EFFECT OF THE ADDITIONAL ANNEALING PRIOR TO HEAT TREATMENT ON THE FINAL PROPERTIES OF THE STEEL

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Abstract

The hereby work presents the influence of an additional annealing prior to heat treatment on the final properties of investigated steel. Often companies despite softened conditions of ordered materials are performing further annealing. In many cases it is just a waste of energy and money because there is already an adequate condition to perform heat treatment. In present study two widely used 100Cr6 and 145CrV6 steels were selected. Two sets of samples were prepared first in the delivered state and second after additional annealing carried out in the laboratory furnace. For each steels a typical heat treatment simulation was performed on the Linseis L78 R.I.T.A. (Rapid Intensive Thermal Analysis) dilatometer. Critical temperatures and thermal expansion coefficient were determined and compared. The microstructures for each set of samples before and after heat treatment, were compared. Obtained results determined the suitability of the additional soft annealing process.

Keywords: steel, dilatometric investigations, annealing, heat treatment, thermal expansion coefficient.

1. INTRODUCTION

There is a continuing research for new tool materials with high wear resistance at high temperatures [1,2] however conventional tool steels are still commonly used. Heat treatment of tool steels whether it is for hot or cold work consists of several stages [3–8]. Most often the steels have a high hardenability, so they are quenched in oil or in air. After quenching tool steels are tempered. Depending on the working conditions and the chemical composition the tempering temperatures are very different [9–14].

The initial state of the steel before hardening often has a major impact on the austenitizing process and final properties of the heat treated elements. Pre-heat treatment in the sense of annealing is a vital step before plastic working or heat treatment and it has significant effect on the microstructure and mechanical properties. A reasonable pre-heat treatment is quite important which could improve the manufacture efficiency and product properties. However, the pre-heat treatment usually costs a significant amount of time and energy [11,12,15–17].

In the tool steels annealing is carried out in order to receive more finer and homogeneous distribution of cementite particles. Inadequate as well as poorly performed annealing process can affect the final dimensions and decrease properties of heat-treated tools. The aim of this study was to investigate the influence of microstructure after annealing on the critical points, the dimensions changes of elements after heat treatment, and changes of thermal expansion coefficient.

2. TESTED MATERIAL AND RESULTS

In hereby work two widely used steels were selected 100Cr6 and 145CrV6. Two sets of samples were prepared: first in the as-delivered condition (AsD) and second after additional annealing (AA). Additional annealing consists of soaking the material in the furnace at 820 °C for 4 hours. After soaking the material was cooled with the furnace. The fig. 1 contains images of the microstructure of 100Cr6 steel in two mentioned earlier conditions and fig. 2 of the 145CrV6 steel.

