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# Study of Distortion on the Example of the Rings from Ductile Iron and Cast Steel

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## Abstract

The paper attempts to analyze distortions of cast iron and cast steel rings, after heat treatment cycles. The factors influencing distortion are: chemical composition of material, sample geometry, manufacturing process, hardenability, temperature and heat treatment method. Standard distortion tests are performed on C-ring samples. We selected a ring-model, which approximate the actual part, so that findings apply to gear rings. Because distortion depends on so many variables, this study followed strictly defined procedures. The research was started by specifying the appropriate geometry of the samples. Then, the heat treatment was conducted and samples were measured again. The obtained results allow to determine the value of the resulting distortion and their admissibility. The research will be used to evaluate the possibility of using the material to produce parts of equipment operated under extreme load conditions.

**Keywords:** Heat treatment, Ductile iron, Cast steel, Micrometric measurements, Distortion

## 1. Introduction

The main cause of deformation during the quenching step is the formation of a martensitic structure, occurring in construction materials such as steel or cast iron alloys. The use of a particular element will determine the conditions of the carried thermal processes [1-3].

Gear wheels, especially those in heavy-duty construction such as mining machine gearboxes, must meet the highest demands, not only in terms of mechanical properties but also in dimensional accuracy. These parts are most often produced from iron alloys with a carbon content of over 0.15% and additions of elements such as Cr, Mn, Mo or Ni. The first step in the manufacturing process is the forging of the gears, followed by machining to give it proper shape. The next step is carburizing, quenching and

tempering to give the part mechanical properties required of the gears [4]. The final process is finishing e.g. cutting of gear teeth. Due to the long-term production and negative phenomena occurring after thermal and thermo-chemical processes, i.e. quenching deformations or quenching cracks. For this reason, it would be reasonable to carry out the hardening process with isothermal stop in the field of formation of bainite with austenite, when there is no conversion of austenite to martensite, the distortion during cooling will be minimized. Furthermore, use of vacuum furnace treatment will avoid surface effects on components that are undesirable due to their operating characteristics. Nevertheless, the analysis of plastic deformations resulting from newly developed processes, where there is no martensitic transformation, is very important both for the quality of the product and for the cost-effectiveness of the production process [5-6].

## 2. Experimental procedure

### 2.1. Geometry selection for distortion testing

Standard distortion tests are performed on C-ring samples. They are not, however, a good representation of the geometry of the gear. For this reason, it was decided to make the samples in the form of rings with a through hole. The formation of distortion is a very complex problem, so the generalization of the problem will only be possible using models with simple geometry [3-4].

Figure 1 shows the geometry of ring prototypes for distortion testing.

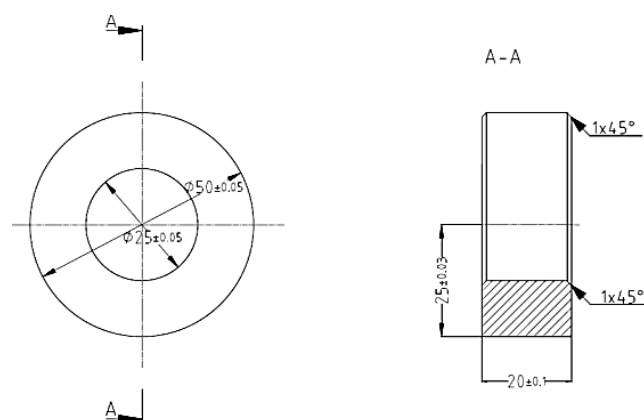


Fig. 1. Designed geometry rings for testing quenching deformations

### 2.2. Tested material

Rings were prepared from ductile cast iron and cast steel, the chemical composition of which is shown in Table 1. Two types of rings were used for each type of material. Figure 2 shows rings before heat treatment cycles.

### 2.3. Measurement methodology

For the prepared samples, the following geometric values were measured: outer diameter, inner diameter, thickness and position error, i.e. parallelism. A micrometer screw gauge and a dial indicator were used for the measurements, which allow for

Table 1.

