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TRIBOLOGICAL BEHAVOUR OF HEAT TREATED HOT WORK STEELS

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ABSTRACT
The aim of the present work is to investigate the friction and wear behavior of commercial hot work tool steels. It is planned 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 the highest values of hardness and friction coefficient were observed for tested specimens that heat treated at salt bath at 250°C quenched and normalized. Maximum wear was displayed by as received specimens, while the minimum wear was shown by tested specimens that treated in salt bath at 500°C quenched and normalized. The highest value of hardness was observed for the test specimens that tempered at 500°C Tested specimens tempered at 700°C showed higher wear than that observed for tested specimens tempered at 500°C and 600°C. The test specimens quenched by air compressed and tempered have the highest values of hardness (43.2 HRC and 42.5 HRC) respectively.

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

INTRODUCTION
The friction and wear behavior of commercial cold work tool steels were investigated, [1]. 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.

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 of steel, chromium, manganese and silicon are added to these steels, [2]. 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, [3, 4] 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, [5]. Due to safety, springs have to meet increasing performance requirements, [6], 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, [7]. 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, [8]. Hardness of material depends upon the type of bonding forces between atoms, ions or molecules. Furthermore for spring steels, [9], 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[10 - 13]. The Taguchi's design is a simple, efficient and systematic approach to optimize designs for performance, quality and cost [14]. In the Taguchi method, Design of experiments approach enables to analyze successfully the wear behavior of materials [15]. 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 [16, 17]. 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, [18, 19]. 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. 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 hot work 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

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.

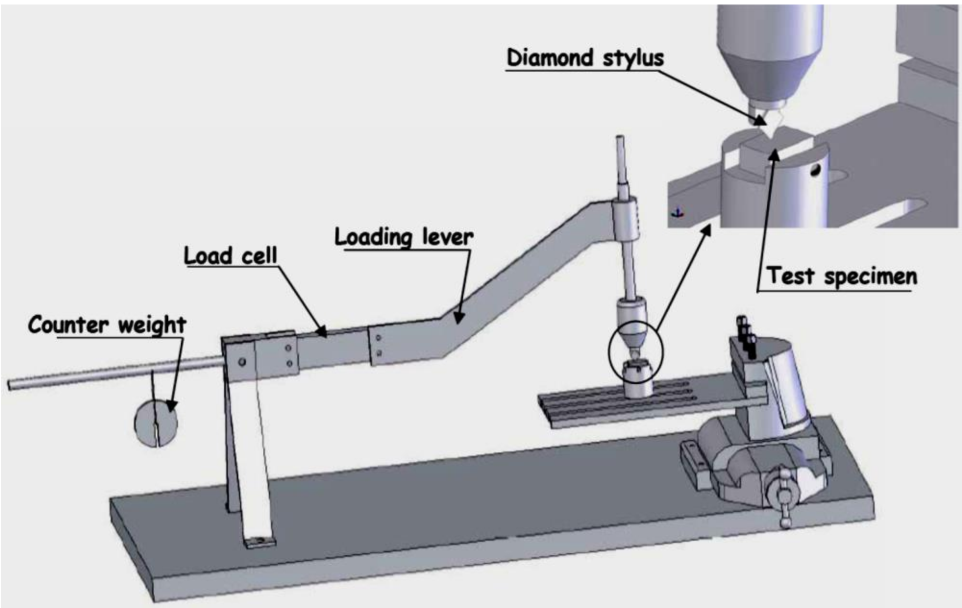

Fig. 1 Arrangement of scratch test rig.

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

Hot work tool steels are mostly subjected to high thermal and mechanical stresses. Heat treatment of hot work tool steels is conducted to produce an optimal combination of high hardness, good wear resistance and toughness for a given application. High hardness is frequently produced by transformation of austenite into martensite and toughness is controlled largely by the tempering of the martensite. The effect of heat treatment on the tribological properties of hot work tool steels is investigated. The surface properties are investigated using the hardness and scratch tests. The hardness of the tested specimens is shown in Fig. 2. As received tested specimens showed the lowest hardness, while heat treated test specimens showed significant hardness increase. The highest value of hardness was observed for tested specimens that heat treated at salt bath at 250°C quenched and normalized. The hardenability of hot work tool steels is quite high, and therefore the steels can generally be hardened by air cooling.

