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DISTORTION BEHAVIOUR OF C15E AND 42CrMo4 STEELS DURING HEAT TREATMENT

POJAVA DISTORZIJE KOD C15E I 42CrMo4 ČELIKA TOKOM TERMIČKOG TRETMANA

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ABSTRACT

Dimensional tolerances of semi-products for the automotive industry became extremely narrow, and allow no deviations in the production process. In present research work the distortion behaviour of C15E (1.1141) and 42CrMo4 (1.7225) steels during two common industrial heat treatments (quenching and controlled heating and cooling) was studied by Navy C-ring test. As expected, the most noticeable was the dissimilar distortion behaviour of testing steels after quenching due to different final microstructure. Results from the present investigation prove, that the most important factor for distortion after heat treatment are microstructure transformations.

Keywords: distortion, Navy C-ring, heat treatment

SAŽETAK

Tolerancije dimenzija poluproizvoda za automobilsku industriju postale su izuzetno uske i ne dozvoljavaju odstupanja u proizvodnom procesu. U okviru istraživačkog rada praćena je pojava distorzije kod dvije vrste čelika C15E (1.1141) i 42CrMo4 (1.7225) u slučaju dva tipa termičke obrade (kaljenje i kontrolisano grijanje i hlađenje) korištenjem Navy C-ring testa. Kao što se očekivalo najizraženija pojava distorzije je uočena nakon kaljenja zbog različitih konačnih mikrokonstituenata. Prema rezultatima ovog istraživanja jasno je da je najvažniji faktor za pojavu distorzije nakon termičke obrade mikrostrukturna transformacija.

Ključne riječi: distorzija, Navy C-ring, termička obrada

1. INTRODUCTION

The aim of the investigation was to analyse the distortion behaviour of C15E and 42CrMo4 steels during heat treatment. Heat treatments are usually used to enhance the mechanical properties of steel parts, but unfortunately they cause uncontrolled distortions. Consequently, additional machining is required to bring part dimensions back into specifications. Distortion therefore may have an important economic role in the production of the steel parts.

Distortion was studied by Navy C-ring, which is one of the oldest but still very useful tests for evaluation heat treatment distortion. The test belongs to deflection methods. Their main advantage is that they are easy to interpret and inexpensiveness [1].

The distortions are the consequence of the interaction among time, temperature, deformation and microstructure (figure 1) [2, 3]. Because their control during heat treatment is an important demand for the sheet forming techniques, a numerous investigations have been performed to date [4-8].

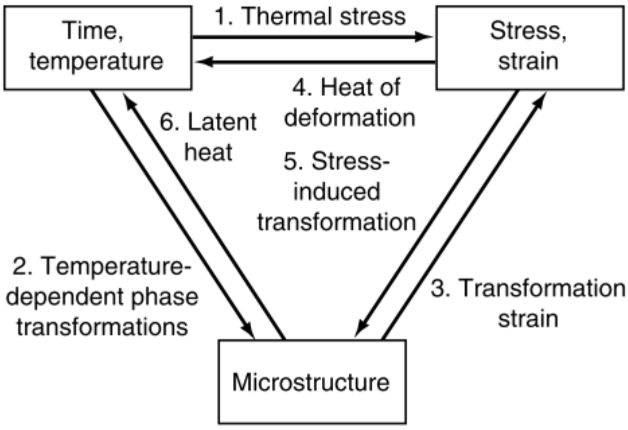
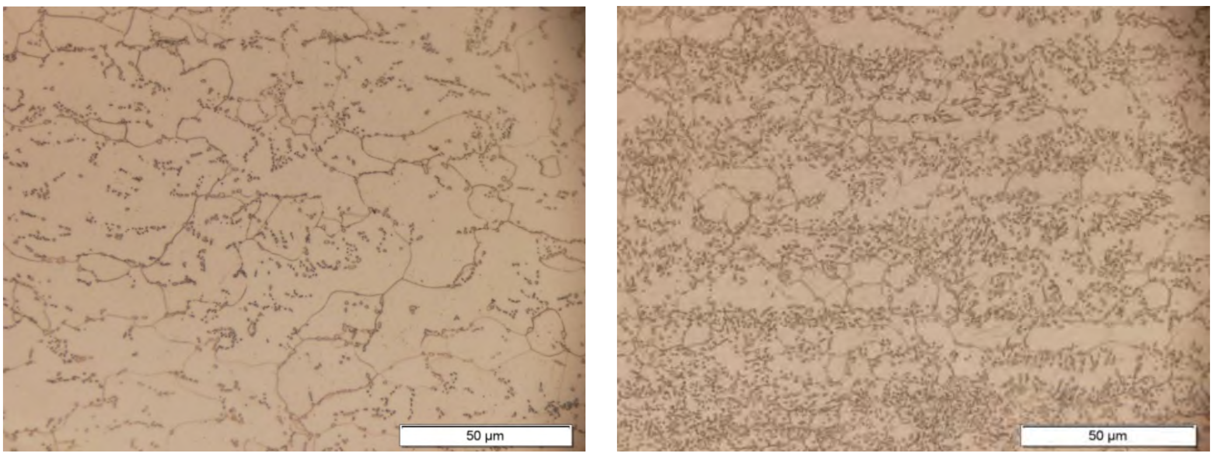


