The heat treatment impact on microstructure quality of 14 260 bearing steel

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Abstract. The paper deals with the investigation of the heat treatment impact on the microstructure quality of the bearing steel. The given heat treatment process as well as its impact on quality was determined for 14 260 material (the designation of the given steel is based on Slovak Technical Standards). Unsuitable conditions of hardening process could be seen in the final steel microstructure as well as in values of mechanical properties. The structural heterogeneity and unsuitable processing conditions of the heat treatment led to pitting and premature initiation of the rupture. The given condition can lead to the component lifetime reduction, and even to the various technical collisions. The mentioned investigation was performed for a component that is mechanically and thermally loaded in its service, where stress-strain states are not allowed. If the material is heterogeneous, even after the heat treatment, there is a risk of immediate destruction of the component and it was also evident in this case. Continuous inspection of the microstructure of the heat treated bearing steel can eliminate as well as prevent from undesirable conditions during the operation of the given structural component.

1. Introduction

Due to the current trend of decreasing production costs and increasing material quality requirements, heat treatment of steels is one of the most important processes in many engineering sectors [1]. In the use of bearing steels for the production of components under the high stress, the heat treatment, and especially the hardening, is the most crucial operation that affects the resistance to wear. Because bearing steels are mostly cyclically stressed components, high demands are established in relation to the base material, which is used for their production [2, 3]. It is a chemical composition, micropurity, microstructure and resulting homogeneity. In addition to design parameters, these steels have to meet high technological requirements, such as formability, machinability and superheatability [4].

The presented paper deals with the investigation of the degradation of a particular component, while the given degradation occurred after the heat treatment (before its use in service). The component was heat-treated (hardened and tempered) and after it had been completely cooled, there was the occurrence of the rupture. Considering the fast that the bearing steel, along with its chemical composition, belongs among alloyed materials with relatively high carbon content, this material is very sensitive to the thermal process [5, 6]. The component, which had to be investigated, is not directly and accurately specified in the terms of company regulations due to the trade competition resulting into trade secret. The experiment was based on microscopic study of bearing steel microstructures and the
designation of the investigated material according to Slovak Technical Standards (STN) is 14 260 (EN 1.7102). Considering the final degradation of the components along with the changes in the structure, it is possible to identify the origin of the damage or rupture from the material aspect.

2. Experiment

The paper deals with the investigation of the critical states leading to the rupture of the heat-treated component, using microscopic investigation methods. The hardening of the bearing steels takes place above the temperature from 800 °C to 880 °C. Referring to change of the basic crystalline lattice, the homogenization of the austenite can be ensured by the mentioned temperatures along with subsequent cooling process at the upper critical (or greater) cooling rate. The result of this homogenisation process is that there is the occurrence of martensite and residual austenite throughout the whole volume of the component. The transformation takes place at temperatures below 220 °C, where the rate of carbon diffusion is completely avoided. This given change depends on the cooling as well as on the chemical composition of austenite. The martensitic transformation involves the change of the crystallographic lattice. Microstructures of prepared samples were investigated in a metallographic way, while the given observed samples were from undamaged and damaged areas of the component. The whole process of investigation was connected with the evaluation of the micro-purity, the nature of the microstructure and the determination of the unwanted phases before and after the heat treatment. Moreover, the material evaluation was complemented by a hardness inspection based on the Vickers method under the load of HV0.2. The chemical composition of the tested material is shown in the table 1. The given investigated material is commonly supplied in the form of bars and sheets that are the most suitable for hot forming process. The component which has to withstand the cyclic loading in operation or service has been hardened and tempered according to the prescribed thermal processing mode, which is shown in table 2.

Table 1. Chemical composition of 14 260 steel (STN) or EN 1.7102 steel.

| Element | C  | Si  | Mn  | Cr  | P    | S    |
|---------|----|-----|-----|-----|------|------|
| in wt. %| 0.50 | 1.30 | 0.50 | 0.50 | Max. | Max. |
| in wt. %| 0.60 | 1.60 | 0.80 | 0.70 | 0.03 | 0.03 |

Table 2. Heat processing mode of the component.

| Type of heat treatment | Heating temperature | Holding time |
|------------------------|---------------------|--------------|
| Hardening              | 910 °C              | 180 min      |
| Tempering              | 490 °C              | 180 min      |