Chemical composition of investigated ring materials [mass pct]

	C	Si	Mn	Cu	Mo	Ni	Mg	S	P	Cr	V
<i>Cast steel</i>	0,67	1,33	0,61	-	0,31	1,54	-	0,02	0,02	0,51	0,12
<i>Ductile cast iron</i>	3,46	2,41	0,34	0,58	0,25	1,84	0,06	0,02	0,04	0,02	-

accuracy  $1\mu\text{m}$ . The following method was used for parallelism measurement: one of the planes of the rings was designated as "P" (right side of the sample). During parallel measurement, two gauge blocks of 18 mm and 1,3 mm were used, giving a nominal size of 19,3 mm.

After conducting the thermal processes mentioned below in table 2, the measurements were repeated to investigate the size of the resulting dimensional changes and the obtained microstructure was examined with us of optical microscope.

### 2.4. Parameters of heat treatment processes

For cast steel and ductile iron, the same two parameters of the heat treatment processes (time and temperature) were selected using the JMatPro computer program. Table 2 contains the design parameters of the processes.

Table 2.

Parameters of performed heat treatment processes

	Temperature [°C]	Time [h]
Austenitizing	930	0,5
Bainitise	300	3
		34

Heat treatment processes were carried out in a Seco/ Warwick gas-cooled vacuum oven. The cooling medium was nitrogen (maximum cooling pressure: 1,5 [MPa]).



Fig. 2. Rings before heat treatment cycles

### 3. Experimental results

The measurements of ductile iron and cast steel rings before and after heat treatment process are presented in comprehensive charts (Fig. 3-10). The results obtained for the 34-hour bainitization process are presented.

The average values of quenching deformations for both processes are presented in Tables 3-4.

Table 3.  
Average distortion after the 3-hour bainitization process.

Tested material	930°C – 0,5h 300°C – 3h			
	Average difference in inner diameter [mm]	Average difference in outer diameter [mm]	Average difference in thickness [mm]	Average difference in parallelism [mm]
Cast steel	0,010	0,026	0,006	0,034
Ductile iron	0,015	0,016	0,007	0,030

Table 4.  
Average distortion after the 34-hour bainitization process.

Tested material	930°C – 0,5h 300°C – 34h			
	Average difference in inner diameter [mm]	Average difference in outer diameter [mm]	Average difference in thickness [mm]	Average difference in parallelism [mm]
Cast steel	0,002	0,049	0,013	0,012
Ductile iron	0,023	0,035	0,007	0,022

#### 3.1. Measurements of ductile iron rings

Results of inner diameter measurement before and after heat treatment [mm]

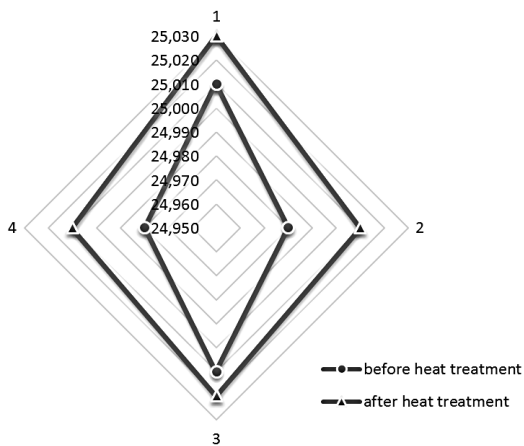


Fig. 3. Results of inner diameter measurement for a ductile cast iron sample (34-hour bainitization)

Results of outer diameter measurement before and after heat treatment [mm]



Fig. 4. Results of outer diameter measurement for a ductile cast iron sample (34-hour bainitization)