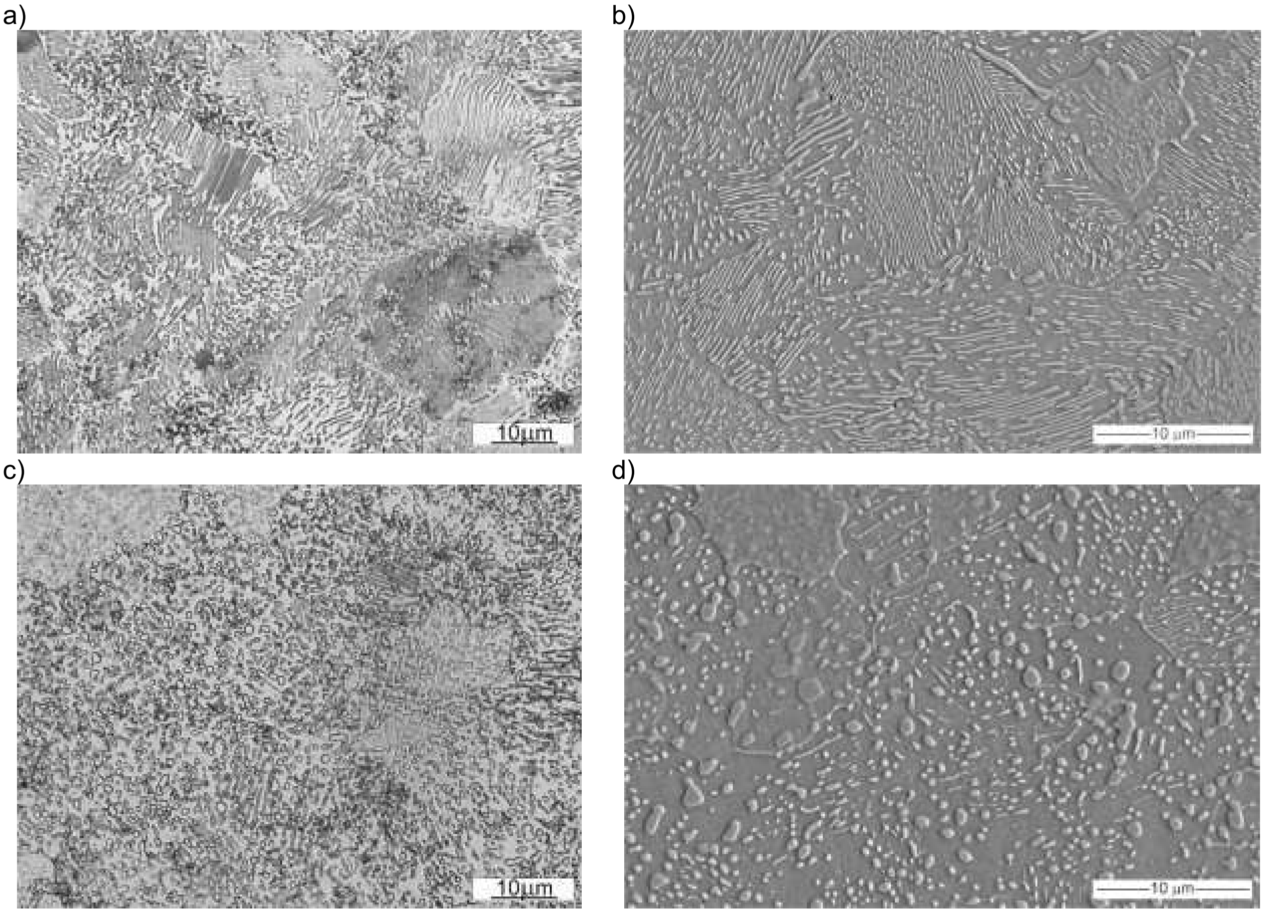


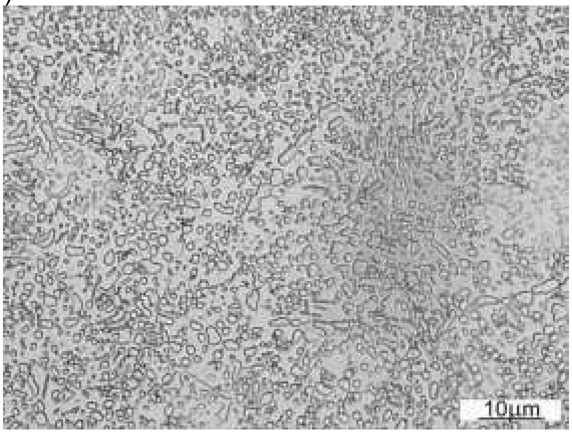
Fig. 1 SEM and light microscopy images of the 100Cr6 steel microstructure a,b) in as-delivered condition (AsD) and c,d) after additional annealing (AA), etched 2% nital

It was found that in the case of 100Cr6 steel differences in the microstructure have occurred. In the microstructure of AsD sample numerous pearlite colonies were observed in which the carbides have not coagulated. At the grain boundaries a hypereutectoid cementite can be seen. Comparing the AsD state to additional annealing AA significant changes can be seen in the microstructure. Nearly the whole cementite in pearlite has coagulated. This microstructure is better for mechanical processing, and the tools wear would be decreased.

