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TRIBOLOGICAL BEHAVOUR OF HEAT TREATED COLD WORK STEELS

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ABSTRACT

The present experimental work investigates the friction and wear behavior of commercial cold work tool steels. The aim of the work is to get optimal combination of hardness, friction coefficient and wear by various heat treatment processes and tempering temperatures. Quenching, tempering, martempering and finally austempring treatments were applied to the tested steels.

The hardness (HRC) of the steels after heat treatment was determined to evaluate the surface resistance to wear. Scratch test was carried out using a diamond stylus of specified geometry along a straight line path under dry sliding condition. Friction coefficient was calculated to give specific information about surface tribological property. Wear scar width as a measure of wear was measured using optical microscope.

It was found that as received specimens showed the lowest hardness, while the highest value of hardness was observed for specimens quenched in oil and normalized in air. The hardness decreased with increasing tempering temperature. The highest values of friction coefficient were displayed by oil quenching followed by normalizing processes. As received specimens showed relatively higher values of friction coefficient. Oil quenched specimens displayed minimum friction coefficient. Significant reduction in friction coefficient and wear was observed for test specimens cooled by compressed air and tempered. Maximum wear was displayed by as received specimens, while minimum wear was presented by specimens quenched in oil and normalized in air. Oil quenched specimens displayed relatively low values of wear. Wear decreased for test specimens cooled by compressed air and tempered.

KEYWORDS

Friction, wear, hardness, scratch test, cold work tool steel, heat treatment.

INTRODUCTION

The applicability of steel depends on its different properties, imparted through suitable alloying and appropriate heat treatment measures. The mechanical properties of steel

depend chiefly on its microstructure. The microstructure of steel can be advantageously changed by heat treatment to obtain the desired mechanical properties. Most coil springs for automotive applications are made of quenched and tempered, medium carbon high-strength steels. In order to increase the hardness s chromium, manganese and silicon are added to these steels, [1]. The primary objective of the heat treatment of steels is to improve wear resistance. The benefit of heat treatment of steels has been cited by several researchers. However, the mechanisms responsible for enhancing the wear resistance by heat treatment are yet to be clearly established. Recent work has also shed light on the effects of heat treatment on bearings, gears and engine components, [2, 3] to reduce wear and improve performance.

Spring steels are used in the quenched and tempered condition which gives optimum strength and toughness, vibrational damping. The change in microstructure and strength after the heat treatment process depends on the cooling rate obtained during quenching, [4]. Due to safety, springs have to meet increasing performance requirements, [5], which concern mechanical properties, tribological properties as well as fatigue strength. The improvement of the sag resistance has been achieved by changing prior austenite grain size, the distribution of precipitated particles, and the chemical composition of the steel, as well as by changing processing treatments such as magnitude of pre-strain and shot-peening, [6]. Some mechanical properties such as elastic modulus, tensile strength, hardness, microstructure, strain hardening and fracture strain also influence the wear of the materials. Hardness is a measure of the wear resistance of a material. In other words it is the resistance of a material to permanent deformation by indentation or scratching, [7]. Hardness of material depends upon the type of bonding forces between atoms, ions or molecules. Furthermore for spring steels, [8], the emphasis in materials research has been focused on increasing the strength while maintaining good ductility, toughness and fatigue properties.

Prevention of wear depends principally on design and operation of component, but can be minimized by the correct choice of material. It is seen that most of the study has been focused on the experimental work for wear behavior of steels, and a few mathematical models based on statistical regression techniques has been reported[9 - 12]. The Taguchi's design is a simple, efficient and systematic approach to optimize designs for performance, quality and cost [13]. In the Taguchi method, Design of experiments approach enables to analyze successfully the wear behavior of materials [14]. The design of an experiment (DOE) technique is an optimized technique mainly employed in determining wear behavior of material, which must follow certain sequence for the experiments to yield an improved understanding of product or process performance [15, 16]. From the literature survey it is clear that there is lot of scope for the study of wear behavior of spring steel. Hence present study was focused on the dry sliding wear behavior of spring steel and the effect of heat treatment on spring steel.