Figure 1: The connection of temperature, stress and microstructure [1].

2. EXPERIMENTAL SETUP

Investigated steels were received as cold rolled strip in annealed condition. The microstructure is presented in figure 2. The chemical composition of the investigated steels C15E and 42CrMo4 is given in table 1. Samples were machined by wire spark erosion into Navy C-rings.



a) *b)*

Figure 2. Microstructure (globular perlite) of cold rolled and annealed steel strips;
a) C15E, b) 42CrMo4.

The distortion of the C-rings were evaluated by dimensional measurements of inner diameter (A), outer diameter (B), gap width (D), and thickness (E). The shape distortion was characterized by measuring the inner (A) and outer (B) shape roundness. All measurements, before and after heat treatment were performed on the same positions, using the coordinate measuring machine of 2, 9 + L/100 [µm] accuracy. The sample dimensions are presented in figure 3.

Table 1: Chemical composition of C15E and 42CrMo4 steels

Steel	**Element [mas. %]**					
	C	**Si**	**Mn**	**Cr**	**S**	**P**
C15E	0,15	0,22	0,45	0,09	0,018	0,004
42CrMo4	0,40	0,15	0,61	1,00	0,009	0,004

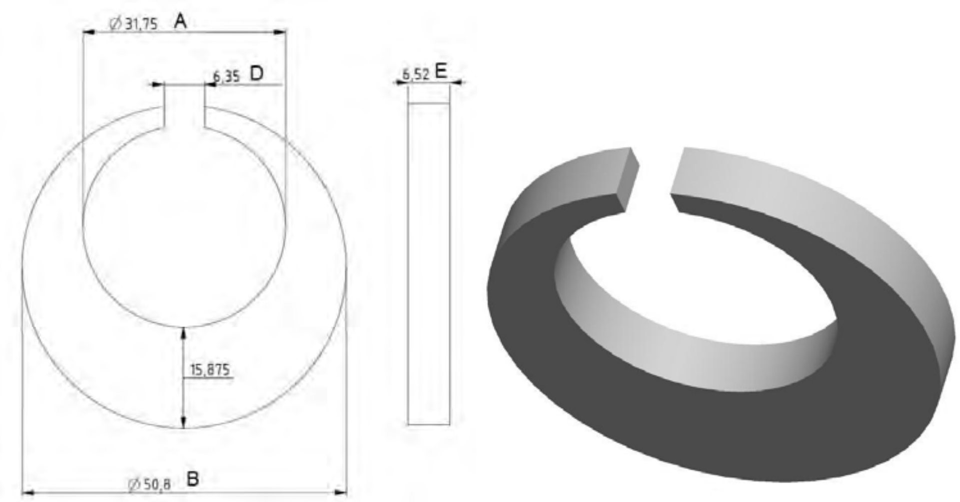


Figure 3: Samples for analyzing distortion behaviour – Navy C-ring; A – inner diameter, B – outer diameter, D – gap width and E – thickness.