In the case of 145CrV6 steel in the microstructure of the sample in AsD condition small amount of partially coagulated perlite remained. Additional annealing resulted in the complete coagulation of cementite in these perlite areas. Any other significant changes in the microstructure where not found. Based on these results it seems that the additional annealing may be unnecessary for these steel.

The hardness measurements 0.3 HV for each sample were performed by the Tukon 2500 hardness tester. The hardness of 100Cr6 steel in AsD condition is 302±17 and for AA is 212±7, while hardness of 145CrV6 steel in AsD is 247±6 and for AA sample is 217±7. Occurred differences in samples hardness can reflect in the wear of the tools especially for 100Cr6 steel.

a)



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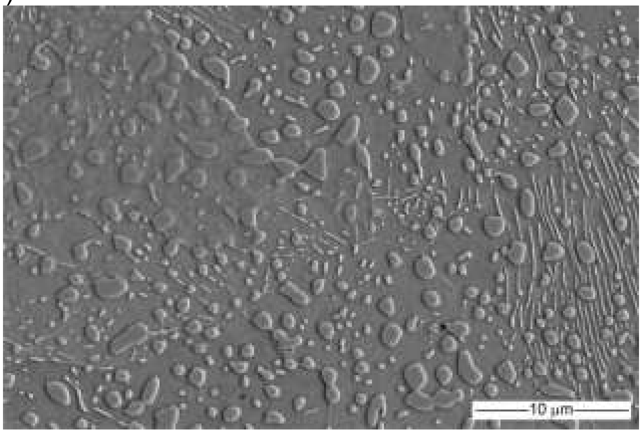

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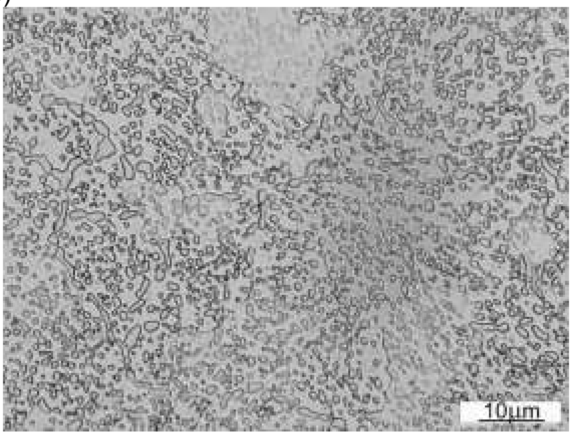

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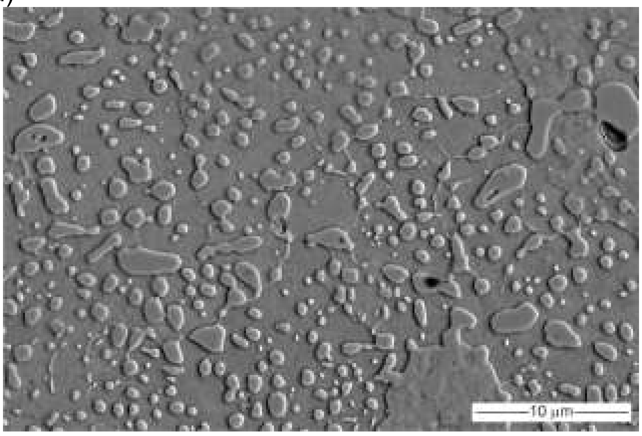
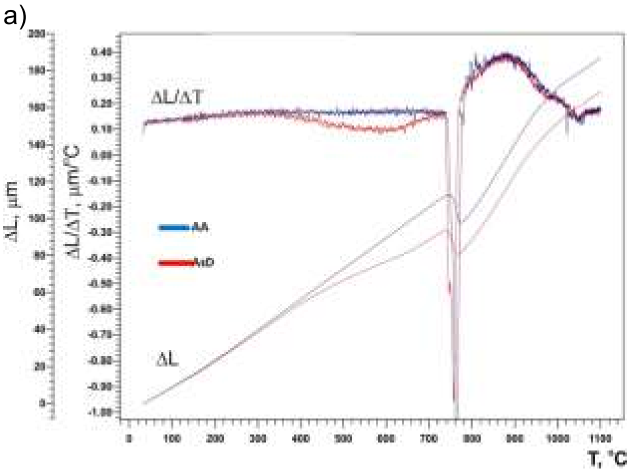