Recently, the effect of alloying elements and heat treatment processes on friction coefficient and wear of ductile iron was investigated, [17, 18]. It was found that adding Cr and Ni to ductile iron (DI) improved its hardness and wear resistance and reduced its friction coefficient at as-cast and heat treated conditions. Adding Mo reduced wear resistance and hardness and increased friction coefficient of as-cast ductile iron but increased the hardenability. A significant increase in wear resistance and hardness and decrease in friction coefficient was produced by heat treatment of Mo – DI. Adding Cu to ductile iron increased the wear resistance and hardness and reduced friction coefficient in as-cast state, but retarded the improvement by heat treatment processes. Finally, heat treated specimens of Ni-DI showed significant increase in hardness. Normalized specimens displayed the lowest values of friction followed by oil, water and compressed air quenched specimens. Normalized as well as oil, water and air compressed quenched test specimens of Cr-DI and Ni-DI showed reasonable values of friction coefficient and wear which recommend them for wide application.

The present study aims to investigate the friction coefficient and wear of heat treated tool steels as well as to determine the optimum conditions for heat treatments of these materials for which the tribological properties can be improved.

EXPERIMENTAL

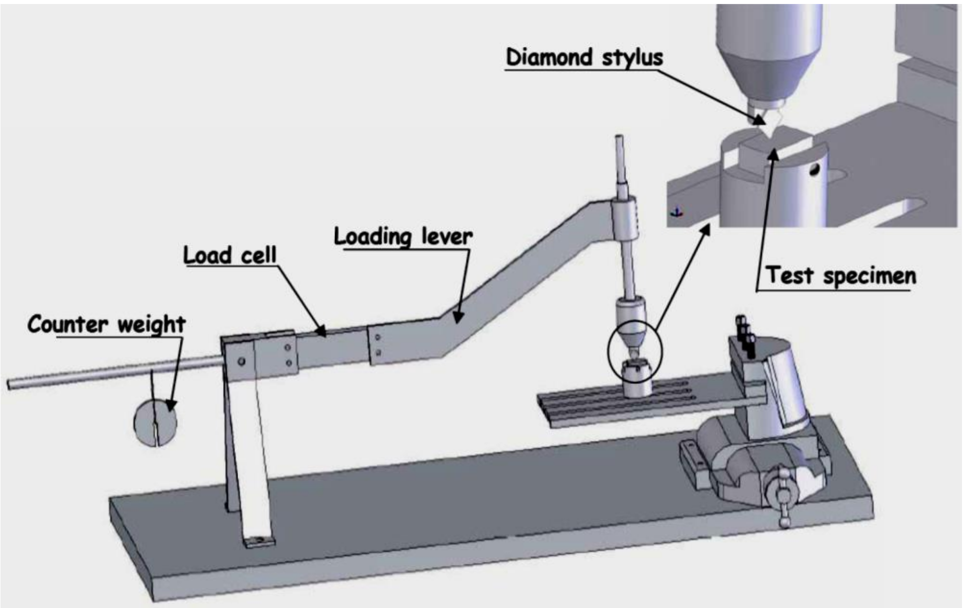

Fig. 1 Arrangement of scratch test rig.

Scratch tester shown in Fig. 1 was used. It consisted of a rigid stylus mount, a diamond stylus of apex angle 90° and hemispherical tip. The stylus was mounted to the loading lever through three jaw chuck. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weights of 5, 10, 15, 20, 25 N. Scratch resistance force was measured using a load cell mounted to the loading lever and connected to display digital monitor. The test specimen was held in the specimen holder which mounted in a horizontal base with a manual driving mechanism to move

specimen in a straight direction. The scratch force was measured during the test and used to calculate friction coefficient. The test was conducted under dry conditions at room temperature. An optical microscope was used to measure scratch width with an accuracy of ± 1.0 µm.

The test specimens were heat treated by normalizing, oil quenching, compressed air (air blast) quenching, martempering, and austempering. This effect of these parameters on friction coefficient and wear of tool steels had been evaluated by scratch test through measuring scratch width. Hardness test was executed as an indicator to wear resistance. The materials used in this investigation were commercial grade (K110) cold work tool steel with a nominal composition of 1.55 wt. % carbon, 11.80 wt. % chromium, 0.80 wt. % molybdenum, 0.95 wt. % vanadium, 0.35 wt. % manganese and 0.25 wt. % silicon. After hardening, several tempering temperatures (200, 350, 500 and 600 °C) were used to investigate the relation between hardness, wear behavior and friction coefficient. Test specimens were 20 mm diameter and 10 mm height.