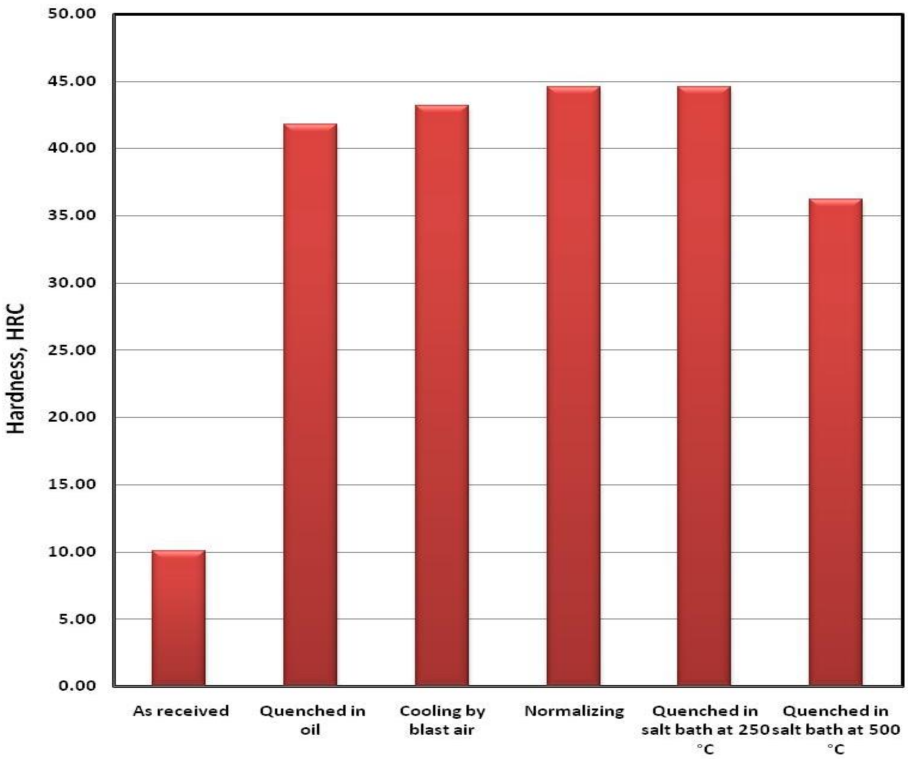

Fig. 2 Effect of heat treatment processes on the hardness of hot work tool steels.

The influence of heat treatment on friction coefficient is illustrated in Fig. 3. In agreement with general behavior of tested specimens, friction coefficient increased with increasing load. The highest values of friction coefficient were displayed by salt bath at 250°C quenched and normalized tested specimens. As received specimens showed relatively higher friction coefficient values. In scratch test is it commonly known that as friction coefficient increases the stylus deeply penetrates the specimen surface so that the volume of the removed material increased. As the hardness of the test specimens increases the stylus finds great resistance to penetrate the scratched surface so that the volume of the removed material decreased.

