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The influence of quenching temperature on distortions during the individual quenching method

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ABSTRACT

Purpose: In this paper, the impact of hardening temperature on the quenching distortions which occur during low-pressure carburizing with gas quenching - using the individual quenching method - was analysed.

Design/methodology/approach: The reference elements were subjected to carburizing at 980°C, followed by gas quenching at temperatures of 860°C, 920°C and 980°C. The geometrical measurements of the elements were made before and after the chemical treatment and the size of the quenching distortions of their geometrical parameters was determined.

Findings: It was demonstrated that a high temperature of quenching has an unfavourable effect on changes in cylindricity and roundness parameters but, at the same time, reduces the size of distortion of outer parameters. Low temperature quenching reduces quenching distortions of cylindricity and roundness parameters while increasing the distortion of outer dimensions.

Research limitations/implications: Based on the research and analysis carried out in this work, it was found that the use of lower quenching temperature is justified in economic and quality terms.

Practical implications: In the case of the aviation or automotive industry, very high quality of manufactured elements along with a simultaneous reduction of their production costs is extremely important. Maintaining the dimensions of the elements during heat treatment is extremely difficult. The tests allowed to determine the optimal hardening temperature, which brings with it acceptable deformations. Since it is easier to “repair” the outer geometrical dimensions (diameter, thickness), it seems that quenching from lower temperatures is a more favourable process.

Originality/value: The conducted tests allowed to determine the most favourable conditions for hardening elements from the automotive industry, taking into account the occurring deformations and their subsequent processing.

Keywords: Thermo treatment, Distortion, Quenching, Low-pressure carburizing

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The problem of the occurrence of quenching distortions and related complications during the production of machine parts has been mentioned in scientific and industrial literature since the 1860s. The objective of quenching is to obtain a martensitic structure that ensures a high hardness of the steel quenched, and its final value depends on the rate of cooling and the quantity of carbon included within that structure. The greatest hardness is obtained in steels with a composition similar to an eutectoid one. Increasing the carbon content above this value has practically no impact on the increase in hardness as after quenching there is quite a lot of residual austenite in such steel, which reduces steel hardness [1,2]. The increase in hardness in low carbon steel varieties is insignificant, which is explained by the minimal distortion of the iron lattice α. Thus, in practice, the steel varieties subjected to quenching contain more than 0.3% C.

In order to achieve the desired content of carbon in the material prior to quenching, the machine elements are subjected to carburizing. It is only after carburizing that one of the treatment options takes place: (1) direct quenching from the carburization temperature (favourable because of low treatment cost), (2) after cooling down, individual quenching from a temperature characteristic of the carburized layer, (3) after cooling down, individual quenching from a temperature characteristic of the core, (4) after cooling down, double quenching: from a higher temperature characteristic of the core, and then from a lower temperate characteristic of the carburized layer [3-5]. To sum up, both quenching from high temperatures (from carburizing temperature) and low temperatures (after precooling) is practised.

Many researchers underline that a significant cause of quenching distortions (geometric distortions) are improper cooling conditions in terms of improper choice of coolant type, quenching temperature and rinsing the element with a cooling medium during quenching, which cause an excessively slow or uneven result of absorption of heat from the element. Dybowski et al. indicate that low pressure carburizing, after which the high pressure quenching is applied, results in less distortions than low pressure carburizing with oil quenching [6]. According to Dybowski et al., in the case of oil quenching, the average value of radial run-out is lower than in the case of gas quenching [7,8]. Stachurski et al. report that applying a higher pressure of the cooling gas (1 MPa, N_2) results in a smaller opening diameter in comparison to the application of a lower pressure of cooling gas (0.6 MPa, N_2) [9]. They also underline that in order to minimise distortions after quenching, the functioning of the quenching chamber has to be optimised with regard to design and working parameters. Atraszkiewicz et al. also indicate the type of cooling medium as a significant factor which has an impact on distortions [10]. They demonstrate that applying helium instead of nitrogen in the quenching process results in a reduction in unevenness and distortions. In the case of quenching in gas, the character of distortions is uniform, in contrast to quenching in oil. Additionally, what happens in the case of oil quenching is partial contraction and a partial increase in the wheel division diameter. Paweta and Pietrasik [11] presents the analysis of hardening distortions using high pressure gas and oil as a hardening medium for the part of machines used in the automotive industry after the carburizing process. The analysis of individual hardening processes showed that depending on the cooling medium used, different distortion values are obtained. The distortion value is also significantly affected by the parameters of the hardening process – gas pressure/oil mixers delay, which affect phase transitions. The smallest hardening distortions were obtained as a result of the hardening process in gas at a gas pressure of 0.3 MPa. Moreover, phase transitions, change in the number of phases and thermal contractions during thermal treatment also play a crucial role in the course of that treatment. In particular, it is known that the plasticity of transformation that is ascribed to a permanent distortion caused by phase transition results in unexpected dimensional instability and difficulties in process optimisation [12-17].

