Identifying causes of defects in bearings used in agricultural machines

K.M. Semev¹, F.A. Kipriyanov², P.A. Savinykh³, N.A. Medvedeva² and S.V. Belozyorova²

¹Closed Joint Stock Company Vologda Bearing Corporation, 13, Okruzhnoye Highway, Vologda, 160028, Russian Federation
²Vologda State Milk Industry Academy, 2, Schmidt Street, Vologda, 160555, Russian Federation
³Federal Agrarian Science Center of the North-East region, 166a, Lenin Street, Kirov, 610007, Russian Federation

E-mail: kipriyanovfa@bk.ru

Abstract. The paper considers causes of principal defects in thermal treatment of bearings and presents the results of microstructural analysis of samples taken from rejected ball bearing steel. It states the causes of the identified defects and introduces proposals aimed at reducing the incidence of defects in bearing manufacture arising during the thermal treatment.

1. Introduction
Bearings are among the most important components of any mechanism; they not only define its useful life, but also its operation parameters, directly influencing friction forces between moving parts. Fatigue stress arising under cyclical loads typical for rolling bearings inevitably lead to their fracture and emergency shutdown of the mechanism as a whole [1]. During the thermal treatment of steel various defects may arise that have a negative impact onto the mechanical properties of the metal [2, 3]. There are multitudes of causes for thermal treatment-related defects, let us consider the most important ones.

The first and the most common cause of thermal treatment (TT) defects is disturbance of the TT due to wrong thermal interval, inaccurate exposure, low cooling rate, incorrect selection of cooling medium, lack of tempering.

The second cause is that it is necessary to take into account that some parts of a product may be more susceptible to risk, e.g., cracks may appear at sharp changes from a large cross-section to a small cross-section when the size of a bearing is reduced, thus requiring increase in the strength of the surface layer [4]. A number of other causes related to chemical composition of steel, carbon content and presence of alloying elements may lead to defects that are identifiable only with special inspection methods [5, 6].

2. Materials and methods
The research involved taking thin sections from bearing racers of agricultural machines that were subjected to emergency shutdown due to the bearing failure. The study was carried out at MIM-7 metallographic microscope using a ×500 magnification objective; the data was output to the monitor with a help of a ToucCam SCMOS02000KPA USB camera. The images were processed in the ToucView editor; numerical data were processed in Microsoft Excel. Classification and scoring of
defects proceeded in accordance with technical regulatory documents: “Rolling bearings. Norms and methods for metallographic monitoring of forging and thermal treatment quality of rolling bearing components made of grade 8X4B9Ф2, 95X18, 110X18M steels. Technical Guide. RTM VNIPP.0710”.

Material: Steel, grade ShKh, 95Kh18, 110Kh18M

Instruments: MIM-7 microscope, ToupCam SCMS02000KPA

Software: ToupView image processor, Microsoft Excel spreadsheet editor.

Machined bearing components are subjected to thermal treatment to provide them with certain mechanical, physical and chemical properties that improve their machineability, ensuring operational characteristics of the final product.

The bearings are subjected to graded or isothermal hardening at 850-900. This temperature is selected due to a necessity to dissolve chromium carbides in austenite and prevent excessive growth of austenite crystallite.

As a result of deviation from the thermal process procedure, defects arise that have direct impact onto the attributes and characteristics of the final product.

Quenching is used to convert austenite to martensite; it requires continuous cooling until the end of the martensite transformation. High-carbon steel is highly susceptible to formation of residual austenite in its structure; the amount of austenite depends on the location of the martensite point: the lower the point, the more austenite is formed [7, 8]. The residual austenite reduces hardness and wear-resisting properties of the tempered steel, which is usually more evident at the surface where carbon content is higher. Rectification of this defect takes place when the part is cooled to temperatures below freezing.

In bearing manufacturing, fine-needled martensite is produced by quenching and low-temperature tempering. Coarse-needled martensite is formed if the steel is overheated. Martensite is formed from austenite grains: the larger the grains, the larger the prismatic martensite needles [9]. This defect may be rectified by normalization, if there is enough of machining allowance in the part, as, if the allowance is small, then after normalization and re-quenching, there will be a large depleted and decarburized zone that will not be removed with burnishing, thus increasing the possibility of crack formation. Thus, the machining allowance shall be 0.08 mm for quenching under shielding atmosphere and 0.2 mm for quenching without the shielding atmosphere.

Troostite is a highly disperse variation of pearlite that appears as darkened spots against the light background of martensite. It is formed in breakdown of austenite due to insufficient cooling intensity. There is a distinction between granulitic (tempered) troostite and laminated troostite that is formed in quenching. Both types have very similar hardness, but the granulitic variety is more plastic and toughened. This defect is rectified by re-quenching and lowering the tempering temperature.

Banded carbide inclusions are non-uniform structures of quenched steel caused by accumulation of small-scale carbides; it is a cause of non-uniformity in properties of final product. This defect may be rectified by prolonged exposure to high temperatures (1150-1160 °C).

Carbide eliquation (sweating) is formation of large carbides in lineage structure due to strong dendrite eliquation. Carbide is easily spalled from the bearing surface, as it is very hard and brittle. This defect is rectified by prolonged exposure to a temperature of 1150-1160 °C.

