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EFFECT OF MACHINING FLUID LIKE QUENCHING MEDIA ON THE FRICTION AND WEAR BEHAVIOR OF AISI 1045 STEEL

E.A. Pérez R, J.F. Llano M and J.S. Ravagli R
Programa de Ingeniería Mecánica, Universidad de Ibagué, Ibagué, Colombia

L.I. Negrín H
Facultad de Ingeniería Mecánica, Universidad Central Marta Abreu de las Villas, Santa Clara, Cuba

ABSTRACT

The hardening of medium carbon steel is commonly reached through the quenching heat treatment. In this treatment are used different substances like quenching media to improve high mechanical properties and wear resistance. In this work, quenching treatments were conducted to study the effect of the water and machining fluid in mixtures like quenching media on the coefficient of friction, the mass loss, the hardness and microstructural behavior at the AISI 1045 steel. The quenching treatments were heated at 850 C in an electric furnace, and sustained 40 minutes, until to achieve a homogeneous structure. The quenching media used were water, 90% water–10% machining fluid, 70% water-30% machining fluid and 60% water–40 % machining fluid mixtures. The results indicated that all quenched samples reduced the coefficient of friction in comparison with steel in commercial condition (without hardening). Likewise, the quenching using water favored to obtain high mass loss (wear) in the samples. The way of reduce both the coefficient of friction and mass loss, was to realize the tempered after quenching process. However, the use of the 60% water–40% machining fluid mixture allowed to obtain values of coefficient of friction and the mass loss at the same level that those obtained after of tempered treatment, indicating the possibility of skip this treatment.

Keywords: AISI 1045 steel, Hardness, Quenching media, Tempering, Tribological behavior.

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1. INTRODUCTION

The AISI 1045 steel is a medium carbon steel without alloy elements that provides a medium strength level. This material is widely used in the automotive, structural and agricultural industries for the manufacture of machine elements that require hardness and toughness at a lower cost than the alloy steels. This steel has good weldability and machinability and can be hardened for heat treatments [1].

The use of this steel under hardening condition, require to be heated to the higher temperature that the Ac3 and subsequent fast cooling. The quenching is achieved by immersing the hot material in water, oil (mineral, vegetable or animal) [2], salt aqueous solution or aqueous polymer solutions. Other cooling substances include molten salt, gas as well forced air. However, the success of the cooling process depends on the chemical composition steel, the agitation process, the temperature and the cooling substance [3].

The role of the quenching media is focused on the heat transfer from the hot metal producing the transformation of the austenite to large amount of martensite with high hardened zone [4]. For hardening of the medium carbon steels, it is common to use water, water with salts under conditions of agitation to obtain the highest cooling rates. Likewise, after the quenching process is necessary to carry out the tempering process with the aim of reducing the residual stresses although the hardness reached is reduced [5].

In the literature, some authors have studied the effect of different quenching substances on the hardness and microstructure behavior in medium carbon steels. Ibrahim and Sayuti [6], shows that for an AISI 1045 steel quenched in water the high cooling rate favors the high hardness as well as the high brittleness and high residual stresses. This condition increase the obtaining of interganular fracture. Adeyemi and Adedayo [7] showed the predominant presence of martensitic structure with carbides with an average hardness of 723 HV, and maximum tension strength of 200 MPa for the quenching in water of the AISI 1045 steel, while the quenching of steel in palm vegetable oil showed mainly bainitic structures with an average hardness of 610 HV and a maximum tensile strength of 555 MPa. Ikubanni Pelumi [8] studied the hardness and the tensile strength of medium carbon steel using coconut water, pap water and spent engine oil as coolant substances for quenching treatment. The results showed that for quenching from 730C the highest hardness values were obtained at 60 minutes of austenization. In this case, the 500 HB Hardness was obtained for coconut water. At the same way, the quenching at 790C with 45 minutes of austenization allowed to obtain the maximum hardness values for the coconut water and pap water. In both cases, the hardness value was close to 600 HB.

