Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 21
ISSUE 2
April
2007

Microstructural heterogeneity of forged rolled rings

J. Herian*
Department of Process Modelling and Medical Engineering,
Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: jerzy.herian @polsl.pl

Received 08.11.2006; accepted in revised form 15.11.2006

Properties

ABSTRACT

Purpose: The paper presents the processes which condition the quality of steel cast strands and properties of rolled products. It touches upon the technology of small-size rings manufacture from the 42CrMo4 steel used for the production of rolling bearings and toothed rings.
Design/methodology/approach: Investigations were made on the 42CrMo4 steel based process of small-size rings manufacture of weight not exceeding 100 kg and the internal diameter up to 600 mm.
Findings: Microstructure heterogeneity has been proven on the cross section of rods and rings under hot rolling and thermal treatment. Non-uniformity in hardness distribution was found on the hot rolled rings' face surface and cross section. Final products made from rings with heterogeneous properties characterize: difficulties with machining, cracking during surface hardening and decrease of life time. After the process modification, the rings' microstructure homogeneity and advantageous hardness distribution were obtained.
Practical implications: A good quality of final rings after heat treatment is obtained in the case of charge characterized by a uniform pearlitic/ferritic microstructure. After the process technology modification, the rings' microstructure homogeneity and advantageous hardness distribution were obtained.
Originality/value: The minimum processing degree in the rolling of rod products should guarantee obtaining a homogeneous microstructure on the rings cross section and properties which would ensure a good quality and the required functional properties of the final products.
Keywords: Mechanical properties; Plastic forming; Heat treatment; Microstructure

1. Introduction

There are three basic technological processes deciding upon the quality and properties of rolled products which include:
- the method of steel production and its off-furnace processing, which determine the chemical composition of the steel and its purity (content and type of inclusions),
- steel casting; in the case of continuous steel casting, the construction of the machine determining the dimensions and geometry of cast strands and their quality (surface conditions, microstructure, internal flaws and arrangement of non-metallic inclusions) is to be taken into account,
- hot plastic working (process parameters, deformation layout and the state of stress), which conditions the product continuity, structure homogeneity and properties.

The content and type of inclusions constitute to a large extent a function of the chemical composition of steel and of the deoxidation method, whereas their shape and arrangement depend on the course of dendrites solidification and their elongation during the subsequent plastic working [1÷3]. Non-uniform distribution (clusters, banding) of inclusions in steel causes scatter of properties after hot plastic working. Reduction of the harmful impact of inclusions on deformability and properties of steel has resulted in considerable improvements in the scope of casting technology, solidification control and off-furnace steel processing [1, 3].

The structure of a cast strand is composed of three crystallisation zones: a thin sub-surface layer – frozen crystals, a middle layer – dendritic crystals and equiaxial crystals of the central part of the cast strand. The middle zone is formed at the final stage of crystallisation and is characterised by large segregation of elements. Additionally, it contains non-metallic inclusions, the number and arrangement of which are conditioned by steel purity. The size of this zone can be considerably increased by means of electromagnetic mixing applied during the steel casting.

With an unchangeable method of steel melting and casing, and regardless of the parameters of the hot plastic working process, the quality of rolled and forged products also depends on the processing degree [1÷5]. In the hot plastic working of a material, the processing degree is a numerical index based on which one can express the changes of structure and properties the material is subject to due to plastic strain resulting from the assumed deformation layout for the process being conducted. In the rolling process, the processing degree is usually defined by the elongation factor as $\lambda=S_o/S_i$, where: S_o and S_i constitute respectively the initial area of the band cross section surface and the same after deformation.

Required properties of products rolled from conventional ingots were obtained when the processing degree amounted to a few tens. In the case of using cast strands, the number in question is considerably smaller and oscillates between 3 and 10 [2]. In certain cases, e.g. when rolling tubes, it reaches the value of 18 [1]. Permanent tendency to form cast strands of the dimensions as similar as possible to the dimensions of the finished product causes that the minimum processing degree of 4÷6 may not guarantee the required functional properties of the given product.

In the recent years, in the country and abroad, one could notice an increasing tendency of the demand for small-size rolled rings used in manufacture of rolling bearings, toothed wheel rims or made into structural components of heavy loads. Rings made of medium-carbon and medium-alloy steel (acc. DIN 40CrMo4) are characterized by:

- wide range of required functional properties,
- stable properties of products with a narrow tolerance range,
- homogeneous properties throughout the product,
- good and stable machinability,
- crack resistance during surface hardening,
- high fatigue strength.