Result of thickness measurement before and after heat treatment

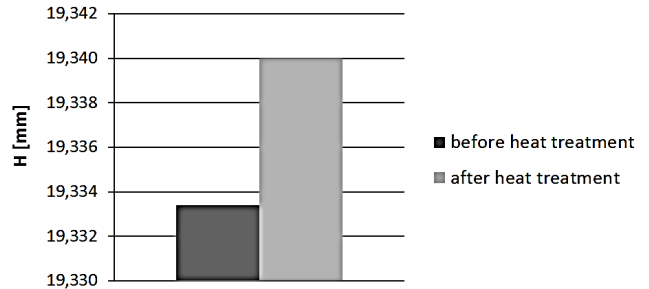


Fig. 5. Results of thickness measurement for a ductile cast iron sample (34-hour bainitization)

Result of parallelism measurement before and after heat treatment

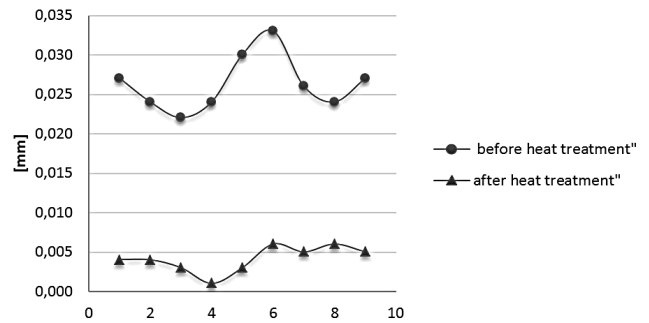


Fig. 6. Results of parallelism measurement for a ductile cast iron sample (34-hour bainitization)

The applied heat treatment increased the geometrical dimensions of the cast iron rings, especially in the case of the outer diameter. The effect of heat treatment on ring parallelism can be regarded as positive – this parameter has reduced its value and scatter.

### 3.2. Ni-Mo-V cast steel rings measurements

Results of inner diameter measurement before and after heat treatment [mm]

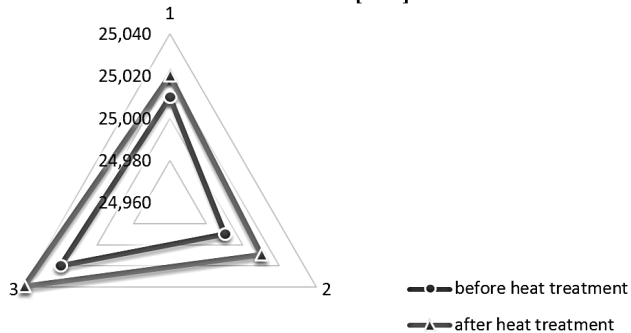


Fig. 7. Results of inner diameter measurements for Ni-Mo-V cast steel samples (34-hour bainitization)

Results of outer diameter measurement before and after heat treatment [mm]

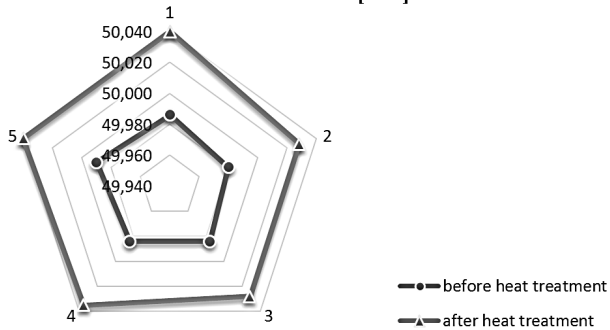


Fig. 8. Results of outer diameter measurements for Ni-Mo-V cast steel samples (34-hour bainitization)

Result of thickness measurement before and after heat treatment

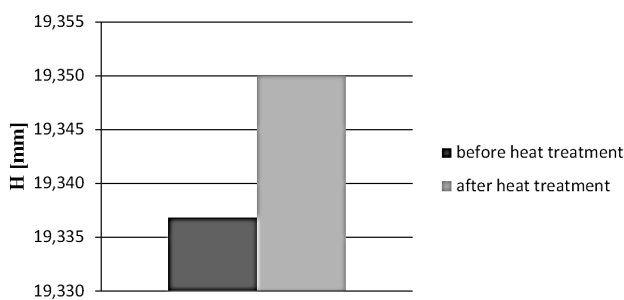


Fig. 9. Results of thickness measurements for Ni-Mo-V cast steel samples (34-hour bainitization)