In the same way, authors like García et al [9], studied the influence of different thermal treatments of quenching and tempering on the microstructure, hardness and tribological behavior of an austenitic steel. The results showed that for without heat treatment, and quenched in air and oil conditions was obtained an increase in the hardness values after of the wear test. In the case of quenched steel in water, the hardness not was obtained. The authors to explain that the increase in the hardness values were consequence of the transformation of austenite to martensite due to the friction force present during the tests. Ulutan et al [10] studied the coefficient of friction behavior on the AISI 4140 steel without heat treatment and with quenched in oil, finding that the steel without treatment presented the highest loss of mass. The coefficient of friction found between the two conditions have practically the same value, however, the values obtained for quenched steel presented lower standard deviation.

Kim et al [11], found that the coefficient of friction and the wear rate decreased with the increase in hardness for medium carbon SPS5 steel. The wear rate was reduced by 60% for the material with a hardness of 62.6 HRC. In tha same way, was established that the martensitic microstructure leads to an increase in hardness and a decrease in the wear rate. Finally, Autay et al [12], studied the effect of mechanical properties on the tribological behavior of ISO C45 steel. The results were obtained for heat treatment steel in five conditions: normalized with hardness of 212 HV, quenched in water with hardness of 608 HV, quenched in water and tempered at 200 C with hardness of 538 HV, quenched in oil with hardness of 275HV and quenched in oil and tempered at 200 C with hardness of 265 HV, and it was not found a direct and obvious relationship between hardness values and coefficient of friction values. However, was possible to identify the variation of the coefficient of friction values in function of the variation of the normal load applied during the tests.

The principal aim of this study, was to know the effect that have the use of machining coolant, used as quenching media on the coefficient of friction and dry wear behavior of the AISI 1045 steel.

2. MATERIALS & EXPERIMENTAL PROCEDURE

2.1. Material and heat treatment

The material used in this study was commercial steel AISI 1045 with chemical composition presented in the table 1. Cylindrical samples of 76.2 mm diameter and 6 mm height were machined (Fig. 1). In each sample the surface was grinding processed with SiC abrasive papers number 180, 220 and 320 obtaining Ra = 0.15 μm as average surface roughness.

Table 1 Chemical composition of AISI 1045 steel in commercial condition

C	Mn	Si	S	P
0.47	0.8	0.3	0.025	0.025

The heat treatment process was performed increasing the temperature to 850 C in an electric furnace and sustained during 40 minutes approximately to ensure uniformity of temperature and achieve an austenite homogeneous structure. This heated was followed by the quenching where the samples were quenched in water and machining fluid in three concentrations (90% water-10% machining fluid, 70% water-30% machining fluid and 60% water-40% machining fluid). In all cases, the quenched was development on immersion and agitation for two minutes. The tempering process was carried out for the quenched in water sample. The process was realized to 400 C for 30 minutes and cooling at air.

2.2. Hardness and Wear Test

The Rockwell C hardness was used to measure the hardness at five points, along the radius in the cross-section for each sample. The hardness was carried out in a TIME HBRVU hardness tester to the commercial condition sample after the each quenching heat treatment. The wear test were performed in dry conditions in an sliding equipment following ball-on-disk method with Zirconia (ZrO_2) ball applying 20 N of normal load and a constant lineal speed of 0.34 m/s along of the sliding distance of 2200 m. The measure of the mass lossed were determined before and after each wear test using a PRECISA XB 220A balance with degree precision of 0,0001 g. The wear test was applied and repeated three times and the average results were used for the analysis.

2.3. Microstructure identification

The microstructural analysis was accomplished to the commercial condition material and the each quenched sample. The samples were grinding with SiC abrasive until 1000 grade paper. The final polishing was done with alumina paste of 1 μm until mirror surface finished. All samples were etched with a concentred solution of 3% Nital in order to obtain suitable microscopic examination. The microstructure studied was examined using an OLYMPUS BX51RF microscope.

3. RESULTS AND DISCUSSION

In order to analyse the effect to use of machining fluid as quenching media on the tribological behavior of AISI 1045 steel, shall be presented the coefficient of friction, mass loss, hardness and microstructures results after of each heat treatment.