3. Results and Discussion

Treatment of ShKh15 steel consisted of quenching that used: a Podina three-zone inertial traveling furnace or a three-zone traveling belt furnace, or salt baths; cooling in quenching oil, tempering at \( T = 150 ^\circ \text{C} \). The thermal treatment (TT) shall result in fine-crystalline martensite with excess of carbides (figure 1).
Figure 1. Structure of defect-free ShKh15 steel (fine-crystalline martensite with excess of carbides).

Deviations from the treatment procedure resulted in areas of troostite. Troostite is a highly disperse variation of pearlite that appears as darkened spots against the light background of martensite (figure 2).

Figure 2. Structure of defective ShKh15 steel (martensite + troostite areas + excessive carbides).

For 20Kh2N4A steel, cementation was performed in a box furnace at a temperature of $T = 920^\circ C$, with a carbon potential of 1.3%, followed with a two-stage high tempering: the first stage is $570^\circ C$, the second stage is $630^\circ C$; followed with tempering at $T = 800^\circ C$ with cooling in Thermol-26 oil. As a result of TT, the structure of fine-crystalline fine-needled martensite with excessive carbides was obtained (figure 3). Carbides here represent a defect arising from overheating or, in this case, from too high a carbon potential. Excess of carbides leads to increased brittleness.

Figure 3. Structure of defective 20Kh2N4A steel (fine-needled martensite with excess of carbides).
An example of quality thermal treatment is 95Kh18 steel after quenching in the box furnace at $T = 1065 \, ^\circ\text{C}$ and cold treatment at $T = -70 \, ^\circ\text{C}$ (petroleum solvent + dry ice) with subsequent low-temperature tempering at $T = 150 \, ^\circ\text{C}$ (figure 4). 

![Figure 4. Structure of the 95Kh18 steel free of defect.](image)

The bearing manufacture employs special scales for evaluating the final product quality; the scales are photographs of microsections that are scored according to increased number of defects in their microstructure.

Scale 3. Microstructure of the ShKh15 steel after quenching and tempering.

The scale is constructed on the principle of increasing size of troostite spots and their quantitative agglomeration in a certain area seen through a microscope.

Points 1-4 are not rejection points; they reflect the structure of hidden crystalline or fine-crystalline martensite + excessive carbides (Figure 1).

Points from 5 to 13 are a basis for rejection, the observed structure shows: troostite areas, large excessive carbides, fine-needled, medium-needled and large-needled martensite (Figure 2, 7 point).

Scale 4. Microstructure of the carburized case of bearing parts from 20Kh2N4A steel after final machining.

Points from 1 to 5 is allowed for bearings with diameters of under 300 mm, higher scoring (6-10) is the basis for rejection. The scale is constructed according to increasing size of martensite needles. Points 6-9 follow the principle of increasing number and density of traces of carbide needles, undissolved during heating for quenching.

Points 1-5 have the structure of cryptocrystalline martensite + excessive carbides, cryptocrystalline martensite with minor traces of carbide needles + excessive carbides.

Points from 6 to 10 differ from scores 1-5 by the following structural formations: residual austenite, residues of carbide needles of various size and density, fine-needled martensite (Figure 3).

Scale 7. Microstructure of 95Kh18 steel after final thermal treatment.

1 point. After the final TT, identification of boundaries between grains by etching to reveal the microstructure of bearing parts in not a basis for rejection (Figure 4).

2 points. After quenching and tempering at a temperature of 160 \, ^\circ\text{C}, a rejection criterion is the presence of fine-needled martensite resulting from overheating the steel in preparation for quenching.

3 points. After quenching and tempering at a temperature of 400-420 \, ^\circ\text{C}, a rejection criterion is presence of medium-needled martensite resulting from overheating the steel in preparation for quenching.

Recommendations for defect identification in microscopic studies:

1) Troostite is a highly disperse variation of pearlite that appears as darkened spots against the light background of martensite.

Under the microscope, troostite corresponding to scores of 6, 8, 9 a appears as non-uniformly black spots of various sizes and ragged edges, the core consists of inclusions; 5-point troostite appears as small
dark woolly needles against the light background of martensite, 7-point troostine appears as large needles. Troostite corresponding to 6, 8 and 9 points may be seen through the martensite structure.

2) Decarburization is a complete burnout of carbon from the surface of metal, under the optic microscope it appears as a white checkered stripe under the beginning of the structure.

3) Impoverishing is a partial burnout of carbon from the metal surface. It may appear as a needle stripe with a certain depth before the beginning of the structure. It may also appear as a stripe, which is darker than the structure.

4) Overheat appears as fine-needled or large-needled martensite.

5) Thermal crack is defined by lack of impoverished or decarburized layer on the surface; its end is serpentine;

6) Metal crack is defined by presence of impoverished or decarburized layer on the surface; its end is obtuse;

Causes of the defects are low rate of cooling and incorrect selection of the cooling medium (for the IIIIX15 steel), excessive carbon potential (for the 20X2H4A steel). The defects may arise due to incorrect selection of the temperature interval; the form of the product (some parts are more susceptible to risk), carbon content and alloy element content, mounting method used in the thermal treatment shall be taken into account as well [4, 10]. The consequences of incorrect thermal treatment are rectified by re-quenching and re-tempering in a different cooling medium, annealing and re-cementation.

4. Conclusion
To reduce the number of rejected parts and increase the productivity of the bearing manufacture, it is necessary to prevent appearance of thermal treatment defects. It requires taking into account the factors described in this paper, constant monitoring of thermal treatment conditions, changing to a more moderate mode that does not cause residual stress. As an alternative, it is possible to consider substitution of materials with steels that are fit for induction thermal treatment [11].

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