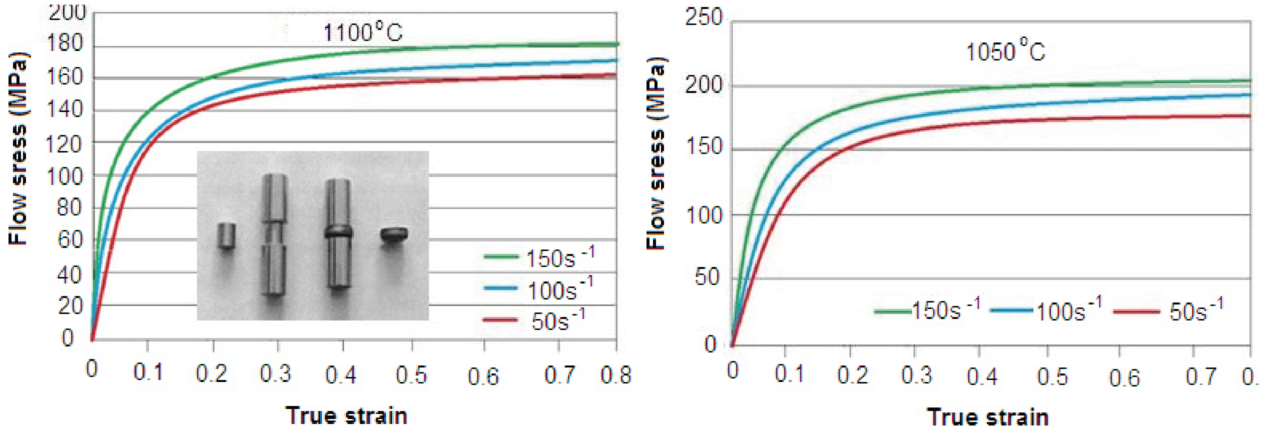


Figure 2 Flow stresses for RB500W steel obtained from compression tests with high strain rates and the temperature 1100 °C (left) and 1050 °C (right)

Physical modelling of the process of deformation in both slitting passes (dog bone and slit pass) was realized with multistage compression test using Gleeble 3800 simulator. The test parameters, i.e. temperature of deformed samples, strain, strain rate and idle time between deformations were selected to reflect the rolling conditions occurring in industrial process as precisely as possible. The obtained results of these tests are presented on **Figure 3**. Application of true strain equal to 0.6 and 0.25 in two multi-compression steps create possibility of the course of dynamic recovery. The values of yield stress obtained in two-stage test are comparable with values obtained in single compression tests, **Figure 2**.

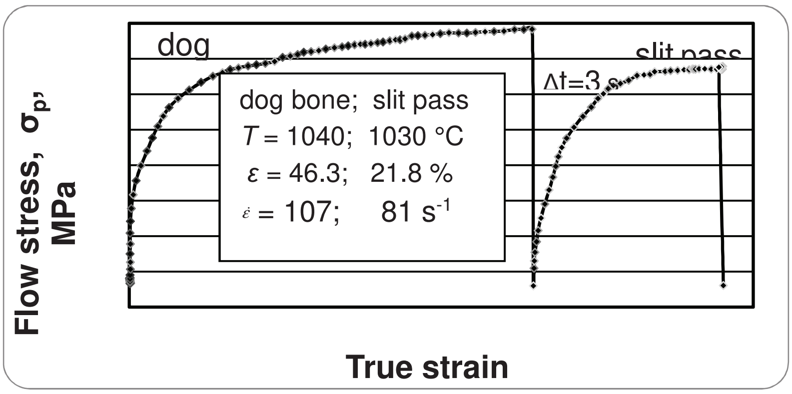


Figure 3 Physical modelling of bar rolling in slitting passes using Gleeble 3800 simulator

4. MULTISTAGE COMPRESSION TESTS OF STRIP ROLLING FROM DP STEEL

Dual Phase (DP) steel with multiphase microstructure belong to the modern steel group called Advanced High Strength Steels (AHSS) and due to their properties are used very often in the automotive industry [8]. The microstructure of DP steels contains soft ferritic matrix, in which 20-70 % of martensite is distributed [1, 9]. To design thermo-mechanical rolling of DP steel a knowledge of their hot workability and multistage cooling rate is of primary importance.