Fig. 2 SEM and light microscopy images of the 145CrV6 steel microstructure a,b) in as-delivered condition (AsD) and c,d) after additional annealing (AA), etched 2% nital

In order to investigate the effect of the pre-heat treated microstructure on the hardening and tempering process firstly the critical point for each state was examined. In these studies a high resolution dilatometer LS78 RITA was used. Figure 3 shows dilatograms of heating with the rate of 30 °C/s, together with corresponding derivative curve. The Fig. 4 contains thermal expansion coefficient changes vs. temperature for each steels.

a)



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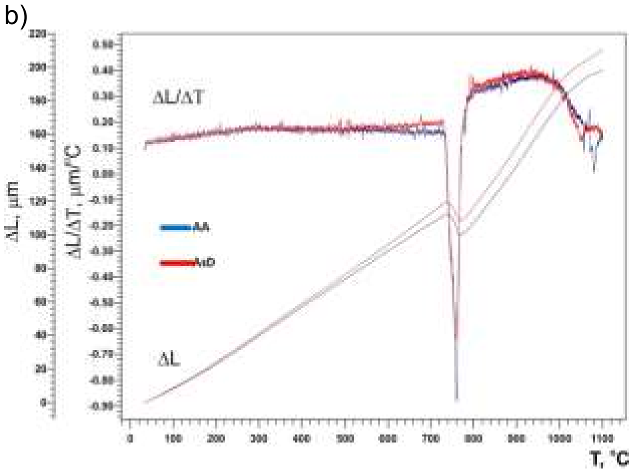

Fig. 3 Dilatograms (ΔL) of heating with the rate of 300 °C/s, together with a derivative curve (ΔL/ΔT) for a) 100Cr6 and b) 145CrV6 steel

a)

b)

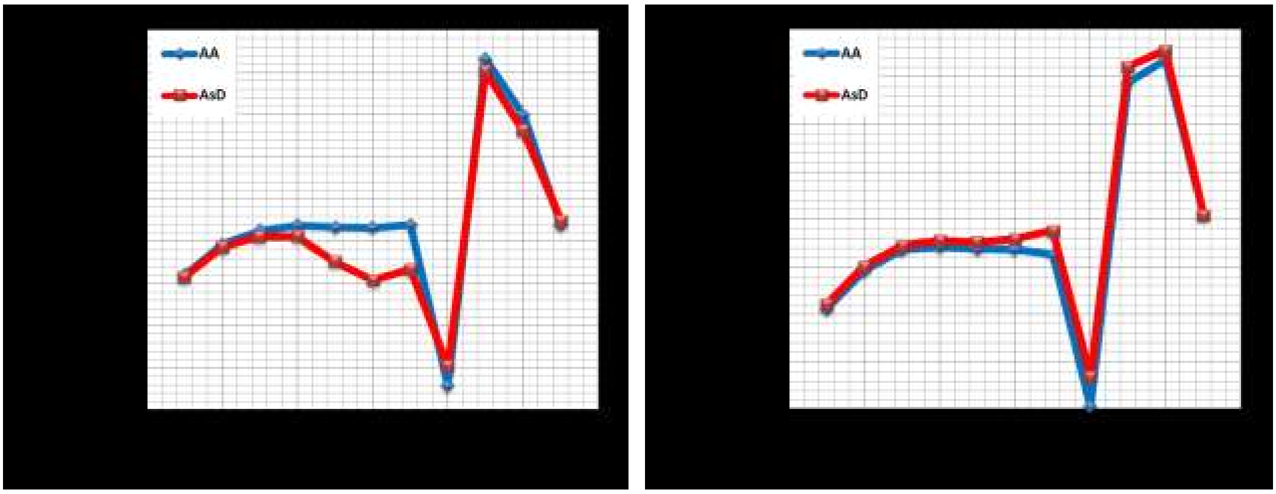

Fig. 4 Thermal expansion coefficient changes vs. temperature for a) 100Cr6 and b) 145CrV6 steel