2. Technological process of rings manufacture

In the domestic conditions (Huta Bankowa), the 42CrMo4 steel based process of small-size rings manufacture of weight not exceeding 100 kg and the internal diameter up to 600 mm consists of the following stages:

- cutting of the charge in the form of round, rolled rods into small blocks,
- upsetting of blocks with one-side punching and forming of a web,
- performance of an opening – cutting the web,
- rolling of the rim in a radial-axial rolling mill,
- thermal treatment.

In the course of manufacturing of rings of the dimensions D_z x D_w x H = Ø418 x Ø286 x 109 mm based on the 42CrMo4 (C=0.40%, Si=0.3%, Mn=0.7%, Cr=1,1% and Mo=0.2) steel, round hot rolled rods are used. Rods of the diameter of Ø250 mm are rolled from cast strands of the cross section of 280 x 400 mm. A sequence of passes (deformations) and gaps between them resulting from the calibrating system assumed and the rolling manner for the given products as well as rolling speed, at the temperature changing in parallel, causes gradual closing and bonding of the discontinuities and voids. Simultaneously, the steel structure is changing with size reduction and homogenization of grains. Regardless of the working temperature and the size of deformations in the passes, homogeneity of the structure and properties are also a function of the processing degree. The higher the processing degree, the finer the structure and the more homogeneous and, simultaneously of more uniform properties throughout the volume of the product. The processing degree during the rolling of rods equals $\lambda_1 = 2.28$.

Rollers with openings of the dimensions D_z x D_w x H = 308 x 128 x 128 mm are manufactured from small blocks of the diameter Ø250 mm obtained in the process of cutting round rods. Upsetting of blocks after heating in a furnace with a rotating hearth as well a their punching take place in a press. The processing degree in the direction perpendicular to the roller's axis, not entailing the punching, equals $\lambda_2 = 1.52$. Therefore, the overall processing degree from a cast strand to a disc equals $\lambda_{1-2} = 3.46$. The discs with a hole should be characterized by a favourable set of properties. They should not demonstrate steel overheating and the section structure should be uniform and without grain growth. Such charge used in the process of rolling ensures obtaining a uniform structure in the cross section and thus, attaining the required functional properties.

Rollers after repeated heating are rolled in a radial-axial rolling mill into rings of the dimensions Ø418 x Ø286 x 109 mm. The factors conditioning the success of the process of rolling rings in a rolling mill are both the rolling methodology, i.e. the optimum feed in a radial and axial pass, the size of deformations, and the appropriate choice of dimensions of the roller with an opening of an appropriate geometry, structure and properties uniformly distributed on the cross section and along the circumference. Due to vacuum degassing of the cast strands, the cooling of rings after rolling takes place in the open air. The processing degree achieves the value of $\lambda_3 = 1.63$.

3. Assessment of the microstructure of charge intended for rolling of rings

The structural examinations conducted on the cross section of rods of the diameter ϕ250 made of the 42CrMo4 steel, after rolling of ingots of the dimensions 280x400 mm revealed inhomogeneous pearlitic and ferritic structure (Fig. 1). A fine-grain structure in the sub-surface layers was shown (Fig. 1a, 1e, 1g) whereas a coarse-grained one was noticed in the central layers of the rod. It is very likely that the above situation was caused by a too high temperature of the rolling final period and the heating conditions.

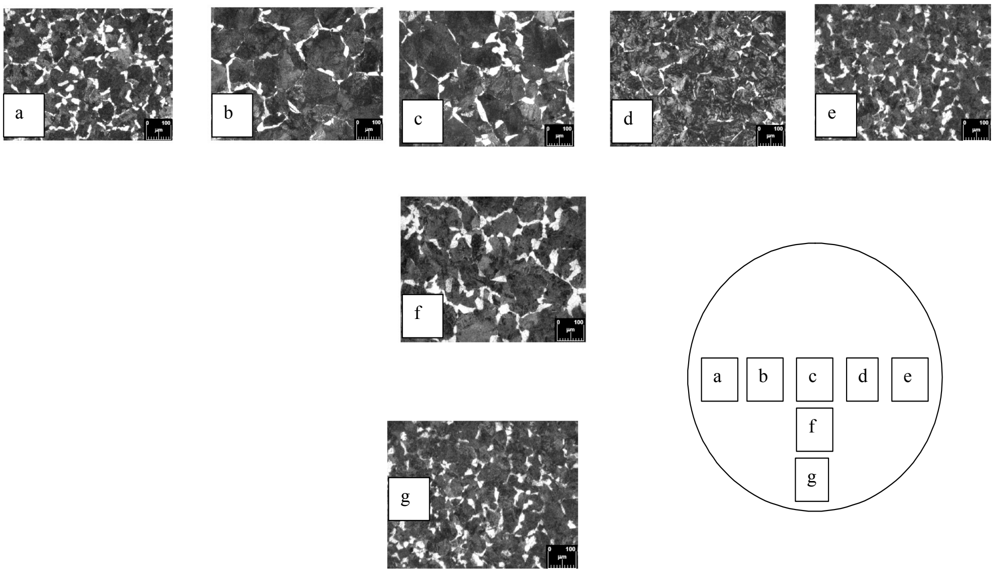

Fig. 1. Structure arrangement on the cross section of a hot rolled rod of the diameter ϕ250 mm