RESULTS AND DISCUSSION

The effect of heat treatment processes on the hardness, friction coefficient and wear of tool steels was investigated. Cold work tool steel was heat treated by different processes (hardening by quenching in oil, hardening by compressed air quenching, normalizing, hardening by quenching in salt bath at 250°C and hardening by quenching in salt bath at 500°C). Wear and friction coefficient of the tested materials were evaluated by scratch test. Hardness was measured to have specific information about wear resistance of tool steels. The hardness of the tested specimens is shown in Fig. 2. As received specimens showed the lowest hardness, while heat treated test specimens showed significant hardness increase. The highest value of hardness was observed for specimens quenched in oil and normalized in air. This behaviour might be attributed to the formation of the martensitic microstructure of high strength.

The influence of heat treatment on friction coefficient is illustrated in Fig. 3. In general, friction coefficient increased with increasing load. The highest values of friction coefficient were displayed by oil quenching followed by normalizing processes. As received specimens showed relatively higher values of friction coefficient. In scratch test it is commonly known that as friction coefficient increases, the stylus deeply penetrates the specimens surface so that the volume of removed materials increases. As the hardness of the test specimens increases the stylus finds great resistance to penetrate the scratched surface so that the volume of material removed decreases. Wear of test specimens was measured by wear scar width. The effect of different heat treatment processes on wear for cold work tool steels is shown in Fig. 4. Generally, wear slightly increased with increasing load. Maximum wear was displayed by as received specimens, while minimum wear was presented by specimens quenched in oil and normalized in air. Wear strongly depended on the hardness of the test specimens. As the hardness increases wear decreases.

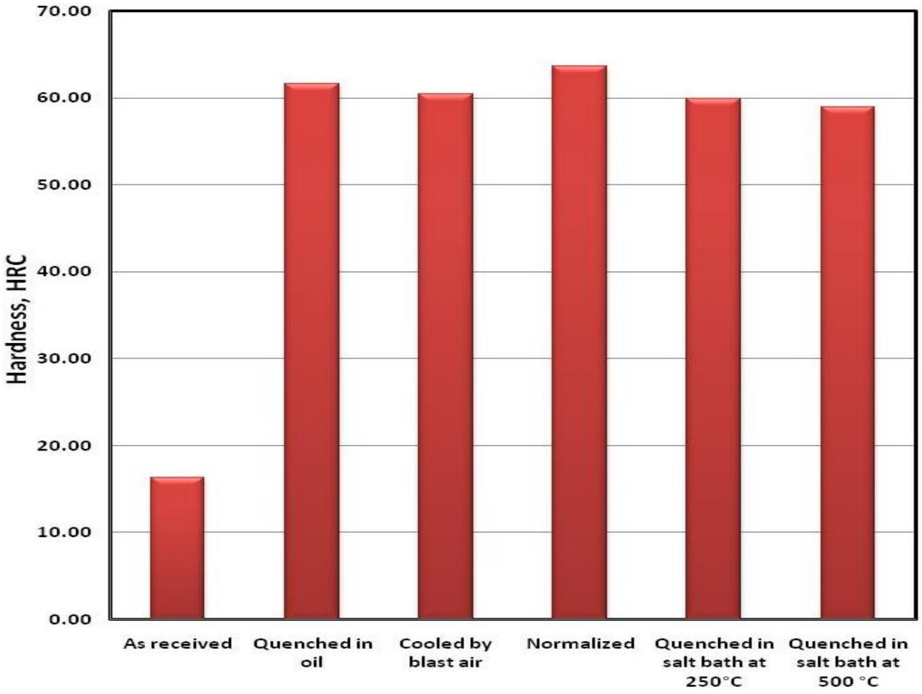

Fig. 2 Hardness of cold work tool steels after different heat treatment processes.