It can be seen that the differences in microstructure are reflected in the dilatations effects. The biggest difference occurs in the case of 100Cr6 steel. It was observed that the start of austenite formation is preceded by a shrinkage effect for the AsD sample. This effect occurred only in the case of this sample in temperature range of 400-700 °C. Most likely it is associated with coagulation of cementite and recrystallization. Despite the differences in the microstructure for each sample AA and AsD in each steel the critical points are similar and are as follows: for 100Cr6 Ac_{1s} = 740 °C, Ac_{1s} = 800 °C, Ac_{cm} = 940 °C and for 145CrV6 Ac_{1s} = 740 °C, Ac_{1s} = 800 °C, Ac_{cm} = 1000 °C.

As could be expected difference between thermal expansion coefficients for AsD and AA samples have occurred only in the in the case of 100Cr6 steel, in the temperature range of 400-700 °C. In other temperatures thermal expansion coefficient for each investigated steels in two conditions is almost identical. Based on these results it can be assumed that during austenitizing samples with different states a significant difference should not occur. Then, in the dilatometer a quenching and tempering test was carried out. Figure 5 contains a cooling dilatogram of investigated steels with the cooling rate of 30 °C/s with marked Ms temperatures. Figure 6 contains dilatogram of continuous heating of the samples after quenching with the rate of 0.5°C/s.

a) b)

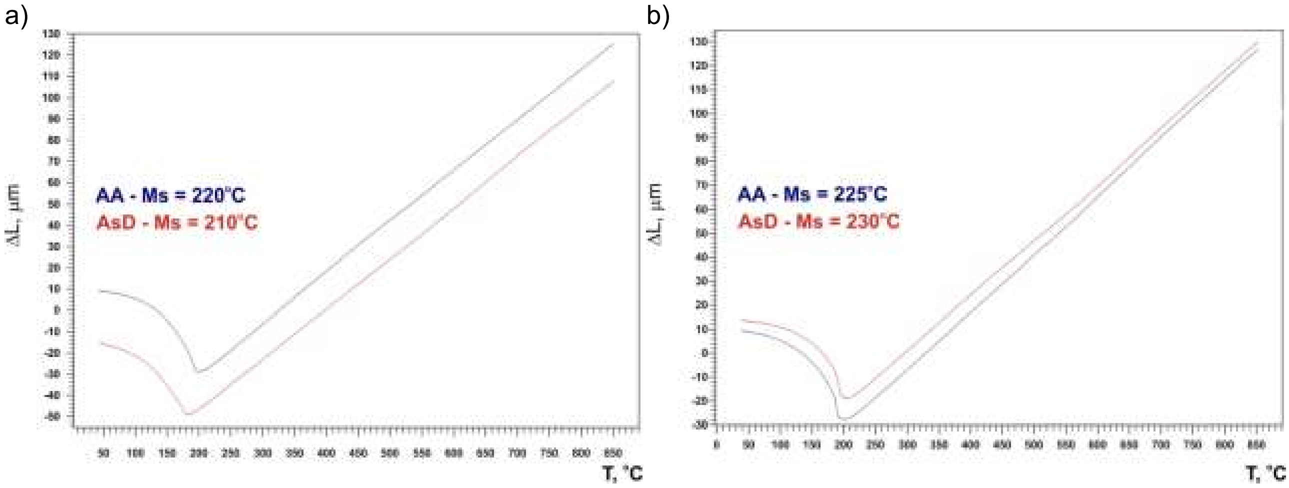

Fig. 5 Dilatograms of cooling with the rate of 30 °C/s for a) 100Cr6 and b) 145CrV6 steel

a) b)