4. Assessment of the microstructure and properties of rings after rolling and thermal treatment

The most crucial problem occurring in the process of small-size rings manufacture is obtaining instable mechanical properties both in the individual product and in the whole batches. Such a state of matters is correctly characterised by hardness distribution in the circumference of a ring's face surface. Measurements of hardness were conducted via a dynamic method using the EQUOTIP device and a G-type beater. During the test, the position of the ring was horizontal.

Results of hardness distribution in the circumference of the ring's face surface for three different radiuses (external, central and internal) are presented in Fig. 2. As a criterion for hardness distribution assessment, the following were assumed:

- the largest range in the whole group of results HB_{max} - HB_{min},
- the largest range based on averaged results for the given circle $HB_{mean\ max} - HB_{mean\ min}$.

After toughening, the rings of dimensions Ø580 x Ø430 x 62 mm (fig. 2) demonstrate uniformity in hardness distribution in the whole circumference on the hot rolled rings' face surface. The maximum range of hardness equalled 12÷80HB, whereas the range of mean values did not exceed the value of 20÷52HB. That corresponds to the range of tensile strength of 160÷223 MPa.

Structural examinations conducted on the cross section of the rings revealed an inhomogeneous pearlitic and ferritic structure (Fig. 3).

The distribution of hardness on the hot rolled ring's face surface of the Ø250 mm rod, corroborates non-uniformity of the face surface (fig. 4). The hardening of rolled rings, Ø249/149x50, and subsequent tempering have not eliminated the hardness distribution non-uniformity on the circumference, nor the inhomogeneity of the structure.

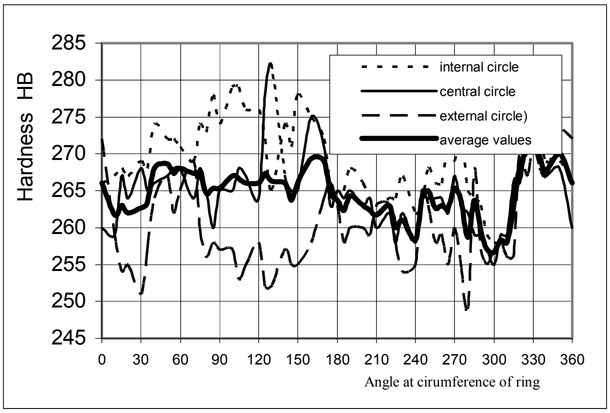

Fig. 2. Distribution of hardness on hot rolled rings' face surface made of 42CrMo4 steel after hot rolling

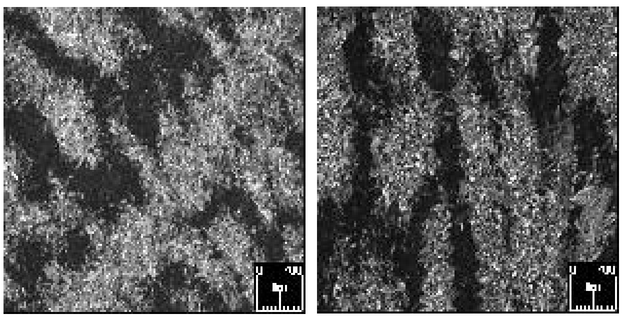

Fig. 3. Heterogeneous bainitic/ferritic microstructure. Visible, a large amount of free ferrite

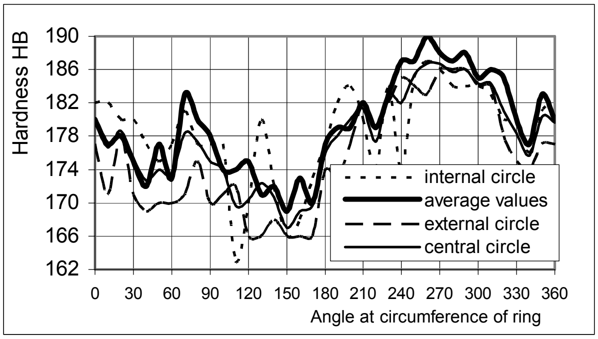

Fig. 4. Hardness distribution on the face surface of a ring hot rolled from a ϕ250 mm rod

