MICROSTRUCTURE AND PROPERTIES OF HOT ROLLED 42CrMo4 STEEL CHARGE AND RINGS

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MIKROŠTRUKTÚRA A VLASTNOSTI ZA TEPLA VALCOVANÝCH DISKOV A KRÚŽKOV Z OCELE 42CrMo4

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Abstrakt

Príspevok sa zaoberá procesmi, ktoré určujú kvalitu liatych oceľových polotovarov a vlastností valcovaných výrobkov. Týka sa technológie malorozmerných (Ø 400 – 580mm) krúžkov vyrobených z ocele 42CrMo4, použitých pre výrobu valivých ložísk a ozubených kolies. Rozhodujúcim problémom je heterogenita mikroštruktúry a vlastností v priečnom priereze a obvode krúžkov valcovaných za tepla a tepelne spracovaných – čo predstavuje nestabilné mechanické vlastnosti jednotlivých výrobkov a tiež celej dávky výrobkov.

Toto spôsobuje nasledovné problémy:

- Ťažkosti pri obrábaní
- Praskanie počas vytvrdzovania povrchu
- Zníženie životnosti finálneho výrobku

Kvalita a vlastnosti valcovaných výrobkov sú podmienené tromi základnými technologickými procesmi, ktoré zahrňujú:

- spôsob výroby ocele a jej mimopecné spracovanie
- odlievanie ocele, v prípade kontinuálneho odlievania
- tvárnenie za tepla a tepelné spracovanie (parametre spracovania, deformačný plán a stav napätí) , ktoré podmieňujú kontinuitu výroby, homogenitu štruktúry a vlastností.

Bola vykonaná analýza mikroštruktúry tyčí v priečnom reze (pásová feriticko-perlitická /bainitická mikroštruktúra s hrubým zrnom) a distribúcia tvrdosti na čelnom povrchu valcovaných krúžkov a taktiež štruktúra v priečnom reze. Bola preukázaná heterogenita mikroštruktúry tyčí a taktiež značná nerovnomernosť vlastností krúžkov ($HB_{max} – HB_{max}$ = cca. 60 po finálnom tepelnom spracovaní).

Na základe výsledkov skúmania sa vykonala nasledovná zmena technológie spracovania:

- Redukcia priemeru tyčí
- Vhodný čas a teplota ohrevu
- Zníženie teploty počiatočnej a finálnej etapy valcovania
- Zvýšenie celkového stupňa pretvárnenia zliatiny do cca. 9 (stupeň pretvárnenia nemá byť nižší ako λ=3)
- Úprava podmienok chladnutia počas vytvrdzovania krúžkov

Úpravou technológie sa dosiahla homogenita mikroštruktúry a tvrdosti v priečnom reze krúžkov.

Abstract

The paper presents processes which determine the quality of steel cast strands and properties of rolled products. It touches upon the technology of small-size (Ø 400 – 580 mm) rings manufacture from the 42CrMo4 steel used for the production of rolling bearings and toothed rings. The most crucial problem is connected with heterogeneity of microstructure and properties on cross section and circumference of hot rolled and heat treated rings – instable mechanical properties both in the individual product and in the whole batches. Consequences of this are:

- Difficulties with machining
- Cracking during surface hardening
- Decrease of life time of final products

The quality and properties of rolled products are conditioned by three basic technological processes, including:

- the method of steel production and its off-furnace processing,
- steel casting; in the case of continuous steel casting,
- hot plastic working and heat treatment (process parameters, deformation layout and the state of stress), which conditions the product continuity, structure homogeneity and properties.

An analysis has been performed of the microstructure of bars based on their cross sections (banded ferrite – pearlite/bainite microstructure, coarrse-grained) and distribution of hardness on the hot rolled rings' face surface as well as their cross-section structure. Heterogeneity of the bars' microstructure as well as considerable non-uniformity of the rings' properties have been shown. (HB_{max} – HB_{max} = ca. 60 after final heat treatment.)

