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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FORGED AND ROLLED RINGS MADE FROM X20Cr13 STEEL

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The article describes the results of microstructure and mechanical properties tests (according to PN-EN ISO 6892-1:2016-09 and PN-EN ISO 6507-1:2007), which were obtained on specimens taken from a fragment of a ring rolled in the temperature range from 1 220 °C to 950 °C, with dimensions ø965/803 x 164 mm, annealed and heat-treated: quenching at the temperature of 1 030 ± 10 °C in oil and tempering at a temperature of 650 °C. The starting material for rolling was a forging with an opening of ø560/230 x 180 mm. Comparative hardness tests were also performed on specimens taken from the ring after rolling and softening annealing. The R_m, $R_{p0.2}$ and A indices of the ring fragment after heat treatment, as assumed, were respectively: 942 MPa, 763 MPa and 17 %.

Keywords: X20Cr13 steel, forged and rolled rings, mechanical properties, microstructure

INTRODUCTION AND RESEARCH AIM

The modern development of industrial products in the energy, mining and machinery industries requires suppliers to manufacture ring elements at the lowest possible price using modern martensitic steels with mechanical properties adapted to a specific application. In order to meet the market requirements, the concept of a low-waste technology of shaping large-sized rings from X20Cr13 steel with profiled sidewalls was created.

The project leader was Zarmen FPA, and the consortium member was Metal Forming Institute in Poznań (now Łukasiewicz – Poznań Institute of Technology, Center of Metal Forming). One of the stages of this project was the development of a technology for the heat treatment of rings made of the above-mentioned steel grade.

Profiling of the sidewalls reduces the amount of material needed [1-3], and thus contributes to a reduction in the amount of energy needed to produce it, which has positive economic and ecological effects [4,5]. The shape of the demonstrator rings was developed based on the inquiries received by Zarmen FPA. Conical rings are used, among others in the aviation industry. Due to the nature of the work, X20Cr13 steel was selected, which is characterized by good resistance to atmospheric corrosion, water vapour, alkaline solutions and diluted organic acids. This steel is used for machine parts with the required higher hardness and strength, such as shafts, screws, springs, machine parts and die casting moulds. After conventional heat treatment of this steel, it is possible to obtain a hardness of 560 HV 10 (approx. 53 HRC) with the fracture energy of an impact specimen of 31 J [6]. The requirements for the chemical composition and mechanical properties after heat treatment of X20Cr13 steel are given in standards [7,8].

The aim of the research was to determine the optimal conditions of heat treatment of rolled rings made of X20Cr13 steel in terms of obtaining a product with a tempered martensite structure and mechanical properties suitable for a large-sized ring. The hardness of the toughened ring of approx. 30 HRC and tensile strength from 700 MPa to 950 MPa were assumed.

RESEARCH MATERIAL AND METHODOLOGY

Chemical composition tests were carried out on a forged bar made of martensitic steel X20Cr13 (No. 1.4021 according to the PN-EN 10088-1: 2014-12 standard), from which a forging with a hole was made, and then a rolled ring. The chemical composition of the steel was determined by means of the optical emission spectrometry with glow discharge excitation and is given in Table. 1. A GDS 500A (Leco) spectrometer was used in the research.The chemical composition of X20Cr13 steel complies with the requirements of PN-EN 10088-1:2014-12. Nevertheless, the chromium content in this steel is in the lower allowable limit of 12,00 %.

The ingot made of X20Cr13 steel was forged into a rod of ϕ270 x 670 mm. Then, a forging was made with an opening of ϕ560/230 x 180 mm, which was the start-

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Table 1 **Chemical composition of X20Cr13 steel**

	Elemental content, wt%				
X20Cr13	C	Cr	Mn	Si	Cu
	0,21	12,28	0,69	0,58	0,15
	Ni	V	P	S	Mo
	0,13	0,094	0,014	0,006	0,01

ing material for rolling the ring. The ring rolling process was carried out at Zarmen FPA in the temperature range (the temperature of the beginning and end of the rolling process) from 1 220 °C to 950 °C. The final dimensions of the ring were ϕ965/803 x 164 mm. The rolled ring underwent softening annealing at the temperature of 750 °C for 4 hours. A fragment of material was taken from the rolled ring, which was quenched at the temperature of 1 030 ± 10 °C in oil and tempered at the temperature of 650 ± 5 °C for 2 hours in Łukasiewicz - INOP.