Result of parallelism measurement before and after heat treatment

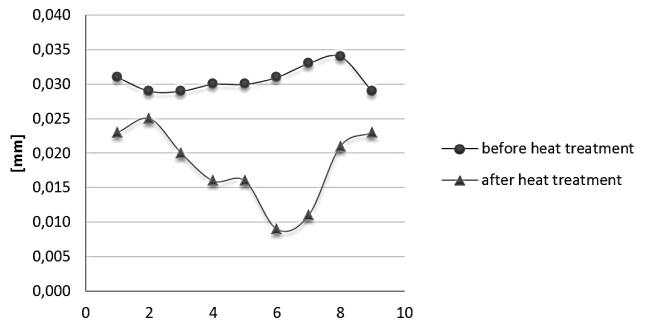


Fig. 10. Results of parallelism measurements for Ni-Mo-V cast steel samples (34-hour bainitization)

The 34-hour bainitization of cast steel rings resulted in increase of the tested geometrical dimensions. The largest distortion are observed for the outer diameter, as in the case of cast iron rings. Another trend is characterized by parallelism deviation, which, although smaller, achieves a greater scatter of measured values.

### 4. Obtained microstructure

Figure 5 presents the microstructure of the cast iron and cast steel rings after heat treatments.

The microstructure of the cast iron after two heat treatment variants is characterized by ferrite and austenite with „vermicular” and spheroidal graphite separation. In the case of 34-hour bainitization, fragmentation of ferrite plates, the reduction of the austenite and graphite fraction separation are noticeable. There is no difference in the morphology of cast steel microstructure.