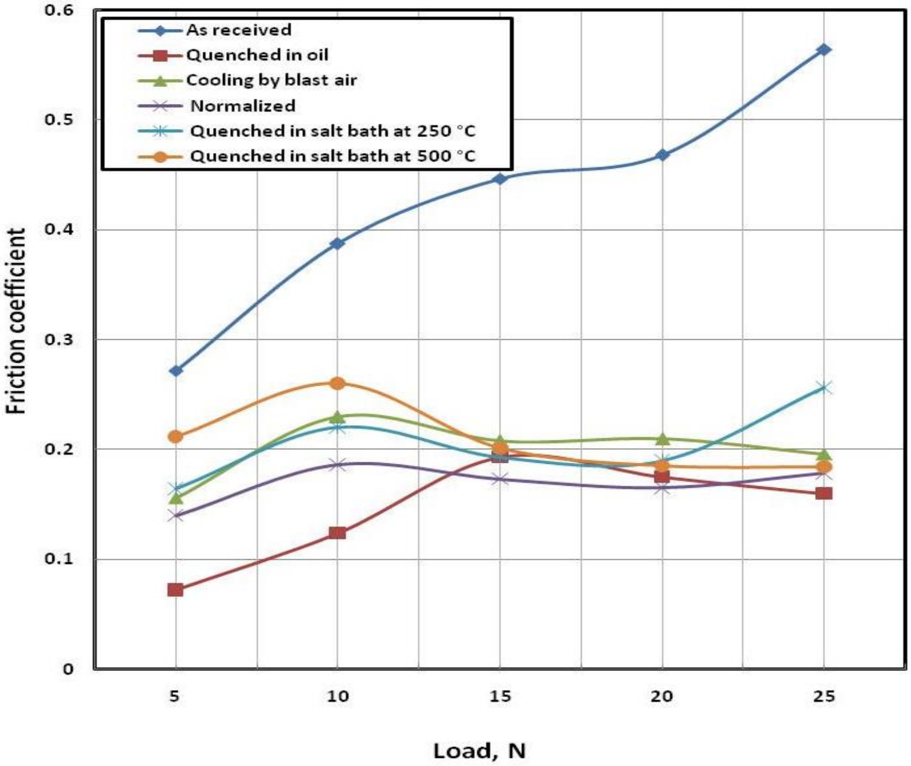

Fig. 3 Effect of different heat treatment on the friction coefficient of cold work tool steels.

The effect of tempering temperature on the tribological properties of cold work tool steels is discussed in Figs. 5 - 7. Different cooling medium had been used for quenching. After quenching, the tool steels had a microstructure consisting of martensite, retained austenite and carbides. Hardening of tool steel should always be followed immediately by tempering. It should be noted that tempering at low temperatures only affects the martensite, while tempering at high temperature also affects the retained austenite. In this section the difference between friction coefficient and wear of test specimens at the same quenching media used and various tempering temperature will be evaluated.

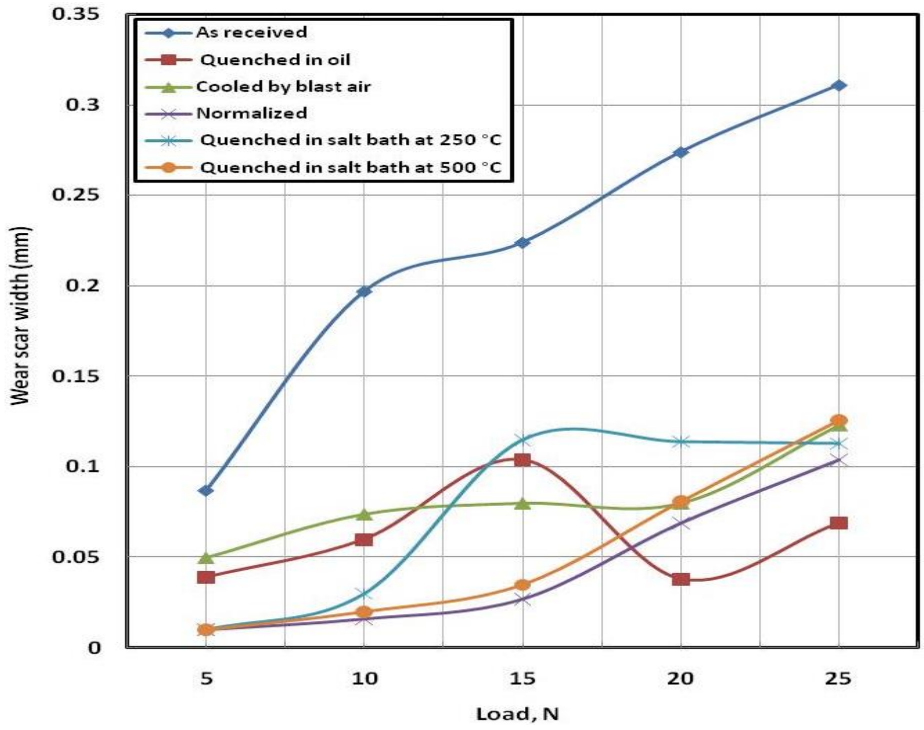

Fig. 4 Effect of different heat treatment processes on the wear for cold work tool steels.