MICROSTRUCTURE OBSERVATIONS -SCANNING ELECTRON MICROSCOPE (SEM)

These tests were performed in accordance with the research instructions Z-IB/3-08 - Surface morphology tests of metallic and non-metallic materials, 4th edition, date of issue 17.03.2020 using an Inspect S (FEI) scanning electron microscope. The microstructure of the specimens was revealed after etching in Mi19Fe reagent (3g FCl_3, 10 ml HCl and 90 ml C_2H_5OH) according to the PN-H-04503:1961 standard - Reagents for examining the microstructure of iron alloys. Longitudinal specimens from the rolled ring and the heat-treated ring fragment were taken from 3 zones on the ring cross-section (upper surface - T, middle of the cross-section - M and lower surface - B). However, after quenching the ring fragment, specimens were taken from the upper and lower zones of the ring cross-section. Observations of the microstructure were carried out at image magnifications of 1 000x and 8 000x.

HARDNESS MEASUREMENT BY VICKERS METHOD

Vickers hardness measurements were made in accordance with the EN ISO 6507-1:2018 standard - Metallic materials - Vickers hardness test - Part 1: Test method, with a loading force of 9 807 N, using an FM-800 hardness tester (Future Tech. Corp.) on cross-sections of the specimens subjected to microscopic observations.

STATIC TENSILE TEST

The static tensile test was carried out in accordance with PN-EN ISO 6892-1:2019 - Metallic materials - Tensile testing - Part 1: Method of test at room temperature, using an Instron 4483 (Instron) testing machine and a measuring head with a load capacity of 150 kN. The test was performed on specimens with the diameter do = 10 mm and measuring length L_o = 50 mm. Table 1 Chemical composition of X20Cr13 steel.

RESEARCH RESULTS AND THEIR DISCUSSION

MICROSCOPIC OBSERVATIONS – SEM

The results of the observation of the microstructure of the specimens taken from the ring after rolling and softening annealing are shown in Figure 1.

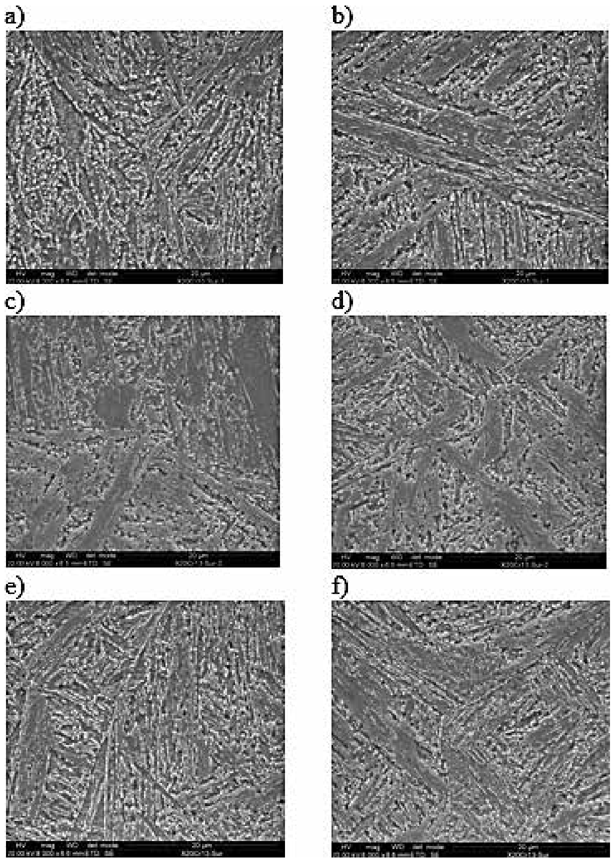

Figure 1 Microstructure of longitudinal sections of specimens taken from ring after rolling and softening annealing. SEM: a and b - specimen taken from upper zone of ring, c and d - specimen taken from middle zone of ring, e and f - specimen taken from lower zone of ring

The microstructure of the specimens taken from the ring after rolling and softening annealing was formed by coarse acicular, tempered martensite (Figure 1). Precipitates of alloy carbides were noticed at the grain boundaries of the former austenite (Figure 1a, e and f).The microstructure of the hardened ring fragment was made of coarse acicular martensite (Figure 2). Coarse grains of the former austenite are visible in the microstructure of the specimens observed at the magnification of 1 000 x (Figure 2a and c).

