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Influence of quenching temperature of the individual quenching method on the geometrical dimensions of the elements

E Wołowiec-Korecka¹, P Zgórniak², A Brewka^{1,3} and K Krupanek¹

¹Institute of Materials Science and Engineering, Lodz University of Technology, Lodz, Poland

²Institute of Machine Tools and Production Engineering, Lodz University of Technology, Lodz, Poland

³Seco/Warwick S.A., Świebodzin, Poland

Email: emilia.wolowiec@p.lodz.pl

Abstract. The quenching process is related to the internal-stress phenomena, resulting in geometric changes (distortions). In this paper, the impact of hardening temperature on the quenching distortions occurring during low-pressure carburizing with gas quenching using the individual quenching method was analyzed. 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: external and internal diameters as well as ring thickness. The study examined whether there is a statistically significant difference between the geometrical dimensions of the elements before and after the thermo-chemical treatment for the elements in three temperature groups. It was shown that for the ring thickness parameter there are no significant differences between the groups of elements before and after heat treatment for the temperature 980°C, while for the temperature 860°C and 920°C these changes are significant. However, for external diameter bottom, there is always a difference regardless of temperature. For the single piece-flow vacuum carburizing with gas quenching using the individual quenching method, it is advisable to use the highest possible quenching temperatures to reduce quenching distortions.

1. Introduction

The problem of quenching distortions is inextricably linked to machine parts production process. The purpose of quenching is to introduce martensite in hardened steel in order to ensure a high level of hardness. The final value of martensitic structure depends on cooling time and the amount of carbon contained in the structure. In practice, only steel grades that contain more than 0.3% C are quenched. Machine parts are often carburized to obtain the desired carbon content in the material before quenching.

Many researchers highlight that an important cause of quenching distortions (geometric changes) are improper cooling conditions, especially the selection of unsuitable coolant type, cooling temperature and the temperature while rinsing the element with coolant during quenching, which causes too slow or uneven heat absorption from the element. Dybowski et al. indicate that low pressure carburizing followed by high pressure quenching causes less distortion than low pressure carburizing with oil quenching [1]. According to Dybowski et al., in case of oil quenching, the mean radial run-out is lower



than in case of gas quenching [2,3]. Stachurski et al. report that the use of a higher cooling gas pressure results in a smaller bore diameter compared to the use of lower cooling gas pressure [4]. They also emphasize that in order to minimize distortion after quenching, the structural and operating parameters of the quenching chamber should be optimized. Atraszkiewicz et al. indicate that the type of coolant is also an important factor for the process of forming distortions [5]. They demonstrate that the use of helium instead of nitrogen in the quenching process reduces unevenness and distortion. For gas quenching, the nature of the distortions is uniform, unlike in the case of oil quenching. In addition, in the case of oil quenching, partial shrinkage and partial increase of the pitch diameter of the wheel can occur. Additionally, phase transitions, phase number changes and thermal shrinkages during heat treatment also play a key role during quenching. In particular, it is known that the plasticity of transformation attributed to permanent distortion caused by phase transition is the reason for unexpected dimensional instability and difficulties in process optimization [6–8].

In recent years, several attempts have been made to design machines and their instrumentation with the purpose of reducing the distortions obtained and achieving uniformity [9–12]. However, there is no conclusive information on the effect of quenching temperature on distortions.

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 [13] in a temperature of 980°C (Table 1), and then to gas quenching at a temperature of 860°C (group A), 920°C (group B) and 980°C (group C). A rotation device for individual quenching was used for carrying out quenching [14]. 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 [9,15]. Geometrical measurements of elements were made before and after chemical treatment, providing the basis for determining the extent of quenching distortions of their geometrical parameters: internal diameter, external diameter, ring thickness. The measurement results were analyzed in order to verify whether any statistically significant differences exist in the average values of geometrical parameters between groups 860°C, 920°C and 980°C. Depending on the assumptions fulfilled, the individual research hypotheses were tested using the t-Student test or a Wilcoxon test, with statistical significance assumed at a level of $\alpha=0.05$

Table 1. Thermal and chemical treatment process parameters.