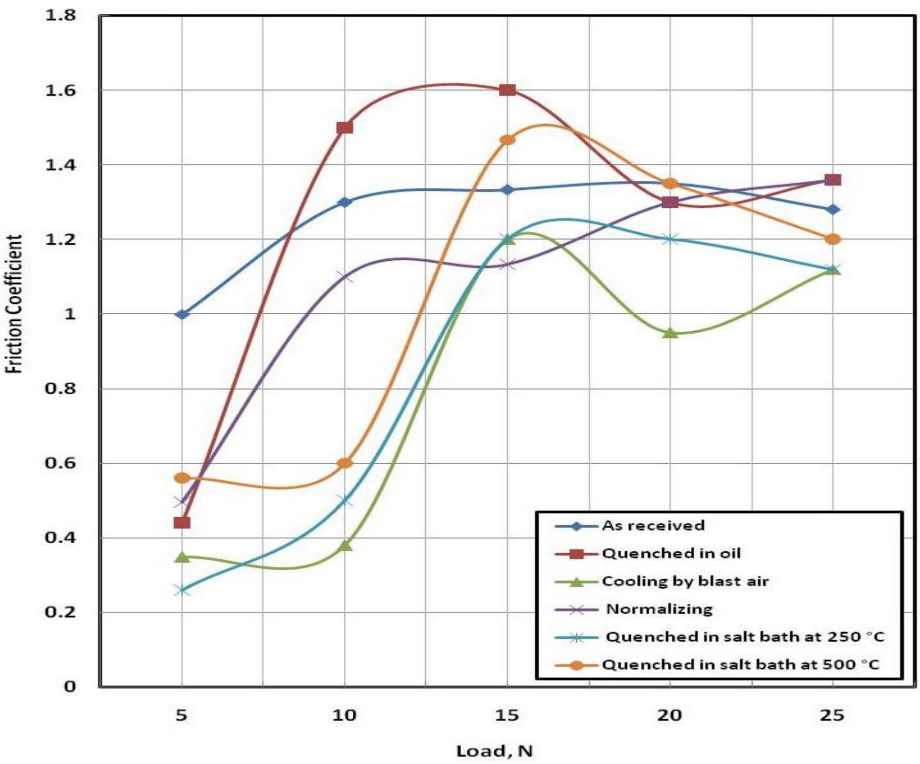

Fig. 3 Effect of heat treatment processes on the friction coefficient displayed by hot work tool steels.

Wear was influenced by the heat treatment processes carried out in the present study. Wear of test specimens was measured by wear scar width. The effect of different heat treatment processes on wear for hot work tool steels is shown in Fig. 4. On the other hand, wear slightly increased with increasing load. Maximum wear was displayed by as received specimens, while the minimum wear was shown by tested specimens that treated in salt bath at 500°C quenched and normalized. Wear strongly depended on the hardness of the test specimens. As the hardness increased wear decreased.

The influence of tempering temperatures on the tribological properties of hot work tool steels was investigated. Many different media have been used for quenching. After quenching, the tool steels had a microstructure consisting of martensite, retained austenite and carbide. The final step of this heat treatment cycle was tempering. Tempering is the process of heating the hardened test specimens to a 300°C, 500°C,

600°C and 700°C respectively, holding at this temperatures for 2 hours, and then air cooling.

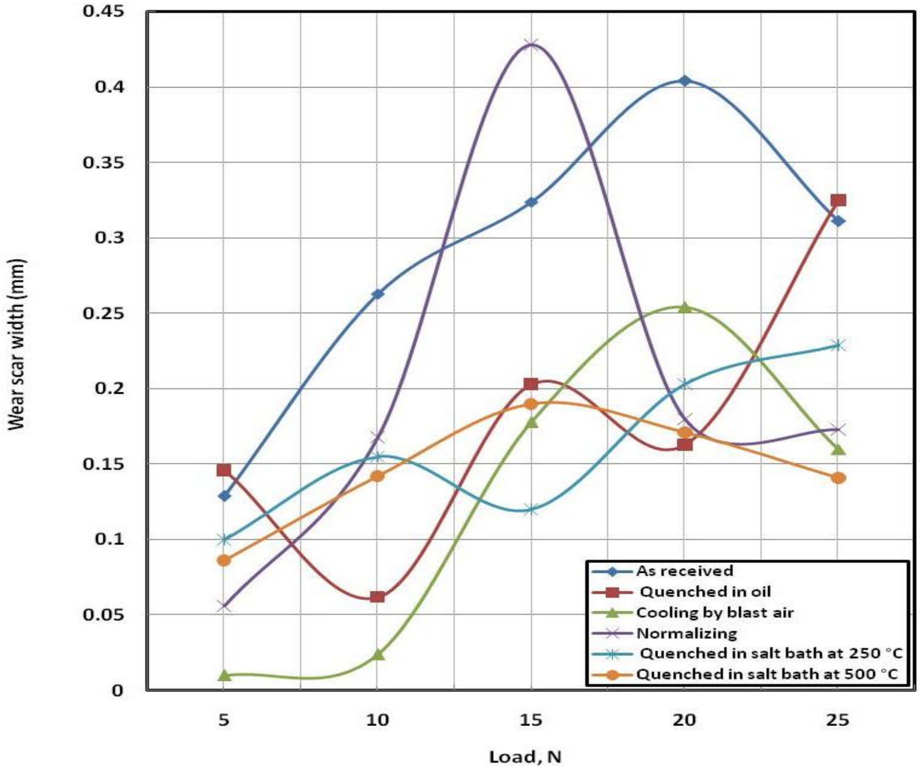

Fig. 4 Effect of heat treatment processes on the wear of hot work tool steels.