Dispersive precipitates of alloy carbides were observed at the boundaries of the former austenite grains (Figure 2b and d). The grain size of the former austenite was assessed with a light microscope (Eclipse L150 - Nikon) according to EN ISO 643:2012 - Steels - Micro-

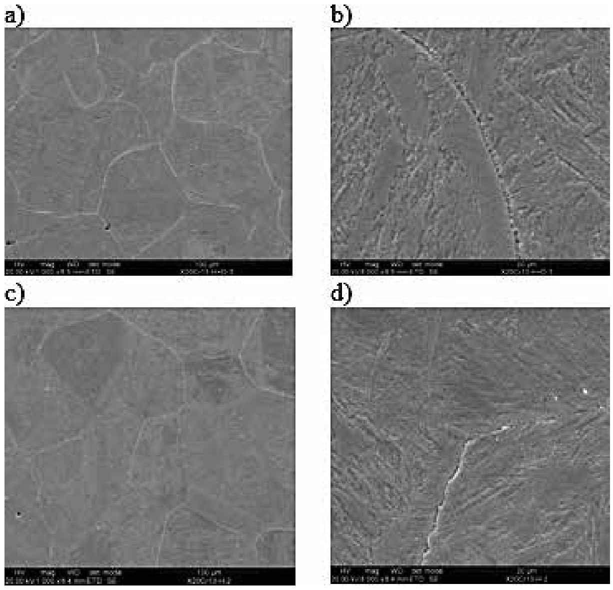

Figure 2 Microstructure of longitudinal sections of specimens taken from fragment of ring after quenching. SEM: a and b - specimen taken from upper zone of ring, c and d - specimen taken from lower zone of ring

graphic determination of the apparent grain size. The G index was 3,5. The content of the residual austenite was determined by the X-ray method using an Empyrean-PANalytical X-ray diffractometer. The investigation used Cu Kα radiation with a wavelength of 1,54060 Å, current intensity and voltage, respectively: 40 mA and 45 kV, 2Θ angle range: from 44,49° to 115,91°. The residual austenite content was 4,65 %.

The microstructure of the specimens taken from the cross-section of the ring fragment after quenching and tempering was formed by tempered martensite (Figure 3). No significant differences were observed in the microstructure of the ring cross-section.

HARDNESS MEASUREMENTS BY VICKERS METHOD OF SPECIMENS COLLECTED FROM RING CROSS-SECTIONS

The results of measurements of the average HV 1 hardness of longitudinal sections of the specimens taken from 3 zones of the ring fragment after rolling and softening (W), quenching (H) and quenching and tempering (HT) are shown in Figure 4. The hardness measurements were carried out in two perpendicular directions to each other.

The average hardness of the ring cross-section after rolling and softening annealing was equalised and ranged from 259 HV 1 to 269 HV 1 (Figure 4a). After quenching the ring fragment, its hardness increased to the maximum value of 593 HV 1 in the upper zone of the ring cross-section (Figure 4b).

In the remaining zones, the middle and lower cross-section of the ring, no significant decrease in the average hardness was noticed. After tempering the hardened part of the ring, the average hardness decreased to the