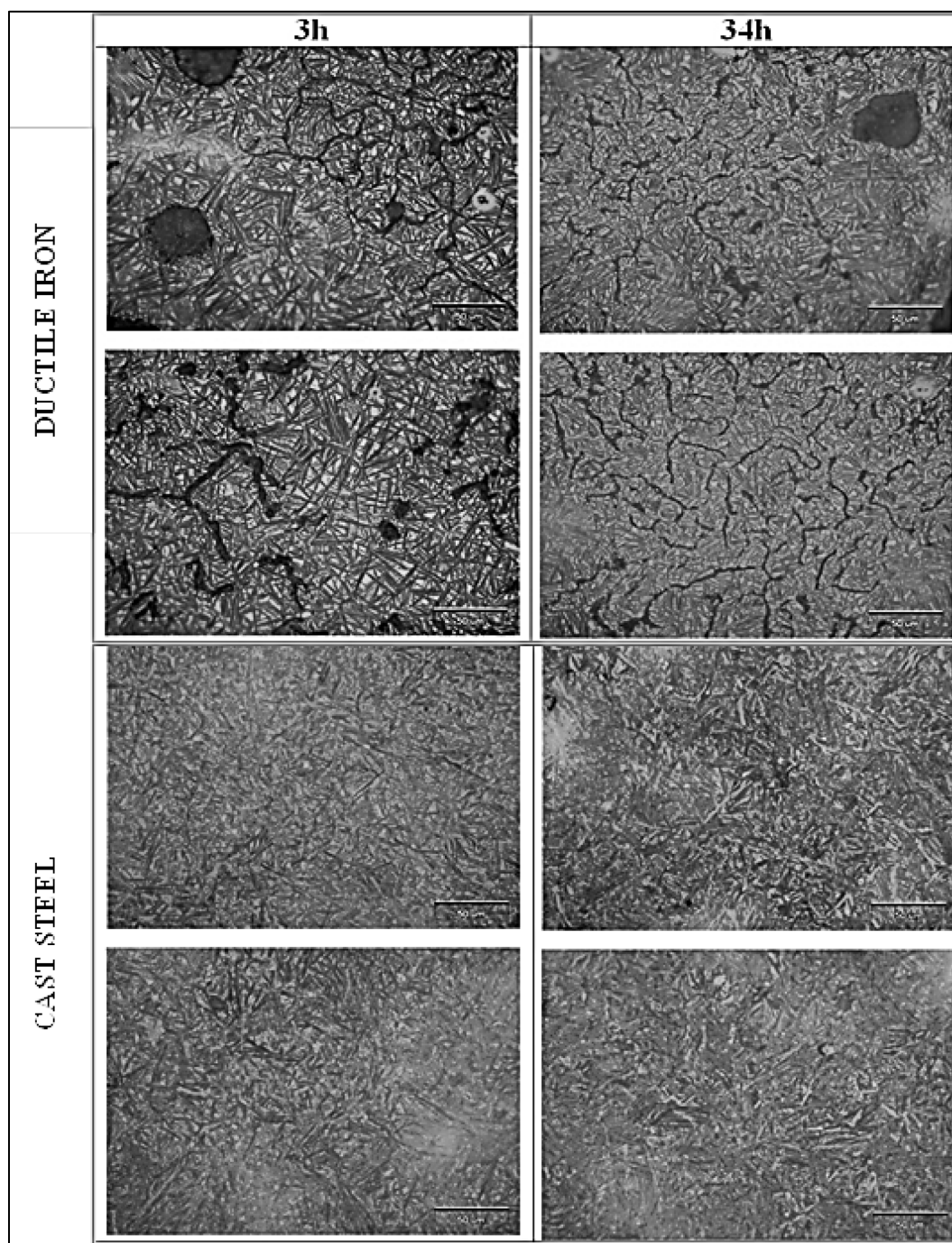


Fig. 5. Comparison of the microstructure of rings resulting from two different bainitization times (mag. x500, etched by nital)

## 5. Results

For both tested materials, the heat treatment increased the outer diameter, inner diameter and the thickness of the ring. For the ductile iron ring the largest distortions are observed after a 34-hour bainitization process. But even after the shorter, 3-hour

bainitization time, the changes in outer and inner diameters can be significant

The distortions of cast steel rings in most cases exceeded  $10\mu\text{m}$ . For the outer diameter measurement of the cast steel ring after a longer bainitization time, one result was significantly out of the rest. It has increased the value of the aforementioned

parameter, which may suggest repeating the experiment to verify such a large deviation.

The residual stresses accumulated in the material will have decisive influence on the results. They are formed at the ingot casting stage and mechanical processing to produce the finished ring. It is therefore justified to measure internal stresses before and after heat treatment. The type of stress (compression/tension) is significant, i.e. whether the stresses before or after the thermal processes will add up or, on the contrary, diminish [7-8].

Another factor influencing the resulting deformations is the cooling medium. The literature shows [9] a difference in distortion after use of nitrogen or helium as a cooling medium.

By analyzing the obtained microstructure, it can generally be said, that it is possible to obtain ausferritic cast iron in a gas-cooled vacuum oven. In the case of cast iron, the reduction of the austenite share after 34-hour bainitization is noted. Ferrite plates were fragmented. Questionable may be the graphite form, which is spheroidal in ADI cast iron. Visible graphite on the images should be regarded as degenerated, due to incorrectly performed melting process. Comparison of cast steel images shows similar morphology after both thermal processes.

## 6. Conclusion

The adopted methodology of the research, allow the measurements of quenching deformations due to heat treatment processes. The distortion of cast iron and cast steel of gears is a new subject that requires a further research, especially the measurement of residual stresses in the material. In addition, it is important to select a model that approximates the target geometry and so generalizes the findings. In the next phase of work, we plan to measure of the distortion of the cogwheels, as gearshift components operate under extreme load conditions.

## Acknowledgements

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