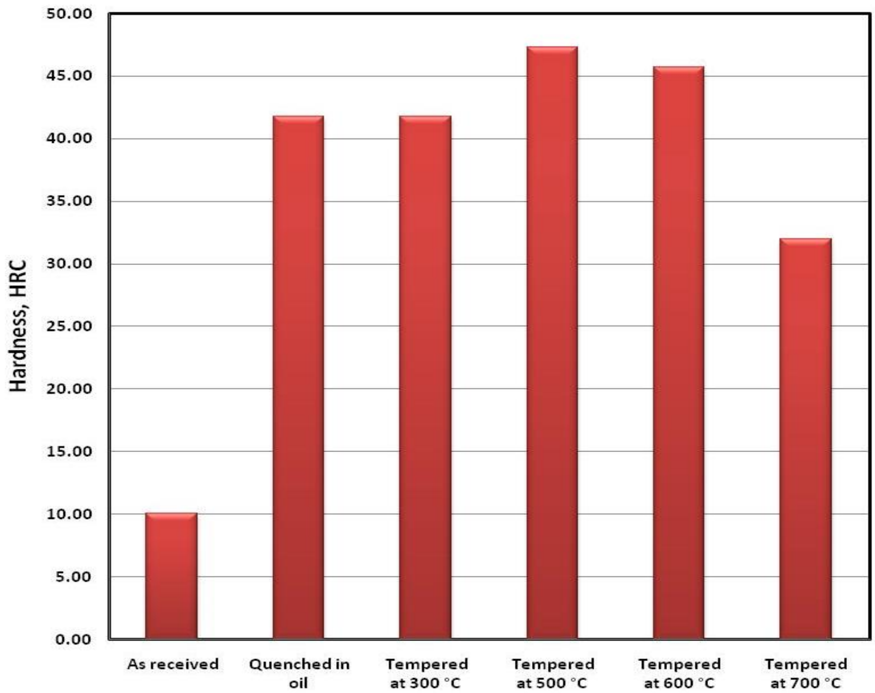

Fig. 5 Effect of tempering temperature after oil quenching on the hardness of hot work tool steels.

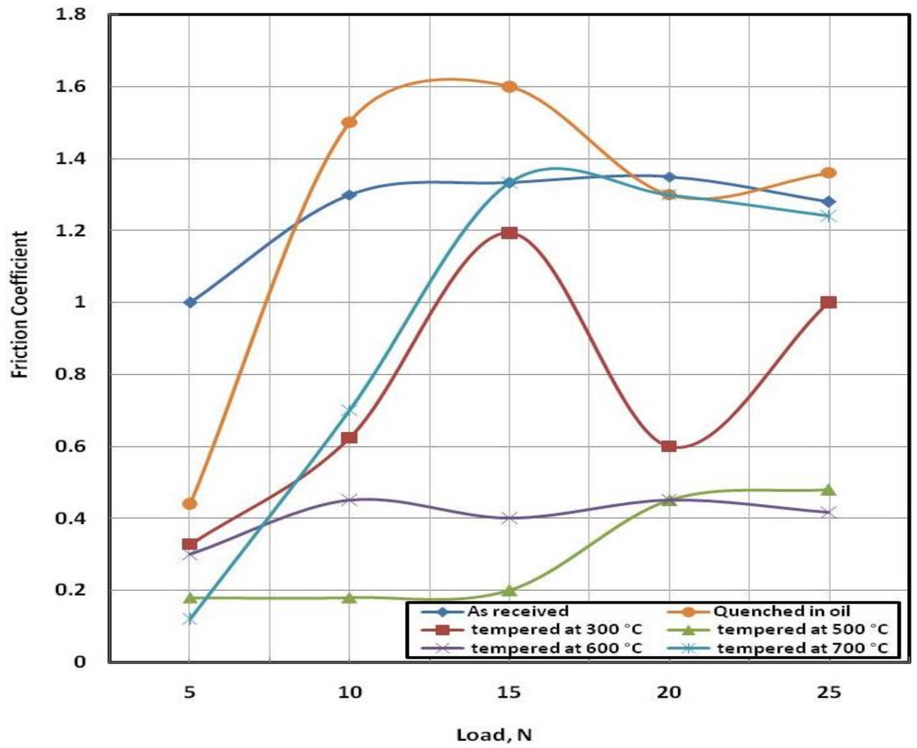

Fig. 6 Effect of tempering temperature after oil quenching on the friction coefficient of hot work tool steels.