The variation of hardness of cold work tool steels at various tempering temperatures is shown in Fig. 5. It was observed that the hardness of the sample decreases with the increase of tempering temperature. At lower tempering temperatures, there were nominal effects on hardness, but as tempering temperature went up its effect on the hardness became prominent. It is clear, Fig. 5, that at tempering temperature 200°C, the hardness decreased from 61.6 to 60 HRC (2.6 %). At tempering temperature 350°C, the hardness decreased from 61.6 to 56.4 HRC (8.5%). At tempering temperature 500°C, the hardness decreased from 61.6 to 53.9 HRC (12.5%). At tempering temperature 600°C, the hardness decreased from 61.6 to 47.7 HRC (22.6%).

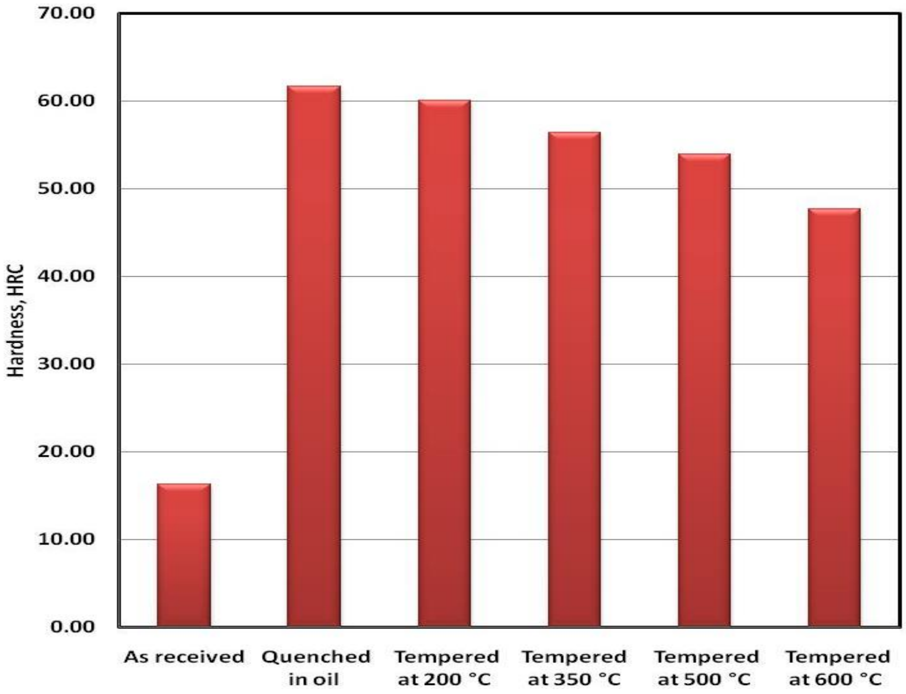

Fig. 5 Effect of tempering temperatures after oil quenched on the hardness for cold work tool steels.