Multistage compression of the process of hot rolling in the six final stands, as in industrial process, was realized for DP steel with application of Gleeble 3800 simulator. The samples have been compressed under conditions close to the plane state of strain. Ni-based lubricant was used in order to decrease the friction between the surfaces of the deformed sample and the die. Thermomechanical processing was started from steel austenitizing temperature equal to 1150 °C. The samples were subjected to six steps of processing, for which the finishing temperature of hot deformation was equal to 830 °C, **Figure 4**. The cooling conditions to the ambient temperature after the last deformation were designed on the basis of CCT diagram for DP steel [1].

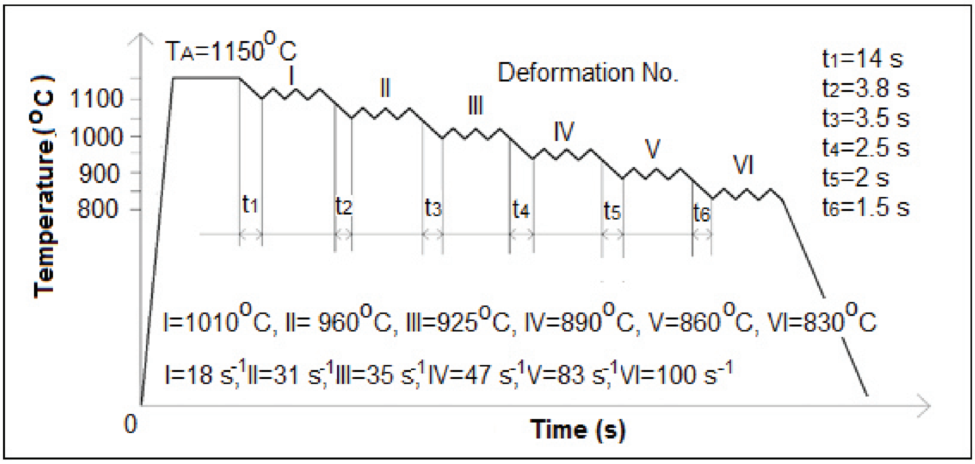


Figure 4 Scheme of thermo-mechanical processing of DP steel using a Gleeble 3800

The individual thermo-mechanical processing differs with strain, strain rates, temperatures and cooling method after the last stage of deformation. The specimen tested in this test was cooled in water spray. The stress-strain curves of the examined DP type are illustrated in **Figure 5**. During multistage compression of DP steel samples the stress values increase significantly with decreasing deformation temperature. The idle time between the passes seem to be to short in order the static recrystallization causes rebuilding of deformed structure. The highest level of stress occurs for deformation in last stages, where temperature is close to 830 °C and the strain rate attains the highest value, **Figure 5**. Presented results can give as well the important information about the force parameters, which can appear during rolling of DP steel in the finishing stands of hot strip mill.

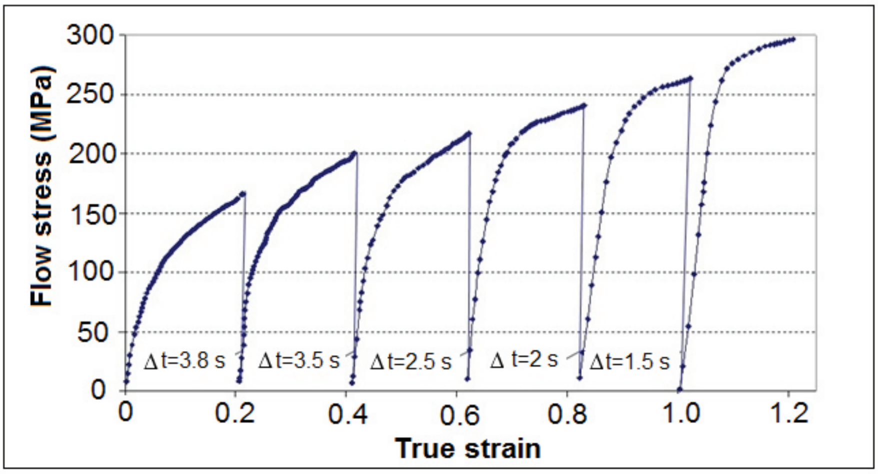
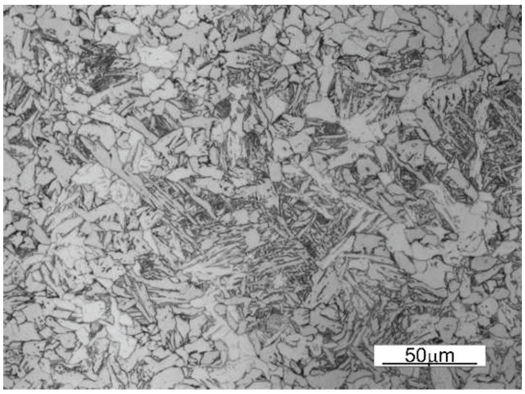