Samples were heat treated by two different procedures: quenching, where samples were heated with a rate of 580K/h to 900 °C, soaked for 30 minutes and quenched in oil, and annealing at high temperature, where samples were heated with a rate of 100K/h to 900°C, soaked for 30 minutes and cooled down to 200°C with the controlled cooling rate of 50K/h. Afterwards, samples were cooled down to room temperature in air. Both heat treatments are schematically presented in figure 4.

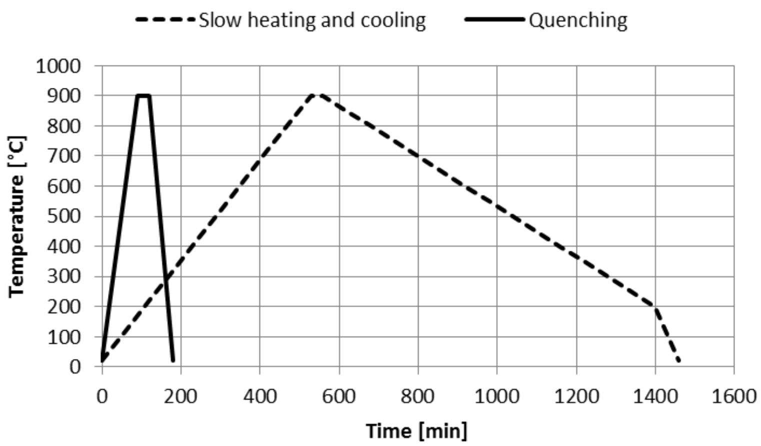


Figure 4: Schematically presented heat treatment procedures.

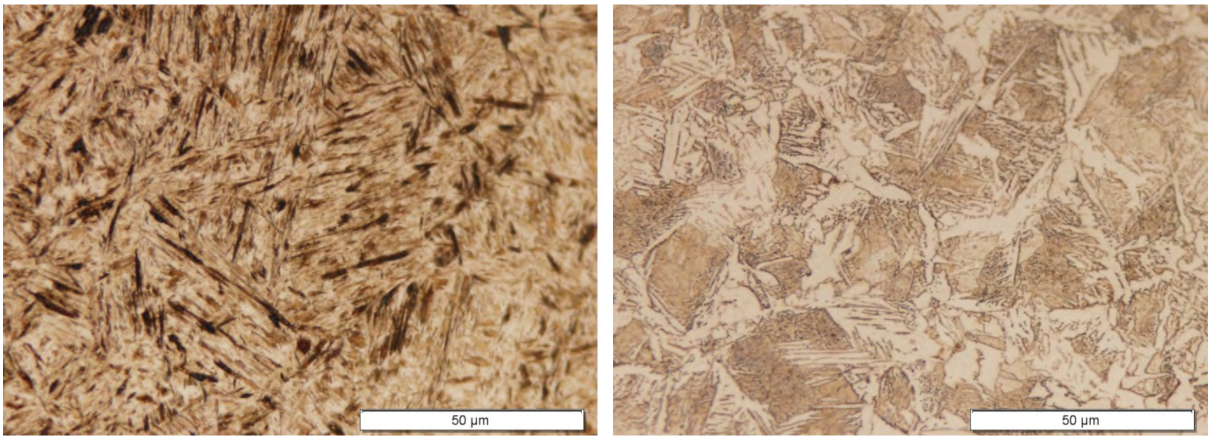
3. RESULTS AND DISCUSSION

In table 2 average variations of the measured sample dimensions after heat treatments are presented. Each analyzed measuring position was evaluated on five samples. When considering the size distortion, the most obvious is an increase of all dimensions during quenching of 42CrMo4 steel. The reason is a phase transformation from austenite to martensite, and associated volume increase (figure 5a). Similar is observed for C15E steel, with the difference that inner diameter didn't change significantly. Deviations are also relatively smaller, due to the lower amount of carbon and consequently different microstructure after quenching (figure 5b). The difference in the inner diameter distortion could be explained in the following way. The change of inner diameter is a combination of an increment in the ring width, which decrease inner diameter, and ring circumference increment, which increase inner diameter. The combination of those two dimensional changes is for 42CrMo4 such, that inner diameter increase and for C15E that the inner diameter decrease or remain unchanged.