As a result of investigations the modification of process technology was used as follow:

- Diameter reduce of bars
- Appropriate time and temperature of heating
- Descrease temperature of the initial and final stage of rolling
- Increase of total wrought alloy up to ca. 9 (The processing degree not be lower than λ=3
- Correction of cooling conditions during hardening of rings

After corrected technology a homogeneity of microstructure and hardness at the cross section of rings was reached.

Key words: Steel rings, heterogeneity, microstructure, hardness, modification of process technology

1. Introduction

The quality and properties of rolled products are conditioned by three basic technological processes (fig. 1), including:

- 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].

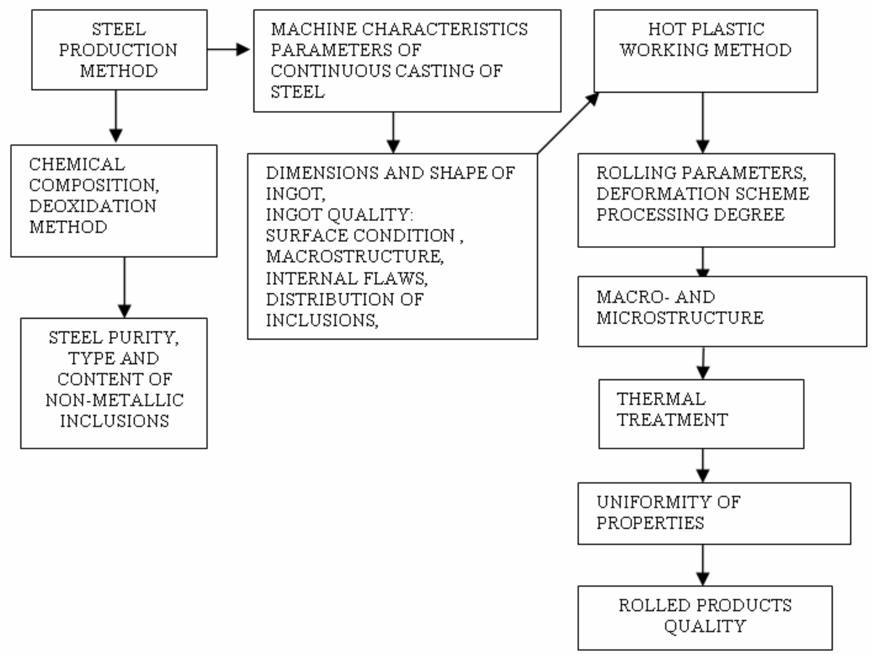


Fig.1 Basic technological processes conditioning the quality of rolled products

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 (40CrMo4, 40HM) are characterised by:

- wide range of required functional properties,
- constant properties of products of narrow tolerance range,
- homogeneous properties in the whole volume of the given product,
- good and stable machining properties,
- 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 bars into small bar sections,
- upsetting of bar sections 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 steel, round hot rolled bars are used. Bars 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 homogenisation 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 microstructure and the more homogeneous and, simultaneously of more uniform properties throughout the volume of the product. The processing degree during rolling equals λ_1 = 2.28.

Discs with openings of the dimensions D_z x D_w x H = 308 x 128 x 128 mm are manufactured from small bar sections, 250 mm in diameter, obtained in the process of cutting round bars. Upsetting of bar sections 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 disc's axis, not entailing the punching, equals λ_2 = 1.52. Therefore, the overall processing degree from a cast strand to a disc equals λ_{1-2} = 3.46. Discs with openings should be characterised 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 rings rolling ensures obtaining uniform structure in the cross section and thus attaining the required functional properties.