Figure 5 Modelling of strip rolling from DP steel in finishing stands (true strains: 4 x 0.21 and 2 x 0.18)

Metallographic examinations after thermo-mechanical processing of DP steel were made by application of Axiovert 200 Matt Zeiss (multiplication 950 x). **Figure 6** presents the results of these examination after cooling to the ambient temperature. Particularly, in a case of analysed DP steel it was found that cooling at the rate of about 20 °C/s leads rather to the ferritic-bainitic microstructure than to ferritic-martensitic. The phase composition shows very good agreement to the results obtained from dilatometric tests [1]. The Vickers hardness at a load 30 kg was measured on all samples by Vickers equipment type HPO 250. For this variant of the multistage compression test the value of hardness HV reaches 174 HV.



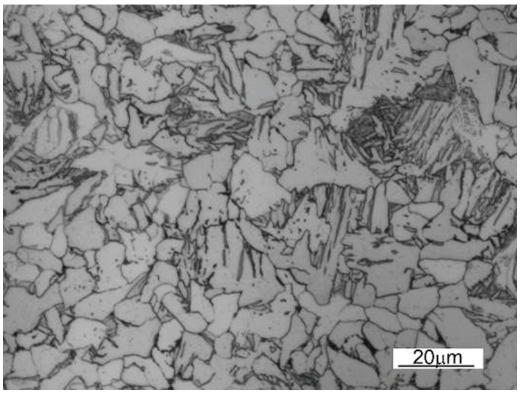


Figure 6 The microstructure of DP steel: multistage compression test - deformations 4 x 0.21 + 2 x 0.18, final temperature 830 °C, cooling to the ambient temperature with the rate 20 °C/s

5. MODELLING OF ROUGHING AND FINAL STRIP ROLLING FROM MARTENSITIC STEEL

Thermo-mechanical processing was carried out using multi-functional Gleeble HDS-V40 simulator, being the equipment of the Institute of Metal Forming at Technical University Freiberg. The samples were subjected to six steps of processing, from which initial three deformations are simulating roughing rolling and next three ones - finishing rolling of strips from martensitic steel (MS). The idle time between them was assumed at 60 s. Ni-based lubricant was used in order to decrease the friction between the surface of the deformed sample and the die. The samples have been compressed under conditions close to the plane state of strain. The finishing temperature of hot deformation was equal to 910 °C and the cooling conditions to the ambient temperature were designed basing on the basis of CCT curves for this steel [3]. As the result of the six-step deformation at the temperature range from 1125 °C to 910 °C the stress-strain curves have been obtained and are presented in **Figure 7**.