Group	LPC temperature [°C]	HPGQ temperature [°C]
1	980	860
2	980	920
3	980	980

3. Results

An increase in the value of the geometrical parameters: external diameter, internal diameter, ring thickness was noticed in the temperature range examined. Analyzing the measurement results, a decrease in internal and external diameters of the bushings was observed. The average difference in the inner diameter was -260 ± 5 μm for temperature 860°C, -259 ± 6 μm for temperature 920°C and -262 ± 7 μm for temperature 980°C (Figure 1, Figure 2, Figure 3). The average difference in the external diameter was -134 ± 6 μm for temperature 860°C, -121 ± 6 μm for temperature 920°C and -116 ± 4 μm for temperature 980°C (Figure 4, Figure 5, Figure 6). The average difference in the ring thickness was -7.8 ± 3.4 μm for temperature 860°C, -6.6 ± 5.9 μm for temperature 920°C and 0.5 ± 5.3 μm for temperature 980°C (Figure 7, Figure 8, Figure 9). These differences are statistically significant for all parameters, in all temperature groups ($p < 0.05$) except for ring thickness, where for 980°C there were no differences between the values before and after heat treatment.

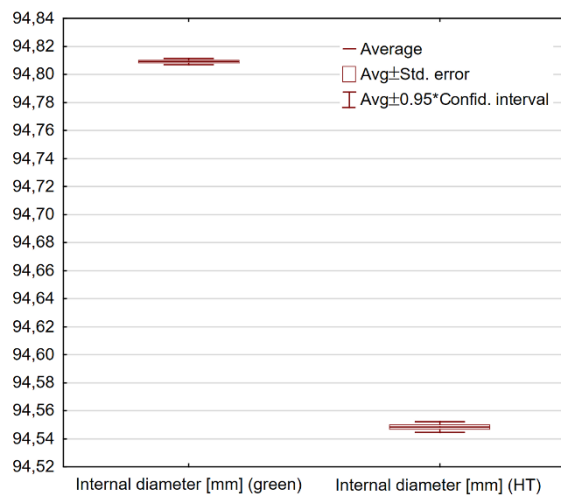


Figure 1. Internal diameters of elements before and after thermo-chemical treatment at 860°C.

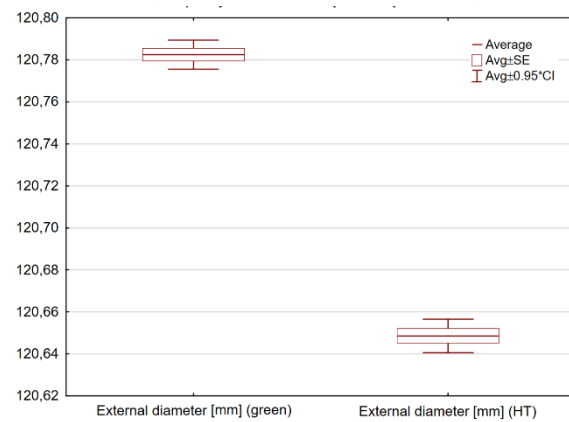


Figure 2. External diameters of elements before and after thermo-chemical treatment at 860°C.

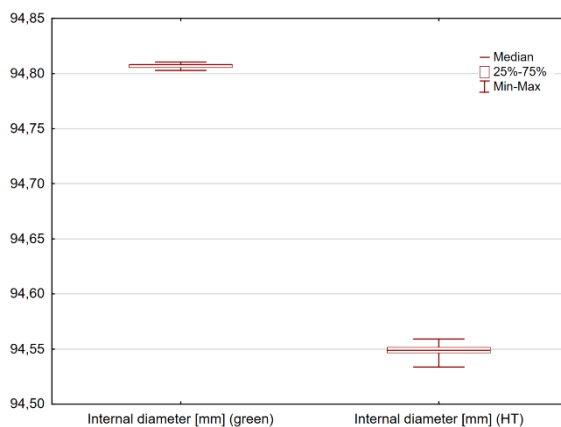


Figure 3. Internal diameters of elements before and after thermo-chemical treatment at 920°C.