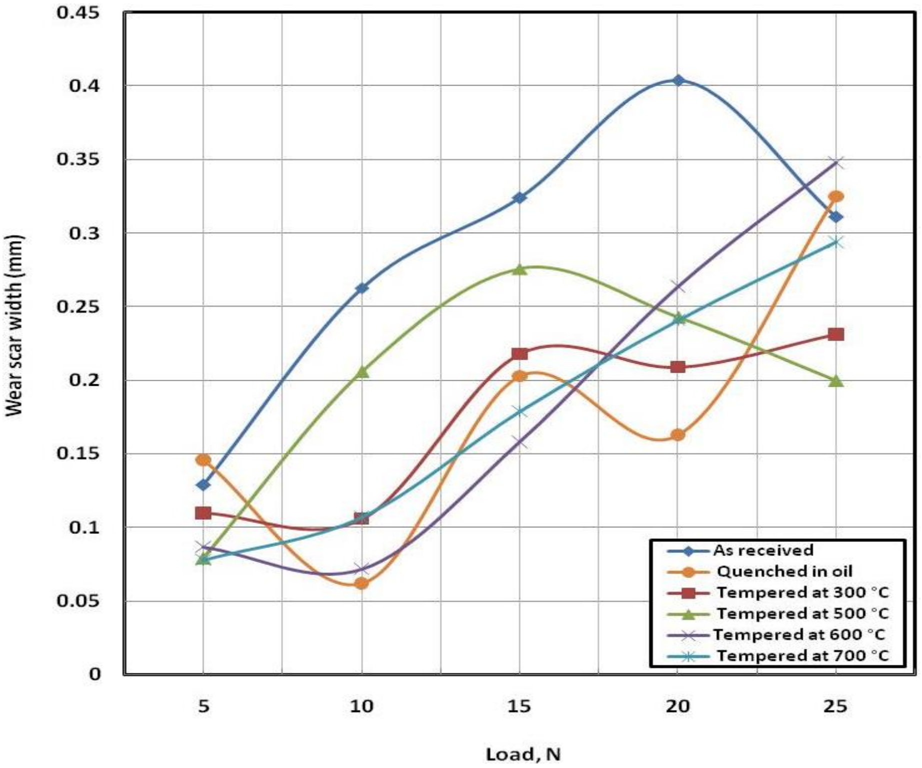

Fig. 7 Effect of tempering temperature after oil quenching on the wear of hot work tool steels.

During tempering of hot work tool steels, secondary hardening occurs due to precipitating carbide (vanadium carbides) in which some molybdenum is dissolved. Because secondary hardening is due to precipitation, its intensity increases with increasing volume fraction and decreasing particle size of alloy carbide. In this section the difference between friction coefficient and wear of test specimens at the same quenching media used and various tempering temperatures were evaluated.

Figure 5 shows the variation of hardness of hot work tool steels at various tempering temperatures. The tested specimens oil quenched and tempered at 300°C have the same hardness values (41.8 HRC) and higher than as received tested specimens (10.1 HRC). The effect of tempering temperatures on the friction coefficient of hot work tool steels is illustrated in Fig 6. The highest value of hardness was observed for the test specimens that tempered at 500°C (47.3 HRC), though, test specimens tempered at 500°C displayed minimum friction coefficient and highly improved wear resistance over oil quenched and other tested specimens. The influence of tempering temperatures on wear of hot work tool steels is shown in Fig. 7. Tested specimens tempered at 700°C showed higher wear than that observed for tested specimens tempered at 500°C and 600°C.

The hardness of hot work tool steels was varied by the tempering temperatures, Fig. 8. The lowest values of hardness for the test specimens were observed for as received and tempered specimens at 700°C (10.1 HRC and 10.8 HRC) respectively, while test specimens quenched by air compressed and tempered have the highest values of hardness (43.2 HRC and 42.5 HRC) respectively.