The micropurity was evaluated in longitudinal and cross-sectional directions with the reference to the grade of 2 (for sulphide as well as oxide particles) and according to STN EN 10 247 (42 0471). The inclusions of the sulphides (figure 1) occurred in the form of elongated shape and they were accumulated in undesirable agglomerations in some areas of the tested or investigated component. The oxide particles could be seen in the shape of lines (figure 2) with the different length and size. The hardness of these inclusions was multiplied by the occurrence of fine oxides in sulphide. The occurrence of such oxisulphide complexes superposes stress states in the material. The mentioned condition can be the reason for the prerequisites relating to the unpredictable and sudden fracture of the component and the given problem was also revealed in the case of our tested or investigated material. From the micropurity evaluation of the material, it was confirmed that there was the negative effect of the sulphur, which was involved in the impurities of the material in the form of sulphides and oxisulphides. It is very difficult to remove these undesirable phases during the heat treatment [7].
From the aspect of the comprehensive assessment of the overall condition of the ruptured component, attention was also paid to the investigation of the nature of the surface as well as the sites where the changes had already been observed in a visual way. After hardening, there was a surface rupture observed and it exhibited the character of corrosion damage, leading to the peeling of the base material (figure 3). The resulting cracks were corroded and filled with oxides (their origin is based on the thermal process), while these mentioned oxides caused the stress in the given volume of the material [8]. It was possible to observe microscopically how the cracks in the material were spread from the initiation sites. The oxidation process caused the surface rupture, which led deeply (directly) to the base material and it is shown in figure 3. The impermissible dimensions of rupture in material were caused due to material weakness and it led to the brittle fracture of tested material and it has to be pointed out that the described phenomenon is characteristic feature for large volume components.

It can be concluded that small intercrystalline cracks (figure 4) were joined together and created large main cracks, which were propagated into a large depth of material and they could be the reason for a total damage of the component [6].

In relation to the microstructure, it was possible to observe the highlighted directions of the phases (bands) that were different in their chemical composition. Formation of the highlighted directions of
phases in the microstructure (figure 5) stands for the unacceptable heterogeneity of the material. In the case of plastic deformation, these areas will behave differently and they will produce uneven stress throughout the volume of the material.

![Figure 5. Sorbite microstructure.](image)

In relation to the microstructure of the component, there was not only the presence of the sulphides and oxides but there were also relatively large carbides (figure 6). The tempering temperature of the bearing steels vary from 120 °C to 380 °C, depending on the type of material and the tempering procedure, while the holding time at this temperature is from 2 to 4 hours. Held at this temperature and after further slow cooling, structures are formed in a near-equilibrium state which is suitable for further processing, such as grinding. The amount of residual austenite is also related to the change of the tempering type because the percentage of the residual austenite decreases with an increasing temperature (e.g.: at 120 °C, the residual austenite content is not more than 20 %, while at 350 °C, the residual austenite content is only 1% in maximum). The heat treatment processes caused undesirable changes in the homogeneity of microstructure and these changes are undesirable for the component under cyclic loading [9].

![Figure 6. Detail of undesirable phases.](image)

Depending on the chemical composition, the occurrence of the homogeneous sorbite could be preserved only if the bearing steel was properly hardened (from 850–880 °C to oil) and by this way, the coarse needles of martensite would be created after tempering procedure (1 hour at approx. 520 °C and with cooling in the air). If the material is overheated during the hardening to a temperature of more than 900 °C, as it is documented in table 2, large martensite needles remain in the microstructure of sorbite. The overall heterogeneity of the microstructure leads to the stress states that are the reason...
for a possible future rupture or violation. From the qualitative point of view, it can be stated that the final character of the microstructure, which was obtained by the mentioned processing technology, is undesirable [6, 7]. Based on the several aspects of the evaluated component, it could be assumed that a sudden and unpredictable violation of the entire component would occur. In relation to the hardness tests, the obtained hardness values (Vickers method at load of HV$_{0.2}$) for the examined microstructures were in the range from 470 HV$_{0.2}$ to 480 HV$_{0.2}$. The high hardness of the material was also caused by the relatively large occurrence of the carbide particles in this microstructure [10].

3. Conclusion
The introduced work and all aspects of the investigation procedures are closely related to the technical problem which is very difficult to be solved on the basis of the computational modelling. Based on the investigation, there were the structure changes resulting from heat processing mode and therefore, the given processing mode can have impact on the material properties and their changes. Considering the effect of stress-strain states for individual operating components, it is important to point out that material properties represent the initiating factor for the creation of the input parameters in relation to the computational modelling. In the case of the introduced bearing steel, the insufficient and inappropriate heat treatment leads to the subsequent heterogeneity of the microstructure.

Relating to the bearing component, the heterogeneity or undesirable structure phases can be the reason for shortening of lifetime interval. During the computational modelling, the homogeneity of the component is taken into account. If the material is heterogeneous, the final computational outputs for prediction of degradation states and failure can be distorted and inaccurate. The given problem deals with the fact that there is a lack of the accurate input parameters which could be included into the computational modelling process in relation to the current software system. Referring to the mentioned fact, the verification and the accuracy for prediction can be mainly based on the experimental principles as well as study or observation of material structure, while the samples of the given tested material are prepared in a metallographic way.

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