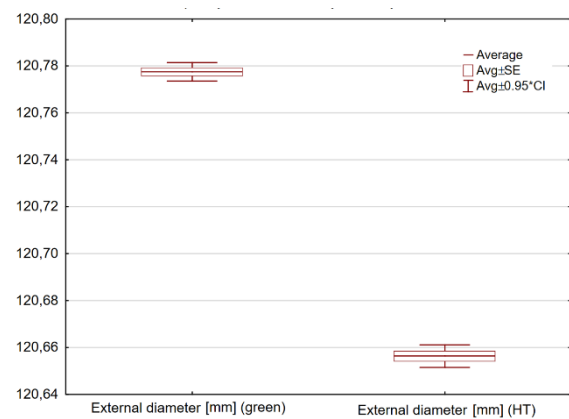


Figure 4. External diameters of elements before and after thermo-chemical treatment at 920°C.

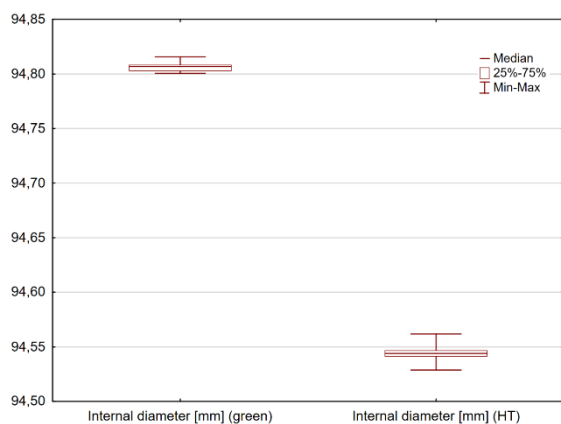


Figure 5. Internal diameters of elements before and after thermo-chemical treatment at 980°C.

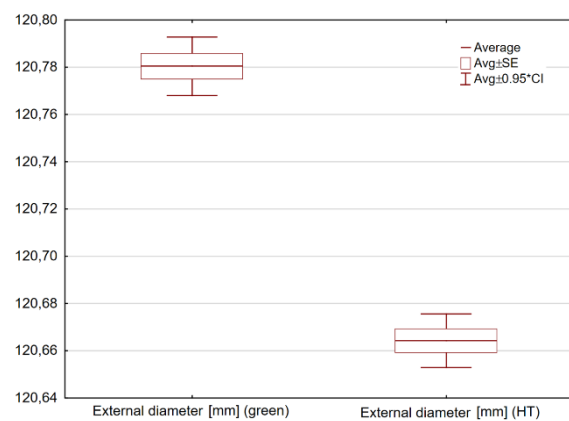


Figure 6. External diameters of elements before and after thermo-chemical treatment at 980°C.

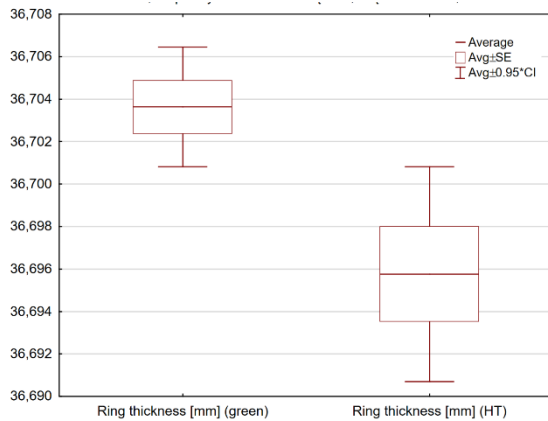


Figure 7. Ring thickness before and after thermo-chemical treatment at 920°C.

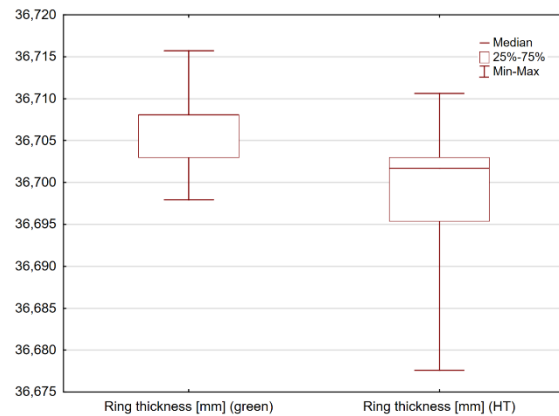


Figure 8. Ring thickness before and after thermo-chemical treatment at 920°C.