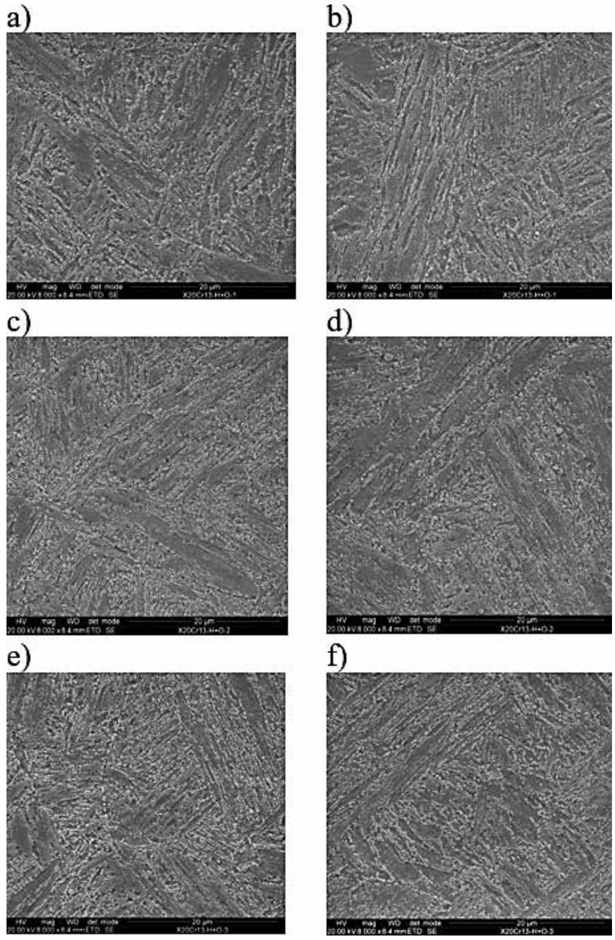

Figure 3 Microstructure of longitudinal sections of specimens taken from fragment of ring after quenching and tempering. SEM: a and b - specimen taken from upper zone of ring, c and d - specimen taken from middle zone of ring, e and f - specimen taken from lower zone of ring

highest value of 298 HV 1 in the middle zone of the ring cross-section (Figure 4c). The lowest average hardness was recorded in the lower section of the ring, which was 287 HV 1.

STATIC TENSILE TEST

The results of the static tensile test - the determined $R_{p0.2}$, R_m and A indices of the specimens taken from the heat-treated part of the ring - are given in Figure 5.

The indices of the heat-treated ring fragment were as follows: R_m - 942 MPa, $R_{p0.2}$ - 763 MPa and A– 17 %.

CONCLUSIONS

Based on the microstructure observations, hardness measurements using the Vickers HV 1 method, and static tensile test of specimens taken from a fragment of a ring made of X20Cr13 steel, it was found that:

The ring was hardened through after rolling at the temperature range from 1 220 °C to 950 °C and subsequent air cooling. Softening annealing at the temperature of 750 °C for 4 hours resulted in a reduction in and equalization of its average hardness. The maximum av-