In recent years, a series of attempts have been made at designing devices and their instrumentation, which is aimed at reducing the distortions obtained and achieving uniformity [18-21]. However, there is no unambiguous information on how the quenching temperature affects distortions. This paper aims at filling in that gap.

2. Materials and methods

30 bushings were made of 20MnCr5 steel. Their outer and inner diameter amounted to 120 mm and 95 mm, and their height was 35 mm. All the elements were subjected to low pressure carburizing using the stream method [22] in a temperature of 980°C (Tab. 1), and then to gas quenching at a temperature of 860°C (group A), 920°C (group B) and 980°C (group C) in nitrogen gas with pressure 0.6 MPa. The required effective case depth of the carburizing layer was 0.6 mm with carbon concentration on the surface 0.8%. A rotation device for individual quenching was used for carrying out quenching [23]. The elements were individually inserted into a chamber where the cooling nozzles were arranged around them and the base with the coolant was rotated thus ensuring identical quenching conditions for each of the elements [18,24].

Table 1.
Thermal and chemical treatment process parameters

Group	Carburizing temperature, °C	Hardening temperature, °C
A	980	860
B	980	920
C	980	980

Geometrical measurements of elements [9] were made before and after chemical treatment, providing the basis for determining the extent of quenching distortions of their geometrical parameters: top surface flatness, outer diameter, inner diameter, outer diameter roundness, inner diameter cylindricity, bushing thickness and cone opening angle. The accuracy of the measurements was 0.001 mm The measurement results were analysed in order to verify whether any statistically significant differences exist in the average values of geometrical parameters between groups A, B and C. Depending on the assumptions fulfilled, the individual research hypotheses were tested using the Kruskal-Wallis test or a single factor ANOVA test, with statistical significance assumed at a level of $\alpha=0.05$.

3. Results

An increase in the value of the geometrical parameters: flatness, cylindricity, roundness and cone opening angle was noticed in the temperature range examined. The values of the inner diameter, outer diameter and bushing width were decreasing. The average difference in the value of the flatness parameter was 11±6 µm. The average difference in the inner diameter was -261±6 µm. The change in the outer diameter of the elements depended on the quenching temperature ($p<0.05$) and amounted accordingly to -134±6 µm for a temperature of 860°C, -121±6 µm for a temperature of 920°C and -116±4 µm for a temperature of 980°C. Statistically significant differences were noticed between all groups (Fig. 1).