The discs 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 disc 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 microstructural examinations were conducted on the cross section of bars of the diameter ϕ250 made of the 42CrMo4 steel. Bars used in the process of rolling of ingots of the dimensions 280x400 mm revealed inhomogeneous pearlitic and ferritic structure (fig. 2). In the sub-surface layers of the bars, a fine-grained structure was noticed (fig. 2a, 2e, 2g) whereas a coarse-grained one was noticed in the central layers. Such large diversification of structure is a result of a too high temperature at the final stage of rolling, non-uniform cooling and a low processing degree.

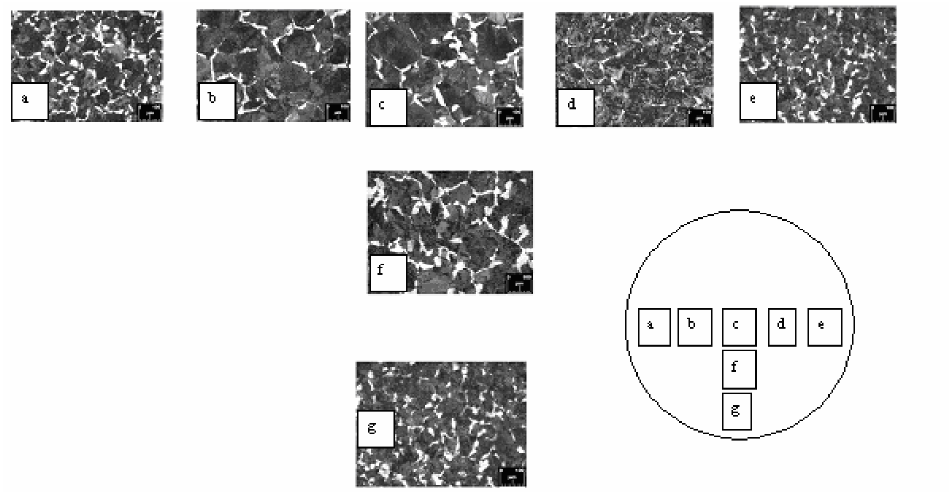


Fig.2 Microstructure arrangement on the cross section of a hot rolled bar of the diameter ϕ250

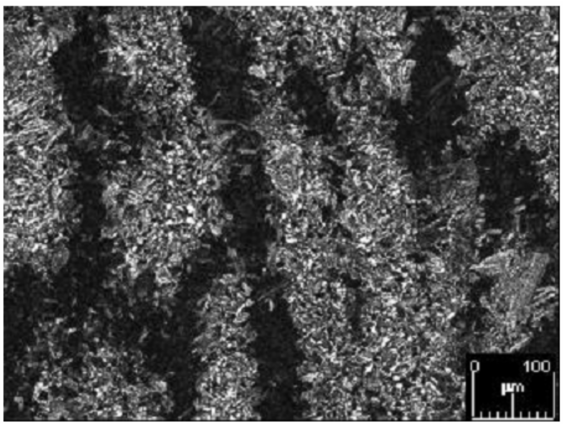


Fig.2 d An example of microstructure inhomogeneity in central part of ring after quenching and tempering