Table 2: Changes of measuring parameters during heat treatments.

Dimension	Heat treatment	Change [µm]	
		42CrMo4	C15E
Inner diameter A	Quenching	*37,86*	*-0,24*
	Slow heating and cooling	*2,80*	*1,12*
Roundness on A	Quenching	*4,54*	*-1,53*
	Slow heating and cooling	*-13,70*	*-4,83*
Outer diameter B	Quenching	*64,46*	*12,44*
	Slow heating and cooling	*0,28*	*0,16*
Roundness on B	Quenching	*6,76*	*-9,25*
	Slow heating and cooling	*-2,74*	*-10,92*
Gap width D	Quenching	*47,10*	*20,70*
	Slow heating and cooling	*5,48*	*-3,20*
Thickness E	Quenching	*11,48*	*4,38*
	Slow heating and cooling	*3,84*	*4,20*

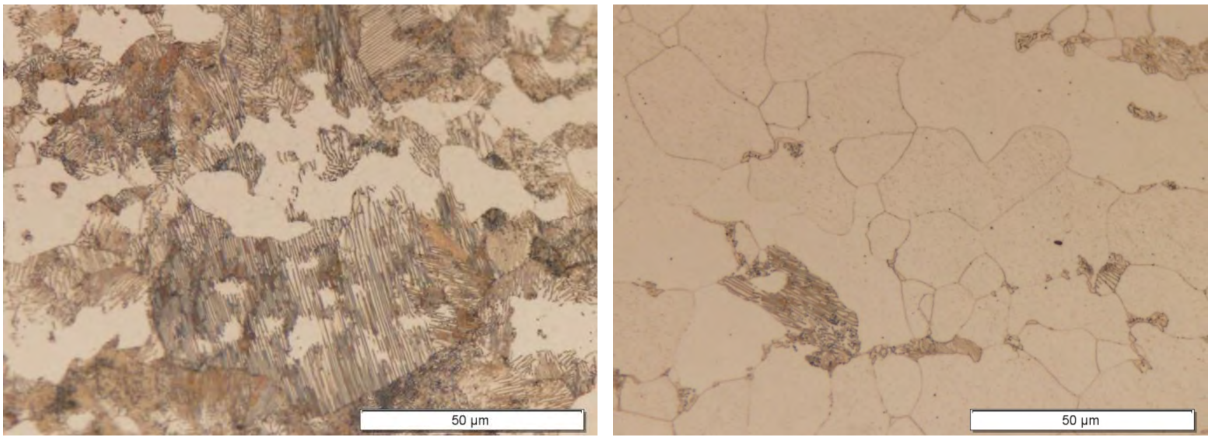
For both steels, size distortions during slow heating and controlled cooling are smaller compared to quenched state, due to different final microstructure, which consists of ferrite and lamellar perlite (figure 6).



a) *b)*

Figure 5: Microstructure after quenching; a) 42CrMo4 - martensite, b) C15E – ferrite, perlite, bainite and martensite.