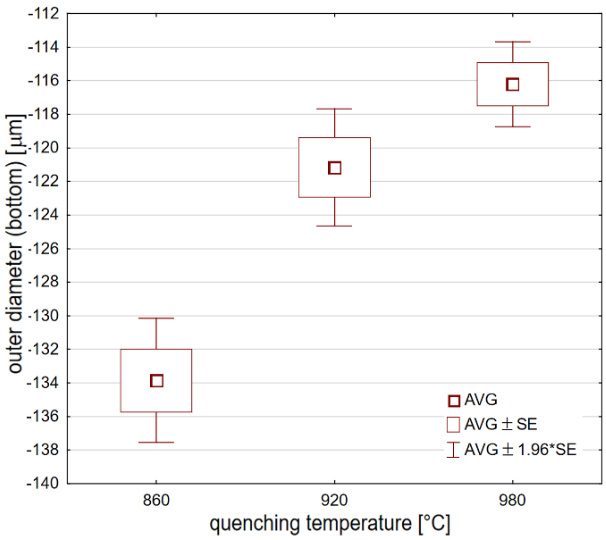

Fig. 1. Graph of changes in outer diameters depending on quenching temperature

The change in roundness and cylindricity parameters also depended on the quenching temperature (a roundness of: 10±11 µm, 23±9 µm, and 21±12 µm and cylindricity of: 15±5 µm, 25±7 µm, and 23±9 µm), but significant changes between the groups were only noticed for the group quenched from a temperature of 860°C ($p<0.05$). At the same time, the changes in these groups were the smallest (Fig. 2, Fig. 3).

In the case of the cone opening angle, the differences in groups were, accordingly, 0.116°, 0.125° and 0.122° for the temperatures of 860°C, 920°C and 980°C (Fig. 4), but only the differences between the 860°C groups and the 920°C groups can be considered significant ($p<0.05$). The change in thickness of the ring of elements also depended on the quenching temperature and in the 860°C, 920°C and 980°C groups it amounted to -8±3 µm, -7±6 µm and 1±5 µm respectively (Fig. 5). Significant differences were demonstrated between the 980°C group and the 860°C group as well as between the 980°C group and the 920°C group.

Based on the results of statistical analyses, charts (Figs 1-5) were prepared, adequate to the types of tests performed.

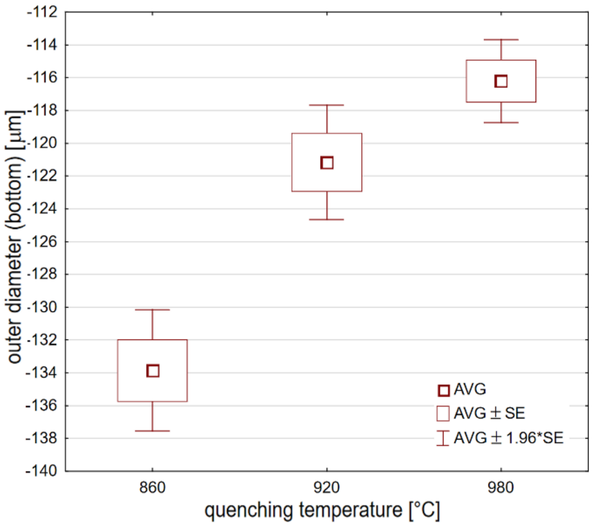

Fig. 2. Graph of changes outer diameters roundness depending on quenching temperature

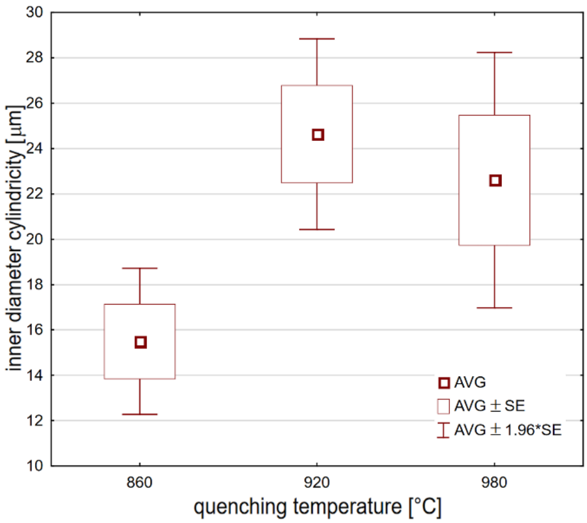

Fig. 3. Graph of changes inner diameters cylindricity depending on quenching temperature