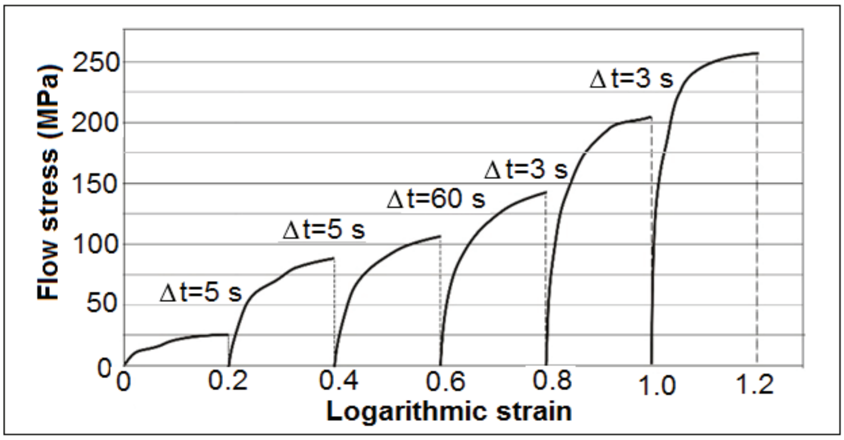


Figure 7 Changes of stress as a function of strain for successive deformation stages within temperature range from 1125 °C (first roughing pass) to 910 °C (last finishing pass), true strains: 6 x 0.20

The stress values increase significantly with increasing of strain rate and decreasing deformation temperature. The highest growth of stress occurs for deformation temperature at 910 °C, what is caused by existing the highest strain rate of around 10 s^{-1}.

6. CONCLUSIONS

The results of investigations presented in the paper provide useful information for the designing of hot rolling of bars and strips from different types of steel. The obtained results also allow for formulating the more general conclusions:

1) The Gleeble simulators are convenient and very often used sophisticated equipment for physical modelling of the deformations proceeded in the single or multi pass rolling. Among from them, thermo-mechanical rolling conditions are very often applied for materials testing.
2) A proper selection of thermo-mechanical rolling conditions, e.g. correct passes schedule, the rolling temperature range as well cooling rates after last pass, allows to manufacture products (strips, bars) with proper microstructures and to obtain the required final properties.
3) The conditions of single or multistage compression tests (temperature, strain rate) are more close to industrial conditions of modern rolling processes and data obtained from Gleeble simulation (e. g. flow stresses, microstructure) are more realistic.
4) Tested steels in this work used for various steel products are characterized by relatively high values of flow stress, varying between 170 and 300 MPa.

ACKNOWLEDGEMENTS

Financial assistance of Polish Ministry of Science and Higher Education (AGH Project No. 11.11.110.292) is acknowledged.
Special acknowledgment for Institute of Metal Forming at Technische Universität Bergakademie Freiberg and Institute of Ferrous Metallurgy in Gliwice for support and using Gleeble simulators

REFERENCES

[1] DZIEDZIC M., TURCZYN S. Experimental and Numerical Investigation of Strip Rolling from Dual Phase Steel. *Archives of Civil and Mechanical Engineering*, 2010, Vol. 10, pp. 21-30.

[2] KUZIAK R., KAWALLA R., WASNGLER S. Advanced High Strength Steel for Automotive Industry, *Archives of Civil and Mechanical Engineering*, 2008, Vol. 8, pp.103-117.

[3] DZIEDZIC M., TURCZYN S., KUŹMIŃSKI Z. Material Aspects of Hot Rolling and Cooling for Strips from Martensitic Steel. *Materials Science Forum*, Vol. 854, pp. 35-41, doi: 10.4028/www.scientific.net/MSF.854.35.

[4] ADAMCZYK J., GRAJCAR A. Blachy stalowe o strukturze wielofazowej dla przemysłu samochodowego. *Hutnik-Wiadomości Hutnicze,* 2005, Vol. 72, pp. 170-176.

[5] REICHERT B., FREIER K. Stahlwerkstoffe für den modernen Leichtbau. In *MEFORM 2003*, Freiberg, 2003, pp. 104-118.

[6] NICOLL R.: Four-Times Slit-Rolling in One Step at BSW. *Steel Times Int.*, 1995, pp. 17-20.

[7] DENING W., KIRCHMANN G., HAASE K. Development of Mill Technology and RPD in the Bar Mill of Badische Stahlwerke AG. *Der Kalibreur*, 1988, No. 49, pp. 25-34.

[8] KEELER S., KIMCHI M. Advanced High Strength Steel Application Guidelines - Version 5.0. *WorldAutoSteel*, May 2014 (online at www.worldautosteel.org).

[9] BLECK W., PAPAEFTHYMIOU S., FREHN A. Microstructure and Tensile Properties in DP and TRIP Steels. In *Conf. for Mechatronics 2004*, Patras, 2004, pp. 55-61.