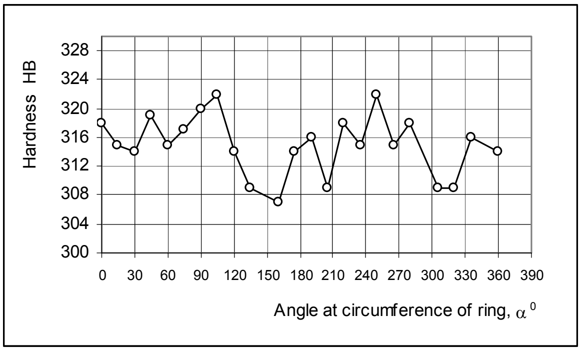

Fig. 5. The distribution of hardness on the ring Ø520/402x107 mm after corrected technology and heat treatment

The reasons for the structural inhomogeneity as well as non-uniformity of the rods' and hot rolled rings' properties, are therefore difficult to determine. They may result from non-uniform heating, cooling rate, a non-uniform distribution of deformation intensity on the cross-section, or finally, from the consolidation processes and subsequent metal softening between hot deformation procedures.

Based on the research results obtained and their analysis, a modified ring manufacturing technology has been proposed. In the new technology:

- the temperature of ingots' soaking is lowered and the heating time is reduced,
- the temperature of the final stage of rolling is lowered,
- the processing degree is increased to the value equal 3 for each stage of plastic processing,
- symmetric heat abstraction is ensured while cooling from the austenitization temperature during hardening.

As a result of these changes, the rings obtained after hot rolling were characterized by a homogeneous pearlitic-ferritic structure on their cross-sections (fig. 6a).

This testifies to the fact that the obtained discs with a hole had an advantageous structure. The structure on the cross-section must have been uniform, without grain growth or steel superheating. The primary austenite grain size according to the ASTM scale was 7. Similarly, after toughening, a homogeneous bainitic structure was obtained (fig. 6b). On the ring's face surface, throughout its circumference, hardness of a minimal range was obtained. The mean value was between 306 and 322HB and corresponded to the desirable one (Fig. 5).

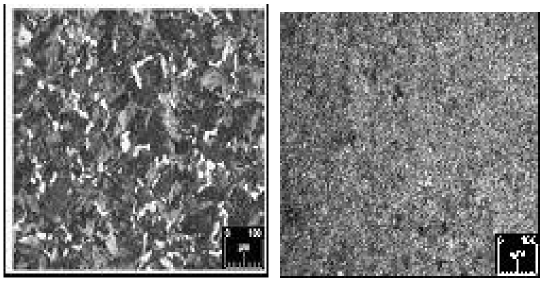

Fig. 6. Homogeneous microstructure on the ring's cross section: a-pearlitic/ferritic; b-tempered bainite

5. Conclusions

The minimum processing degree in the rolling of rod products should guarantee obtaining a homogeneous microstructure on the rings cross section and properties which would ensure a good quality and the required functional properties of the final products. The nature of structure formation in the steel during plastic working is determined to a large extent by the degree of the deformation intensity non-uniformity and the material's phase composition. The rings which showed structural heterogeneity after hot rolling keep demonstrating the inhomogeneity after thermal treatment although, it is a little lower.

A good quality of final rings after heat treatment is obtained in the case of charge characterized by a uniform pearlitic/ferritic microstructure. After the process technology modification, the rings' microstructure homogeneity and advantageous hardness distribution were obtained.

References

[1] C.V. White, G. Kraus, D.K. Matlock, Solidification structure and the effects of hot reduction in cotinuously cast steels for bars and forgings. Iron a. Steelmaker, t. 25, 1998, nr 9, 73-79.

[2] B. Hoderny, B. Garbarz, J. Grabelus, B. Zdonek, Metallurgist 7 (2002) 283-289 (in polish).

[3] H. Filigranek, H. Szwej, Report Huta Baildon 3, 1999, 36-53 (in polish).

[4] J. Sińczak, L. Cybula, J. Florys, Metallurgist 6 (1998) 200-208. (in polish)

[5] J. Śińczak, W. Madej, Rolling Conference 1999, 161-166.(in polish)

[6] J. Herian, R. Sułkowski, K. Aniołek, Rolling conference 2005, Ustroń 2005, 115-120 (in polish).

[7] A. Hernas, J. Herian, Report of P/X-1/05 „PROMA" Katowice 2005 (in polish).

[8] S. Casotto, F. Pascon, A. Habraken, S. Burschi, Thermo-metallurgical model to predict geometrical distortions of rings cooling phase after ring rolling operations, Journal of Machine Tools & Manufacture 45 (2005) 657.

[9] J. Szabo, E. Dittrich, Manufacturing systems for the production of seamless-rolled rings. Journal of Materials Processing Technology 60 (1996) 67.