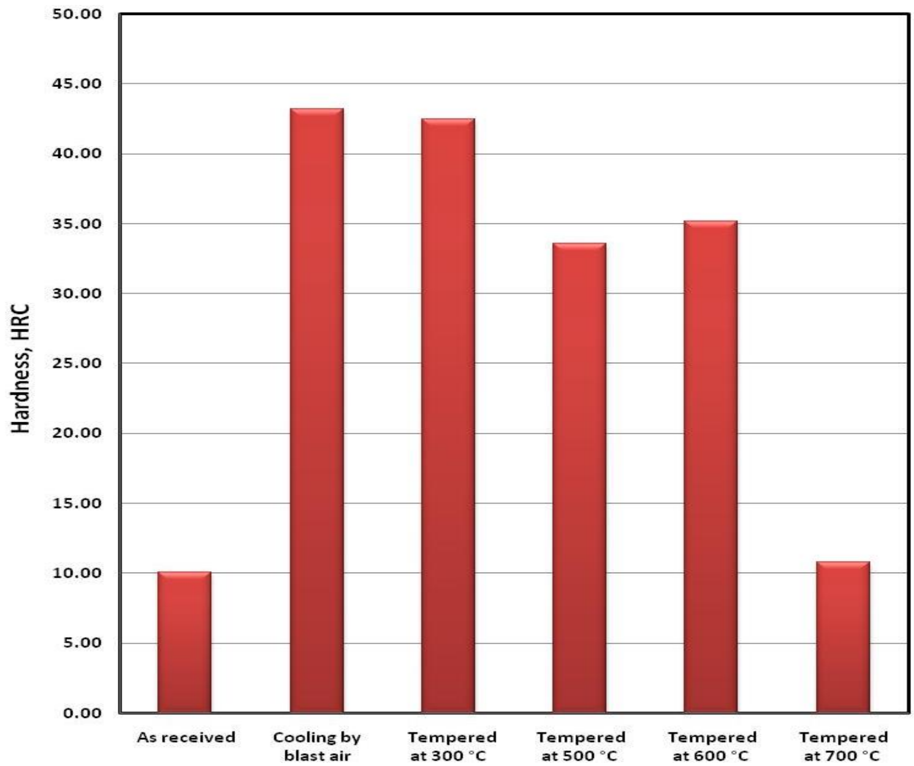

Fig. 8 Effect of tempering temperature after blast air cooling on the hardness of hot work tool steels.

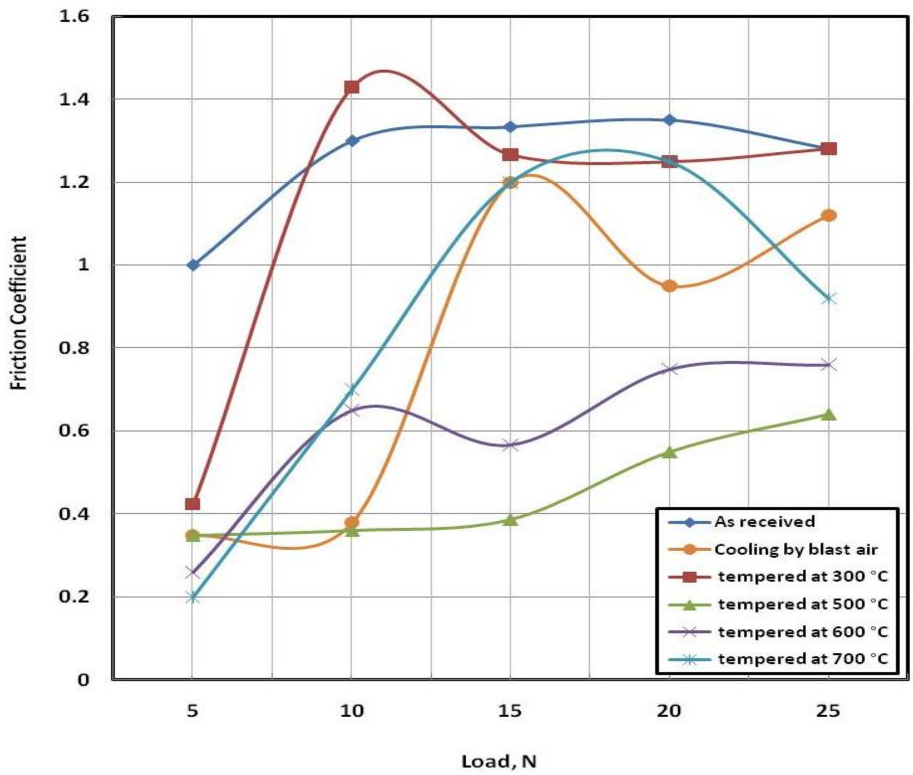

Fig. 9 Effect of tempering temperature after blast air cooling on the friction coefficient displayed by hot work tool steels.