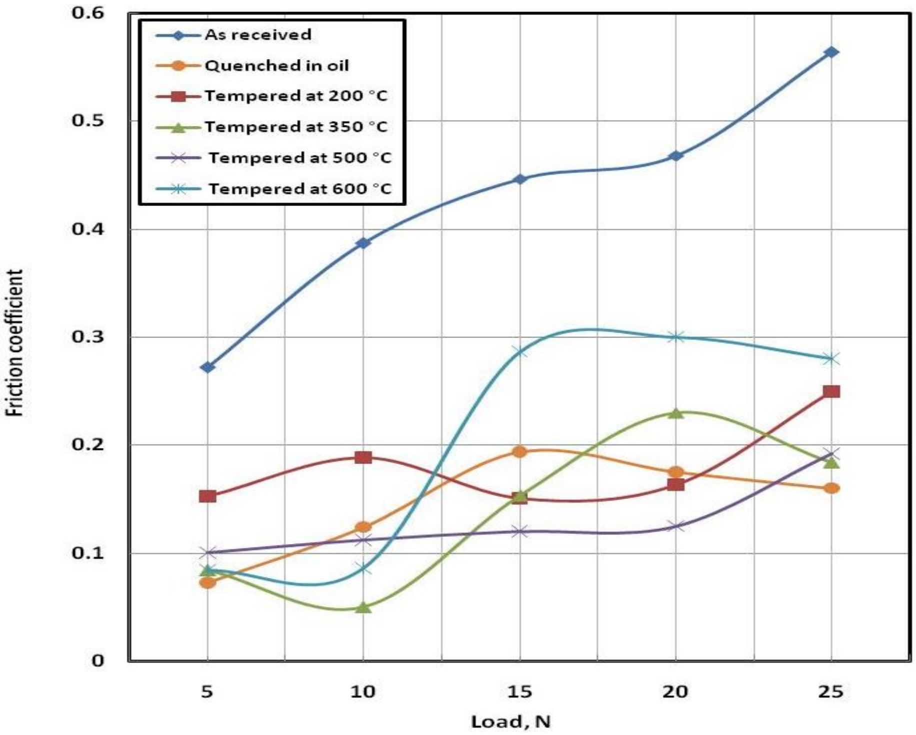

Fig. 6 Effect of tempering temperatures after oil quenched on the friction coefficient for cold work tool steels.

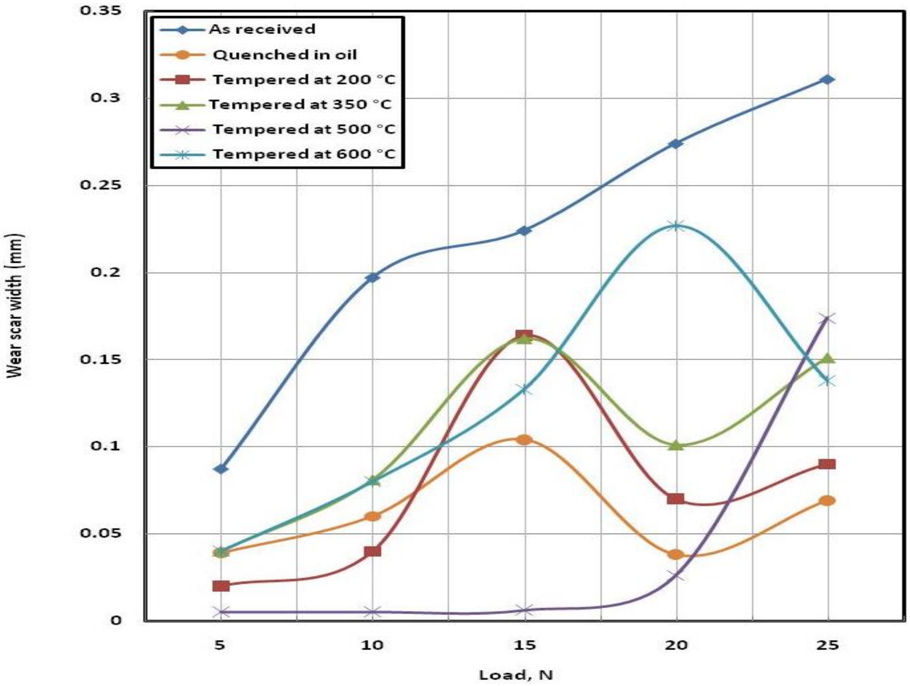

Fig. 7 Effect of tempering temperatures after oil quenched on the wear for cold work tool steels.