4. Assessment of the structure and properties of rings after rolling

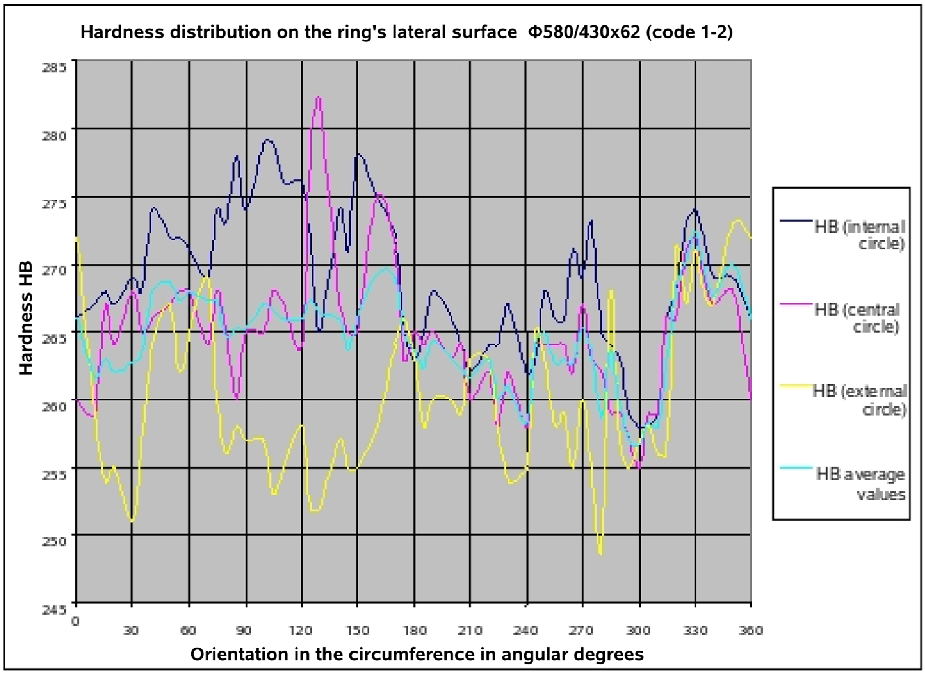
The most crucial problem occurring in the process of small-size rings manufacture is obtaining instable mechanical properties both in the individual product and in the whole batches. Such a state of matters is correctly characterised by hardness distribution in the circumference of a ring's face surface. Measurements of hardness were conducted by the application of a dynamic method using the EQUOTIP device and a G-type beater. 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. 3. 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 $HB_{mean\ max} - HB_{mean\ min}$.

For instance, a ring of the dimensions Ø580 x Ø430 x 62 mm (fig. 3a) was characterised by fairly uniform hardness in the whole circumference. The maximum range of hardness equalled 31HB, whereas the range of mean values did not exceed 14HB. Another ring of identical dimensions (fig. 3b) revealed considerably larger changes in hardness distribution. For the criterion assumed, the range of hardness equalled 66HB and 52HB, respectively. Such changes in the range of hardness values cause a non-uniform distribution of tensile strength in the ring circumference. Their range in the circumference amounts to ca. 223÷176MPa.

Structural examinations conducted on the cross section of the rings revealed inhomogeneous pearlitic and ferritic microstructure.

Having modified in the rings rolling process (disc heating time was decreased and temperature of the final stage of rolling reduced), rings were obtained characterised by homogeneous pearlitic and ferritic structure on the cross section (fig. 4).