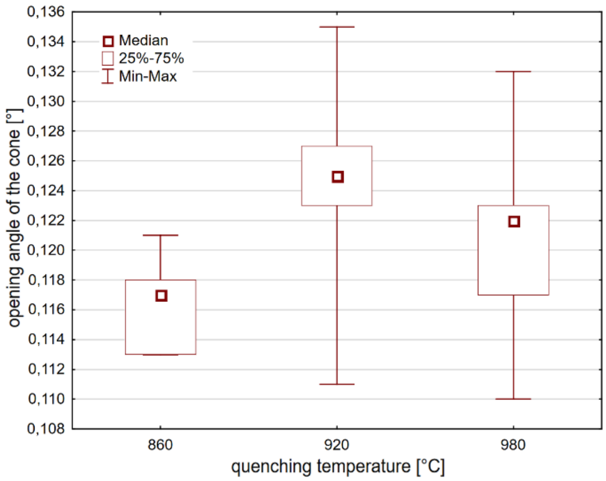

Fig. 4. Graph of changes in cone opening angle depending on quenching temperature

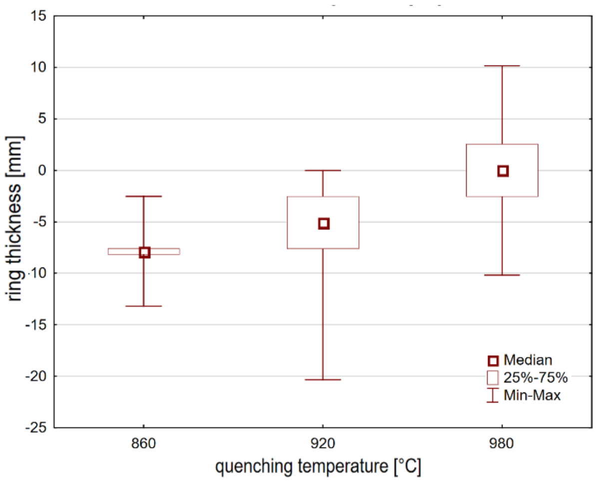

Fig. 5. Graph of changes ring thickness width depending on quenching temperature

4. Discussion

Statistical analysis (ANOVA) of the measurements made indicates that statistically significant differences exist between temperature groups for the following parameters: cylindricity, roundness, cone opening angle, outer diameter and ring thickness. At the same time, the average differences in the flatness and inner diameter parameters have to be considered independent of the quenching temperature. The lower quenching temperature (860°C) results in unfavorable changes in the outer diameter and ring thickness parameters. At the same time, a reduction in the deformation of roundness, cylindricity and cone opening angle parameters is noticed in such temperatures.

A high temperature of quenching (980°C) has an unfavorable effect on changing the cylindricity and roundness parameters but, at the same time, reduces the degree of distortion of the outer diameter and ring thickness parameters. In the opinion of the authors, quenching from high temperatures (usually from quenching temperatures) results in the immediate occurrence of martensitic transition and a “freezing” of the geometrical dimensions on the outer side of the element. Consequently, the "deformation front" is pushed deep inside the element and the inevitable changes in volume, related to transition of the material from austenite to martensite, take place in the inner parts of the element. This causes distortions in roundness and cylindricity. Quenching from low temperatures (i.e. after the stage of precooling for quenching) delays the moment of martensitic transition in the outer parts in relation to the inner parts of elements, which leads to retention of the cylindricity and roundness parameters but does not prevent an increase in the outer volume of the element. Since it is easier to "repair" the outer geometrical dimensions (diameter, thickness), it seems that quenching from lower temperatures is a more favorable process.

5. Conclusions

1. A high temperature of quenching has an unfavourable effect on changing the cylindricity and roundness parameters but, at the same time, reduces the size of distortions of the outer parameters (outer diameters, length of elements).
2. Low temperature quenching reduces quenching distortions of cylindricity and roundness parameters while increasing the distortions of the outer dimensions.
3. Quenching from lower temperatures is a more favourable process.

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