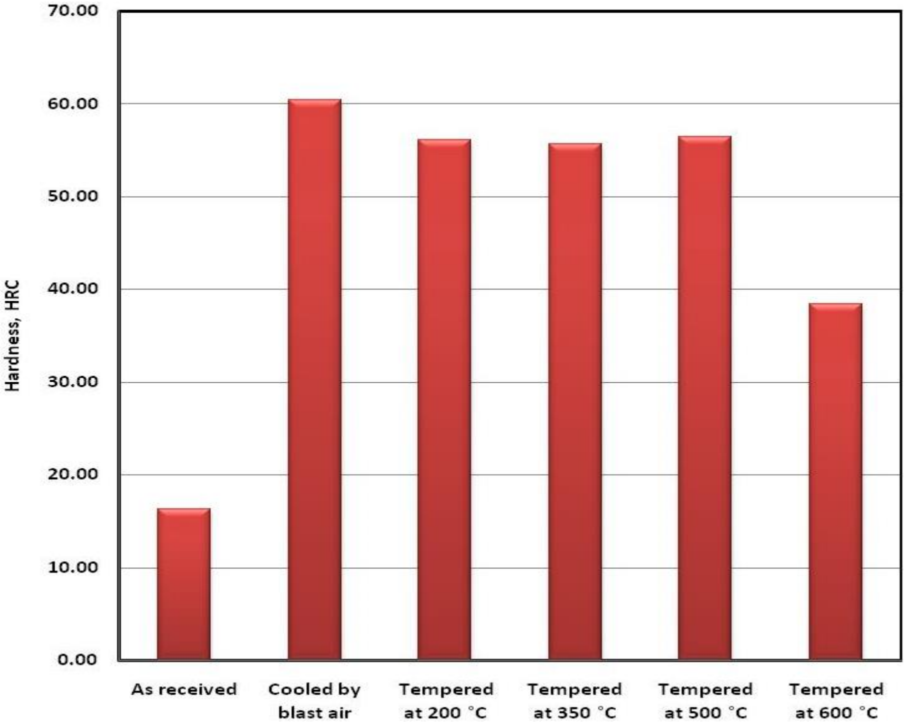

Fig. 8 Effect of tempering temperatures after blast air cooling on the hardness for cold work tool steels.

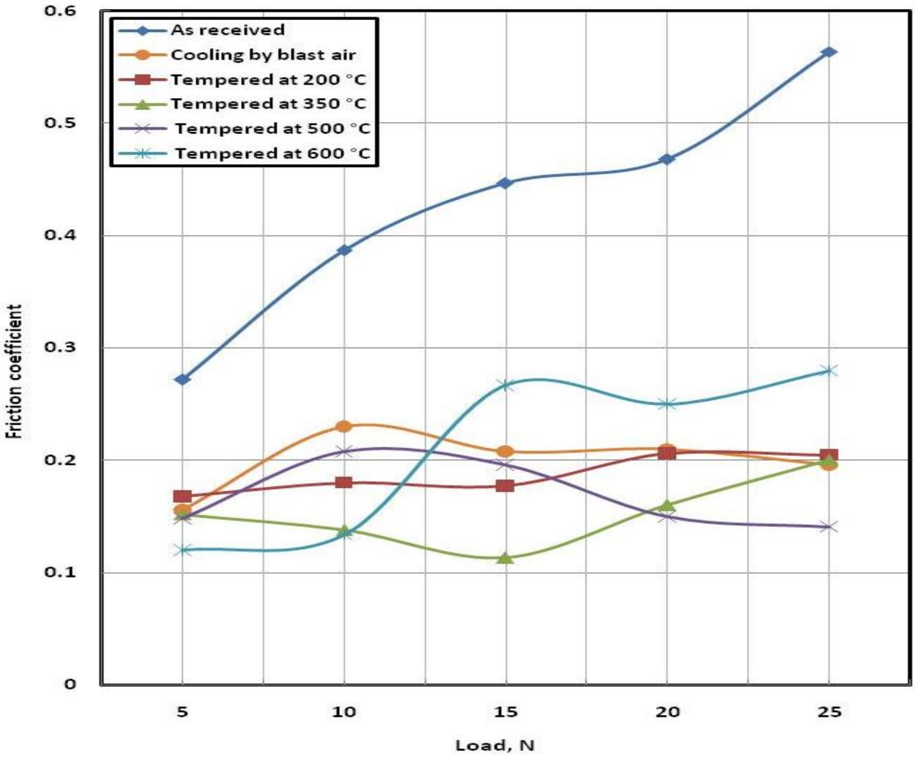

Fig. 9 Effect of tempering temperatures after blast air cooling on the friction coefficient for cold work tool steels.