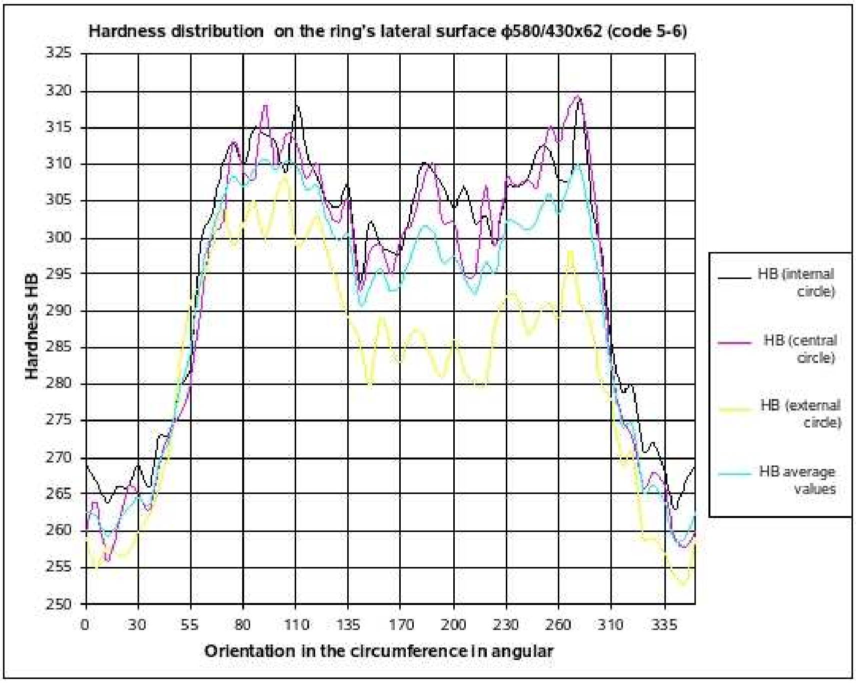


Fig.3 Selected examples of hardness distribution on the face surface of rings made of the 42CrMo4 steel after hot rolling

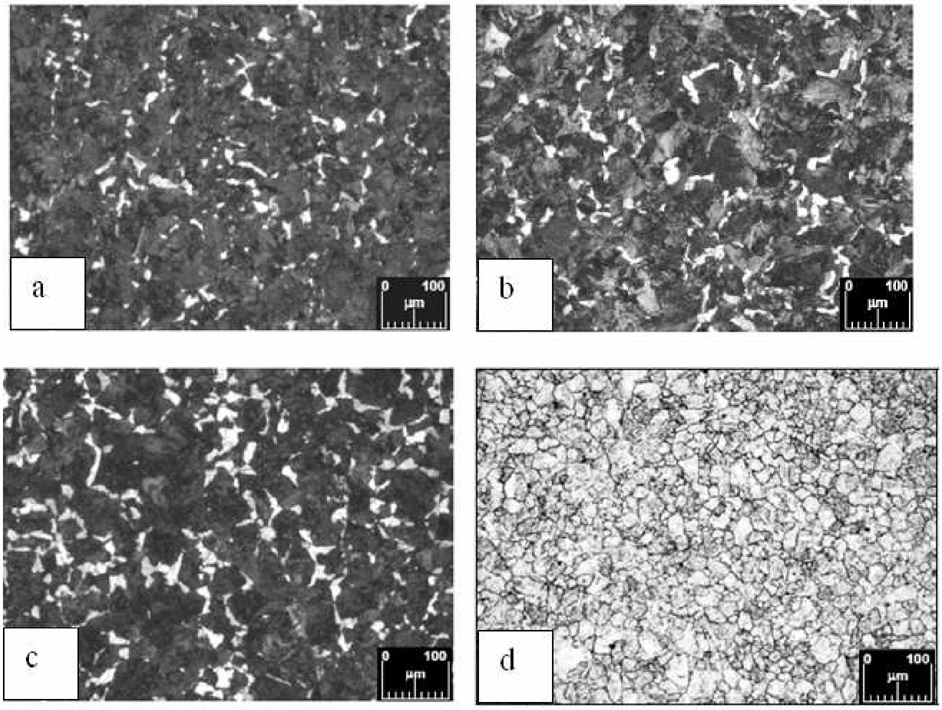


Fig.4 Homogeneous pearlitic and ferritic structure on a transverse section of a ring; zones: a – external subsurface, b – internal subsurface, c – central, d – size of the original austenite grain – 7 according to the ASTM scale

5. Conclusions

The minimum processing degree in the rolling of bar products should guarantee obtaining a homogeneous structure on the cross section and an appropriate level of the product's properties. The processing degree should not be lower than $\lambda = 3$. Another advantageous solution is the use of thinner charge (bar section) for upsetting the discs, which will also positively influence the processing degree, homogeneity of the structure and the properties, both on the disc's cross section and in its circumference.

The technology of heating the discs and rolling of rings must guarantee minimum time of heating, appropriate temperature of the initial and final stage of rolling, and the processing degree of at least $\lambda = 3$. The aforementioned solutions should ensure good quality of rolled rings to be used for the appropriate components of rolling bearings and toothed wheel rims in power transmission systems.

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