Effect of delay in quenching on hardness of high carbon steel

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Keywords: Delay in quenching, hardness, high carbon steel.

Introduction

Steel is a widely used category of metals in engineering applications due to its superior mechanical and fabrication properties. Its cost is also reasonable. Plain carbon steel is a major subgroup of steel, and carbon is the main alloying element that controls its properties. Properties of carbon steel can be changed with heat treatments. Hardening is the main heat treatment applied for medium and high carbon steel to increase hardness [5]. The main parameters that control the hardness of carbon steel include heating temperature, holding time, cooling rate, and delay in quenching [5].

Studies based on variables of the hardening process of steel are found in the literature. Examples include change of quenching medium [4], cooling rate [1] and quenching temperature [3], etc.

Delay in quenching is a variable that can be used to control the hardness of hardened steel. To get the highest hardness, delay in quenching should be avoided as much as possible, so the structure is of the highest martensite content. Even a short delay in quenching may cause a considerable reduction of martensite content. Higher the martensite content, brittleness, hardness, strength and wear resistance properties increase while ductility decreases. However, studies based on delay in quenching to control the hardness of steel are not common. Mitani's study was to investigate the hardness variation of surface layers of medium carbon steel and low alloy steel with medium carbon content, by varying delay in quenching. Surface layers of steel were converted to austenite with induction heating, and a jet of water was applied as a means of quenching. It needed several seconds' delay in quenching for medium carbon steel to reduce the hardness of surface layers, whereas it was about twenty seconds for low alloy steel to get a similar output [2].

This study was aimed to check the hardness of cross-section with a variation of a delay time of quenching of 0.95% C steel.

Methodology

Chemical analysis verified the material is 0.95% C steel. Altogether 26 test specimens with 20 mm thickness were cut out from a 20 mm diameter bar of chosen steel. A normal oven was chosen for heat treatments, and 13 separate heating cycles were conducted under similar conditions, with two specimens in each cycle. The heating temperature was 770 °C, holding duration was 50 minutes while cooling medium was agitating water maintained at room temperature, according to guidelines given in the literature, for hardening heat treatment of carbon steel [5]. Since the same person was involved in agitating water in all cases, the same cooling rate was assumed to be applied throughout the process. The heating rate of the furnace was set to 8 °C/min. Delay time was changed in five-second intervals between different cycles, such that 0 seconds for the first cycle and 60 seconds for the thirteenth cycle. The temperature of the samples was read from the value indicated in the oven. After cooling to room temperature specimens were tested for Vickers hardness, and average hardness was calculated for each cycle.

Results and Discussion

Vickers hardness versus change of delay time is shown in the figure 1.

The obtained results indicate that hardness reduces drastically for short delay periods, and

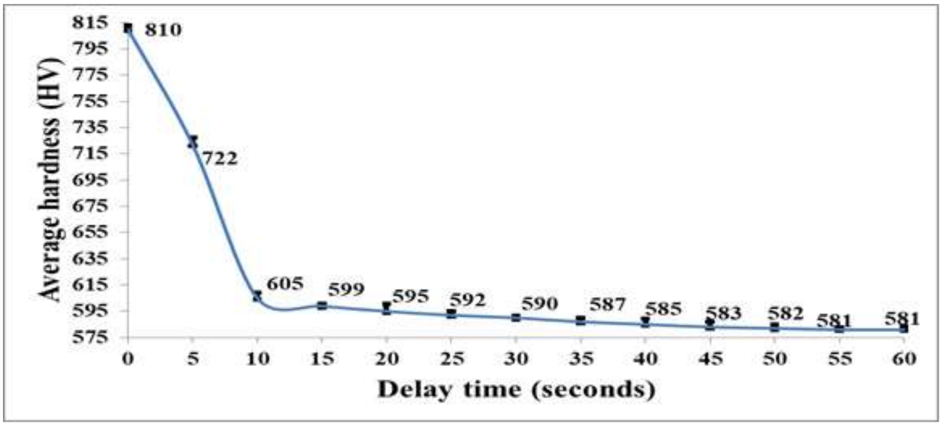

Figure 1. Average hardness (HV) versus delay time in quenching

only a slight variation is observed for longer periods than 10 seconds. Up to 10 seconds' delay in quenching, hardness has reduced up to 605 HV from 810 HV, and for 10 to 60 seconds' hardness has reduced only up to 581 HV from 605 HV.

At the heating temperature of 770 °C for 0.95% of steel, the structure is austenite and cementite. The amount of martensite obtained after cooling is based on austenite content at heating temperature. It is assumed that the structure attained the maximum amount of austenite, for the allowed soaking period. Hardness level is mainly based on the amount of martensite obtained after quenching.

Conversion of steel to different structures below the lower critical temperature of iron – carbon phase diagram is depended on cooling rate and temperature of transformation. Isothermal transformation of austenite can be described with time, temperature, transformation (TTT) diagram of a particular steel, and it gives the relationship between time and temperature of transformation of austenite.

Martensite formation should need a cooling rate faster than the critical cooling rate, which should be maintained well below the temperature at which martensite begins to form (Ms point) for the concerned steel. Martensite transformation is completed at Mf point, and both, Ms and Mf points reduce with the increase of carbon content. Lower cooling rates than the critical cooling rate or higher temperatures than Ms point may result in the conversion of austenite into equilibrium products of ferrite and cementite [5].

Since cooling rate affects grain size of converted ferrite and cementite, samples subjected to moderate delay time may get fine size ferrite and cementite (bainite and sorbite) while samples with long delay time may get large size ferrite and cementite with low hardness due to application of slow cooling rates.

The amount of cementite at temperatures above 723 °C (lower critical temperature) is stable until room temperature; no transformation takes place upon quenching [5]. However, specimens with a longer delay time may get large size grains, due to slow cooling rates. This might be the other reason for low hardness in samples with a long delay time.

Since mechanical properties such as strength and wear resistance increase, and ductility reduces with hardness, change of delay time can be applied to control these properties, as well. Apart, since an increase of martensite causes the increase of the brittleness, this technique can be used to control brittleness of steel also.

Though zero delay time in quenching is recommended to get the highest hardness, practically it is impossible. There is a chance for all specimens to undergo an extra delay time of a few seconds than they indicate. Even though the temperature indicated in the oven was assumed to be equal to the samples inside it, there can be a mismatch.

Obtained results can be used to get a required hardness, within the range given in the graph. Accordingly, concerning any hardenable steel, such plots can be prepared to get the required hardness.

Conclusion

Hardening is a heat treatment process applied to change the hardness of steel. Delay in quenching is a variable of the hardening process that can be used to control hardness and other related properties. Within the first few seconds of delay in quenching, reduction of hardness is drastic, and the extent of the effect is minimum after several seconds of delay in quenching. For any hardenable steel, a plot of hardness versus delay time in quenching can be used to predict delay time for required hardness values, under the prescribed hardening process conditions.

References

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