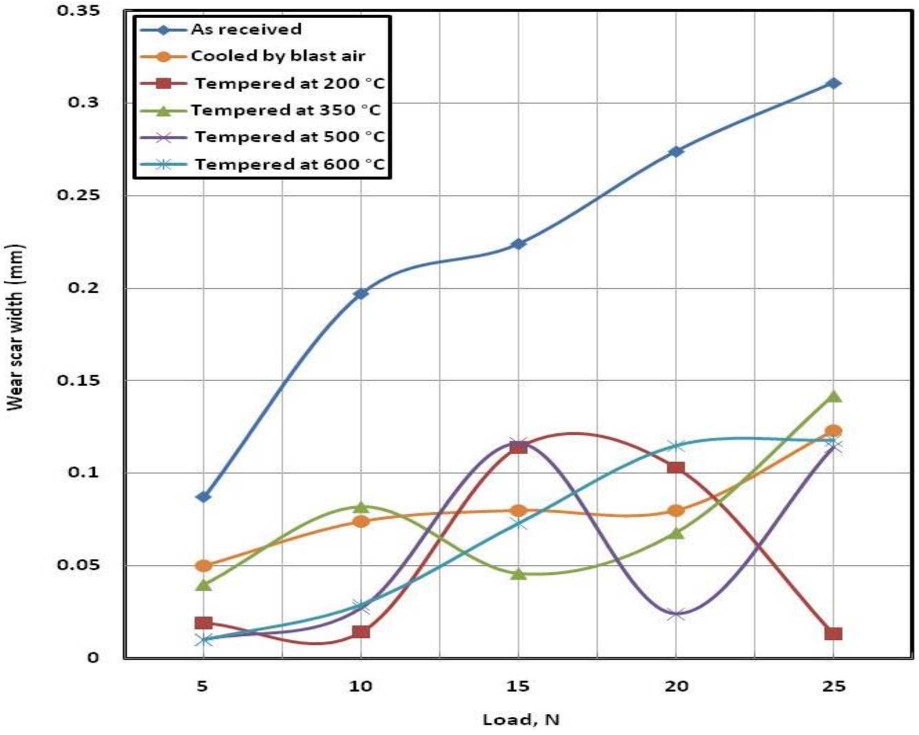

Fig. 10 Effect of tempering temperatures after blast air cooling on the wear for cold work tool steels.

Figures 6 and 7 show the effect of various tempering temperatures on both friction coefficient and wear of cold work tool steels respectively. Quenched specimens in oil displayed minimum friction coefficient (0.16) and highly improved wear resistance which was measured by minimum wear scar width (0.069 mm).

Specimens tempered at 600°C showed higher wear than that observed for specimens tempered at 500°C and oil quenched. This behavior could be attributed to that martensite (hard constituent) was transformed to comparatively soft troostite (tempered martensite).

The effect of tempering temperatures on hardness of cold work tool steels quenched by compressed air is shown in Fig. 8. Hardness of test specimens decreased gradually by increasing tempering temperatures. Figure 8 shows that, at 200°C tempering temperature, the rate of decrease in hardness was 7.1% (from 60.4 to 56.1 HRC). At 350°C tempering temperature, the rate of decrease in hardness was 7.8%. At 500°C tempering temperature, the rate of decrease in hardness was 6.6%. The rate of hardness decrease was 36.4% at 600°C tempering temperature.

Based on the fact that at low tempering temperature stresses are removed, while at high tempering temperature there is change of microstructures from martensite to tempered martensite that improves mechanical properties. The influence of tempering temperature on both friction coefficient and wear of cold work tool steels is shown in Figs. 9 and 10 respectively. Similar friction coefficients were given by test specimens that were quenched by compressed air. Test specimens tempered at 500°C and quenched by compressed air had the lowest values of friction coefficient and wear scar width, indicating that they possessed quite good wear resistance. As shown in Fig. 9 and 10, the behavior of friction coefficient and wear was significantly affected by tempering temperature similar to the trend observed in Figs. 6 and7.

CONCLUSIONS

1. As received specimens showed the lowest hardness, while the highest value of hardness was observed for specimens quenched in oil and normalized in air.
2. Friction coefficient increased with increasing load. The highest values of friction coefficient were displayed by oil quenching followed by normalizing processes. As received specimens showed relatively higher values of friction coefficient.
3. Wear slightly increased with increasing load. Maximum wear was displayed by as received specimens, while minimum wear was presented by specimens quenched in oil and normalized in air.
4. The hardness decreased with increasing tempering temperature.
5. Oil quenched specimens displayed minimum friction coefficient and minimum wear.
6. Hardness of test specimens decreased gradually by increasing tempering temperature after quenching by compressed air.

7. Significant reduction in friction coefficient and wear was observed for test specimens cooled by compressed air and tempered. This behaviour confirms that they possessed quite good wear resistance.

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