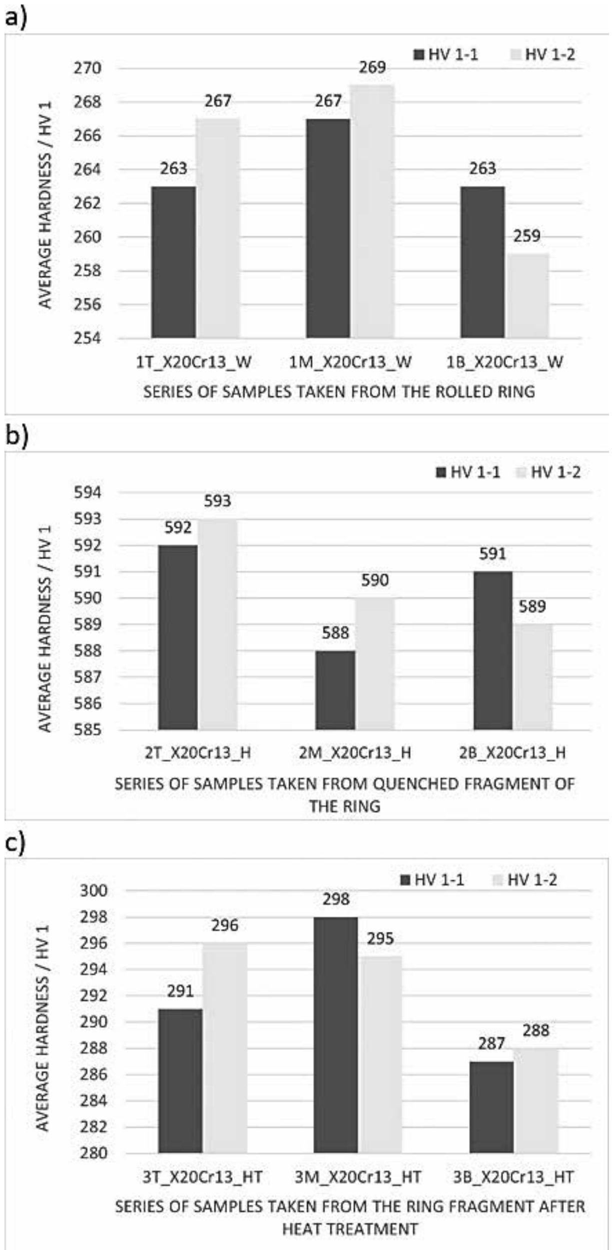

Figure 4 Average HV 1 hardness of longitudinal sections of series of specimens taken from:a - rolled and annealed ring, b - quenched ring fragment, c - ring fragment after quenching and tempering

erage hardness of the annealed ring was 269 HV 1×7 HV 1 in the middle of the ring.

As a result of quenching the ring fragment at the temperature of 1 030 ± 10 °C in oil, martensite was obtained in the entire cross-section, with a maximum average hardness of 593 HV 1×10 HV in the upper zone of the ring cross-section. Tempering at the temperature of 650°C for 2 hours and further cooling in air caused a reduction in the average hardness to the maximum value of 298 HV 1 ± 4 HV 1.

The mechanical property indices $R_{p0.2}$, R_m and A of the heat-treated ring material met the requirements for the QT800condition according to EN 10088-3:2014. These indices were respectively: 763 MPa, 942 MPa and 17 %, and in terms of the conventional yield point and elongation, they were much higher than those re-

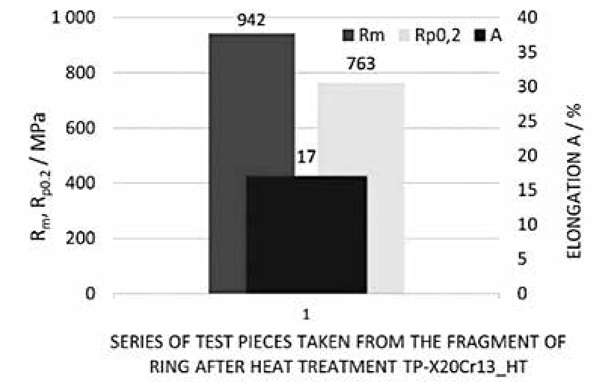

Figure 5 Results of static tensile test of series of specimens taken from heat-treated part of ring

quired by this standard - $R_{p0.2}$ minimum 600 MPa, Rm from 800 to 950 MPa and A minimum 12 %.

Acknowledgements

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REFERENCES

[1] Y.M. Zhao, D.S. Qian, Effect of rolling ratio on groove-section profile ring rolling, J. Mech. Sci. Technol. 24 (2010),1679-1687.

[2] J. Song, Y.Y. Liu, J.D. Yang et al.: Impact of preformed blank dimension to contour ring, Proceeding of the 13th Seminar on Global Chinese Plastic Technology, 2013. 10.15-16.

[3] X.Q. Chen, L.G. Guo, H. Yang et al.: Study on blank optimization design of conical ring rolling process for TC4 titanium alloy by numerical simulation, J. Plasticity Eng 21 (2014), 25-31.

[4] M. Park, Ch. Lee, J. Lee, I. Lee, M. Joun, B. Kim, K. Lee: Development of L-Sectioned Ring for Construction Machines by Profile Ring Rolling Process. International Journal of Precision Engineering and Manufacturing Vol. 17(2016), 233-240.

[5] H. QI, Y. LI: Research Status and Developing Trends on the Ring Rolling Process of Profile Ring Parts, Procedia Engineering 207 (2017), 1260–1265.

[6] Prieto G., Perez Ipiña J. E.,Tuckart W. R.: Cryogenic treatments on AISI 420 stainless steel: Microstructure and mechanical properties. Materials Science & Engineering A 605 (2014), 236-243.

[7] Standard EN 10088-1:2014 – Stainless steels – Part 1: List of stainless steels.

[8] Standard EN 10088-3:2014 – Stainless steels – Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes.

Note: The responsible for English language is Jarosław Lulkiewicz, Poznań, Poland.