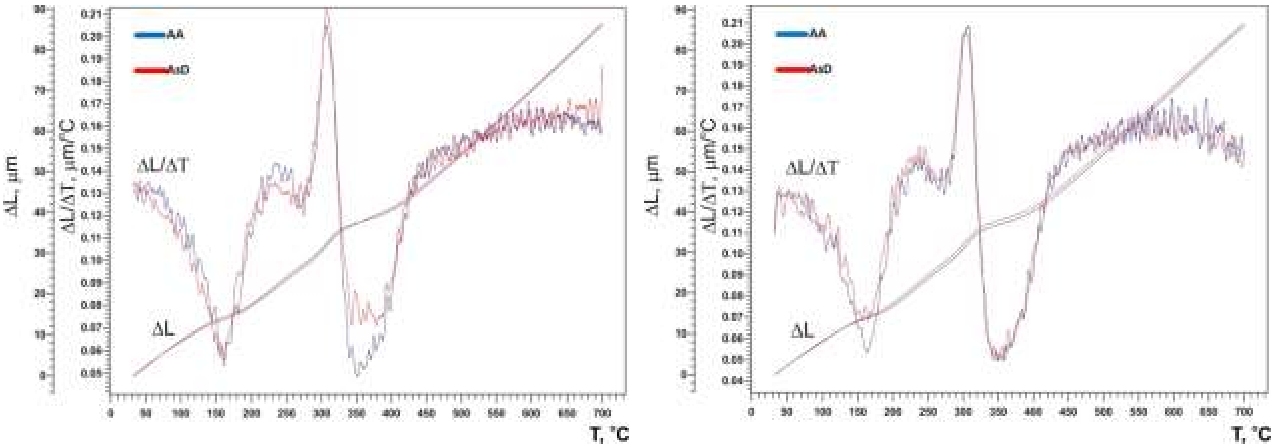

Fig. 6 Dilatograms of heating (after quenching) with the rate of 0.5°C/s together with corresponding a derivative curve for a) 100Cr6 and b) 145CrV6 steel

On each cooling curve, there is one positive dilatation effect related with martensitic transformation. There is a small incompatibility in Ms temperatures for AA and AsD samples but that should not affect the final properties of investigated steel. This is confirmed by the tempering test. After overlapping the dilatations and derivative curves dilatometric effects can be found to be exactly the same. The first negative effect is related to the precipitation of iron transition carbides. The second negative dilatation effect is related to the precipitation of cementite. Dominant of approximately 300 °C temperature positive effect is related to transformation of retained austenite. It has been found that the temperature ranges and dilatation effect of the individual phase transformations are similar. Based on the results it can be concluded that the additional annealing does not significantly affect the quenching and tempering process. However, to resign from the additional annealing mechanical and tribological properties should be determined as well as microstructural analysis after heat treatment.

CONCLUSION

The biggest differences in the microstructure occur in the case of 100Cr6 steel. In the AsD conditions we can see numerous pearlite colonies in which carbides have not coagulated. Additional annealing significantly changed the microstructure, nearly the whole cementite in pearlite has coagulated.

The start of austenite formation in 100Cr6 steel in AsD sample is preceded by a negative dilatation effect. This dilatation effect occurred only in the case of this steel in temperature range of 400-700 °C. Most likely it is associated with coagulation cementite and recrystallization.

The hardness of 100Cr6 steel in AsD condition is 302±17 0.3 HV and for AA is 212±70.3 HV, while hardness of 145CrV6 steel in AsD is 247±6 0.3 HV and for AA sample is 217±7 0.3 HV.

Despite the differences in the microstructure for each sample AA and AsD the critical points are similar and are as follows: for 100Cr6 Ac_{1s} = 740 °C, Ac_{1s} = 800 °C, Ac_{cm} = 940 °C and for 145CrV6 Ac1s = 740 °C, Ac_{1s} = 800 °C, Ac_{cm} = 1000 °C. There is a small incompatibility in Ms temperature for AA and AsD samples in each steel. The temperature ranges and dilatation effects of the individual phase transformations during tempering are similar for AA and AsD condition in each steel.

ACKNOWLEDGEMENTS

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