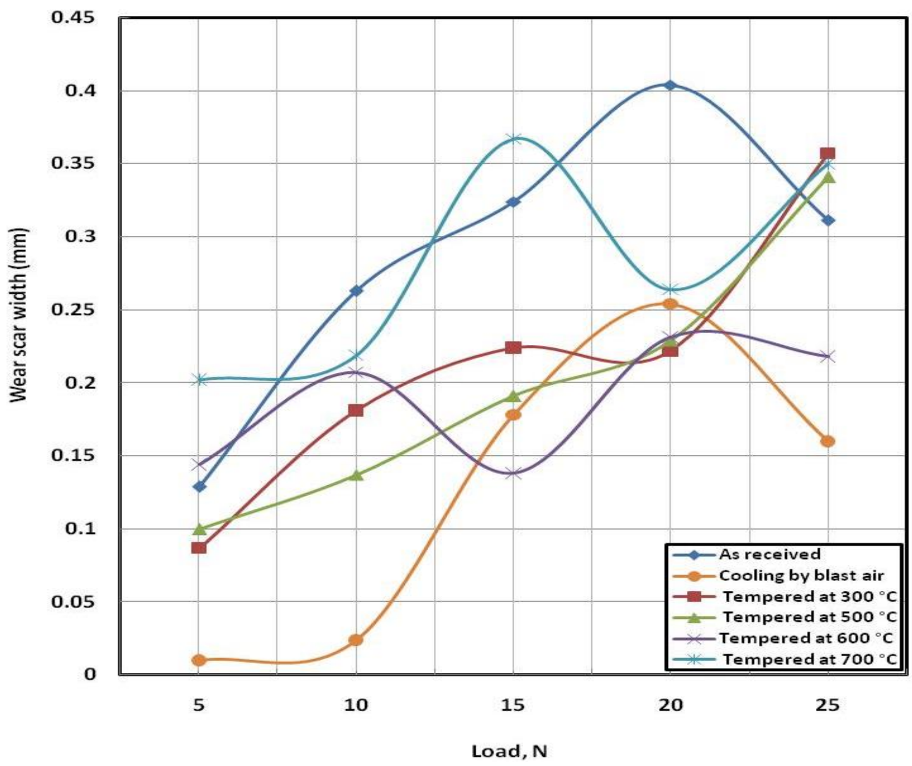

Fig. 10 Effect of tempering temperature after blast air cooling on the wear of hot work tool steels.

The influence of various tempering temperatures on both friction coefficient and wear of hot work tool steels is shown in Figs. 9 and 10 respectively. The same trend was observed for friction coefficient displayed by test specimens that air compressed quenched and

followed by those tempered at 500°C and 600°C. Wear of the tested specimens of heat treated hot work tool steels is illustrated in Fig. 10. Maximum wear was displayed by as received tested specimens, while minimum wear was observed for test specimens quenched by air compressed and tempered at 600°C.

CONCLUSIONS

1. The highest values of hardness and friction coefficient were observed for tested specimens that heat treated at salt bath at 250°C quenched and normalized. As received specimens showed relatively higher friction coefficient values. Maximum wear was displayed by as received specimens, while the minimum wear was shown by tested specimens that treated in salt bath at 500°C quenched and normalized.

2. The test specimens tempered at 500°C displayed minimum friction coefficient and highly improved wear resistance over oil quenched and other tested specimens.

3. The lowest values of hardness for the test specimens were observed for as received and tempered specimens at 700°C, while test specimens quenched by air compressed and tempered have the highest values of hardness. The same trend was observed for friction coefficient displayed by test specimens that air compressed quenched and followed by those tempered at 500°C and 600°C. Minimum wear was displayed by test specimens quenched by air compressed and tempered at 600°C.

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