Furthermore, using the Tukey test it was demonstrated that the differences in internal diameters are significantly greater for 860°C ($p < 0.05$) (Figure 10) and using the Kruskal-Wallis test it was shown that ring thickness was significantly smaller for 980°C, compared to other temperatures ($p < 0.05$) (Figure 11).

4. Discussion

Statistical analysis of the measurements made indicates that statistically significant differences exist between temperature groups for the following parameters: outer diameter and ring thickness. The lower quenching temperature (860°C) results in unfavorable changes in the outer diameter and ring thickness parameters. A high temperature of quenching (980°C) 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. 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. It seems that quenching from lower temperatures is a more favorable process.

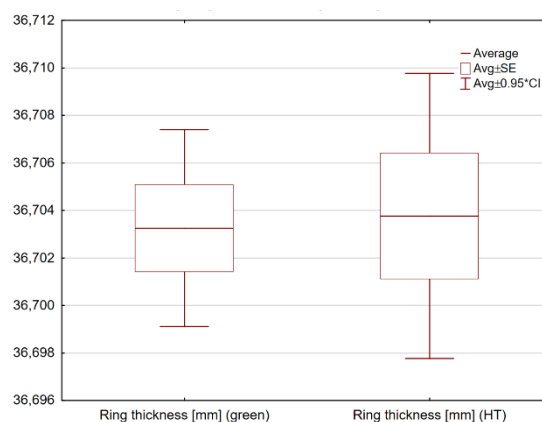


Figure 9. Ring thickness before and after thermo-chemical treatment at 980°C.

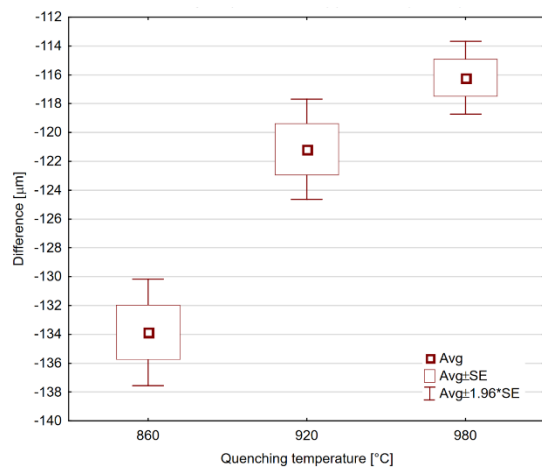


Figure 10. Differences in ring external diameter before and after thermo-chemical treatment depending on quenching temperature.

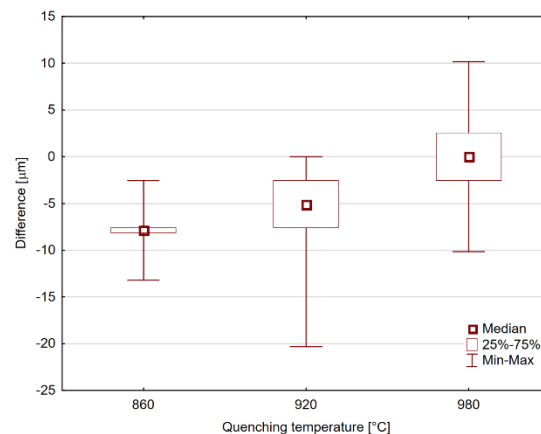


Figure 11. Differences in ring thickness before and after thermo-chemical treatment depending on quenching temperature.

5. Conclusions

Based on the results of the research, the following conclusions were reached:

1. A low temperature of quenching has an unfavorable effect on changing the external diameter and ring thickness parameters.
2. High temperature quenching reduces quenching distortions of external diameter and ring thickness.
3. at the same time, reduces the size of distortions of the outer parameters (outer diameters, length of elements).
4. High temperature quenching does not change the ring thickness parameter before and after heat treatment.

Acknowledgments

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