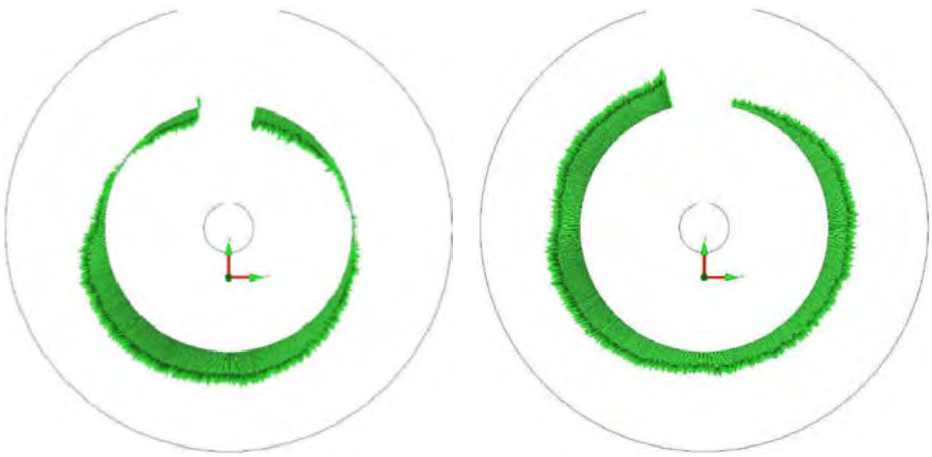
Shape distortion was evaluated by the roundness of inner (A) and outer (B) contour of the C-ring. For samples made of C15E steel, both heat treatments make roundness more uniform. On the other hand, only the controlled cooling makes the roundness more uniform when 42CrMo4 steel is used. These changes can be explained as follows. The design of C-rings in non-heat treated state is such that a gap between C-tips is closed and starts to open during heat treatment (figure 7a and 8a) [9-11]. For quenched samples made from 42CrMo4 opening was so large that deformation from the opposite direction was achieved.



a) *b)*

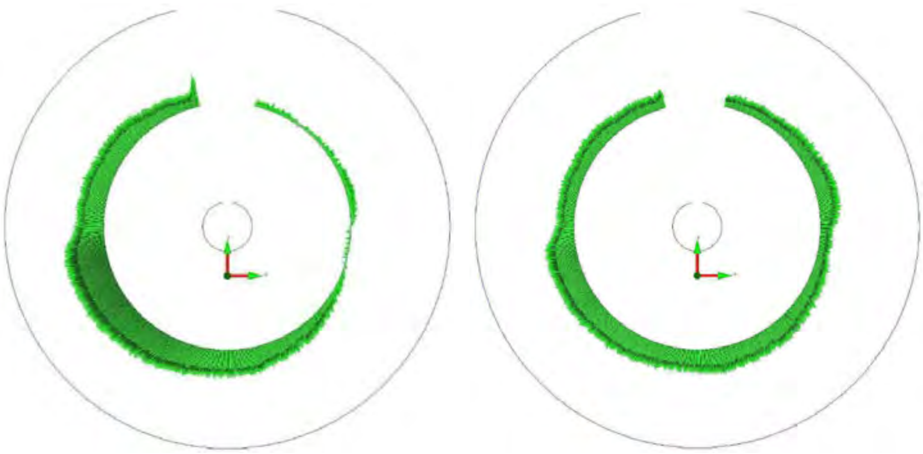
Figure 6: Microstructure after slow heating and cooling; a) 42CrMo4 – ferrite and lamellar perlite, b) C15E – ferrite and lamellar perlite.

When comparing distortion of the inner (A) and outer (B) contour of a C-ring for steel C15E, dissimilarity after heat treatments is not so strong. One of the reasons is that after both heat treatments differences in microstructure are not so distinctive as for 42CrMo4 steel, especially when the amount of martensite is taken into account. Furthermore, it can be concluded that fast cooling does not form temperature gradients steeper enough, that could play an important role in the shape distortion of the samples. Most likely, due to small cross-sections.



a) b)

Figure 7: Inner shape of C-ring produced from 42CrMo4: a) sample produced by wire spark erosion – roundness 0,043 mm, b) sample after quenching – roundness 0,048 mm.



a) b)

Figure 8: Inner shape of C-ring produced from 42CrMo4: a) sample produced by wire spark erosion – roundness 0,037 mm, b) sample after slowly heating and cooling – roundness 0,022 mm.

4. CONCLUSIONS

In the presented research work following conclusions can be made. During quenching increase of dimensions can be expected and has to be taken into consideration when fine blanking technique is applied. Dimension increase strongly depends on the amount of carbon and associated volume increase, due to formation of martensite. When considering the temperature gradient and its influence on the distortion of fine blanked product made from steel strip we can conclude, that temperature gradients are not as important for distortion as a variation in volume alteration, due to microstructure transformation. Actually, the main effect of the steeper temperature gradient is in the increased microstructure transformation inhomogeneity.

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