3.1. Friction and wear tests

The Fig. 1 presents the behaviour of coefficient of friction as a function of the sliding distance. The values were obtained for all cases studied (Com = commercial condition, Q1 = Quenched in water, Q-T = quenched in water and tempered, Q_SOL1 = quenched in solution of 90% water-10% machining fluid, Q_SOL2 = quenched in solution of 70% water-30% machining fluid, and Q_SOL3 = quenched in solution of 60% water-40% machining fluid).

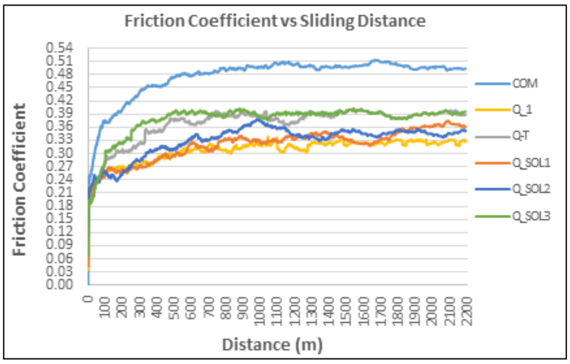

Figure 1 Coefficient of friction as a function of sliding distance.

In the figure is possible to observe that, the higher value of coefficient of friction was obtained in the commercial condition (Com). Also is possible to observe that, the intermediate coefficient of friction was obtained for the conditions Q-T and Q_SOL3. In the same way, the lowest coefficient of friction value was obtained for the quenched in water case (Q1).

On the other hand, the vales of the mass lossed for the AISI 1045 steel studied in each studied case, are summarized and presented in the table 2. The table shows that the highest mass loss was obtained for the steel quenched in water condition and on the machining fluid (Q_SOL1 and Q_SOL2 cases), followed for the sample in the commercial state condition. In addition, the lowest mass was loss obtained for the quenched and tempered Q-T and the Q_SOL3 conditions.

Table 2 Average values of mass loss (g) after of the ball on disk test

Sample	test 1	test 2	test 3	test 4	Average values
Com	0.0152	0.0164	0.0162	0.0149	0.0157
Q1	0.0686	0.0620	0.0494	0.0539	0.0585
Q-T	0.0144	0.0169	0.0244	0.0210	0.0192
Q_SOL1	0.0316	0.0292	0.0288	0.0371	0.0317
Q_SOL2	0.0161	0.0648	0.0309	0.0108	0.0307
Q_SOL3	0.0183	0.0139	0.0267	0.0132	0.0180

3.2. Hardness and Microstructures

The hardness in HRC scale was measured at five points along the radial distance for the each case studied. In the table 3 is presented the average of HRC hardness value obtained along of the radial distance.

Table 3 Average Hardness along of the radial distance

Sample	Average Hardness (HRC)
Com	17
Q1	58
Q-T	38
Q_SOL1	57
Q_SOL2	35
Q_SOL3	30

The results of the table 3 allows to identify that, how is it supposed, the hardness of the AISI 1045 steel in commercial condition was the lowest value, the hardness of the sample quenched in water was the highest and the hardness of the sample quenched and tempered was intermediate. Additionally, is possible to observe that, to use machining fluid in the lower concentration (Q_SOL1) cause a hight hardness value while the machining fluid in the high concentration allow to obtain lower hardness values.

On the other hand, the microstructures obtained in the metallography analysis are summarized in the figures 2 and 3. In the Fig. 2a and 2b is possible to observe the AISI 1045 steel in commercial condition (Com). In this condition, the microstructure exhibit ferrite and pearlite like principal structures. The Fig 2a was obtained with optical objective 20X and the figure 2b was obtained to 100X. The figures 2c and 2d were obtained to 50X and 100X respectively and to correspond to condition quenched in water (Q1). The figures show a long structure in needle form. This structure is martensite obtained during the cooling. The figures 2e and 2f were obtained to 50X and 100X and to correspond to condition quenched and tempered (Q-T) and the structure observed was tempered martensite.

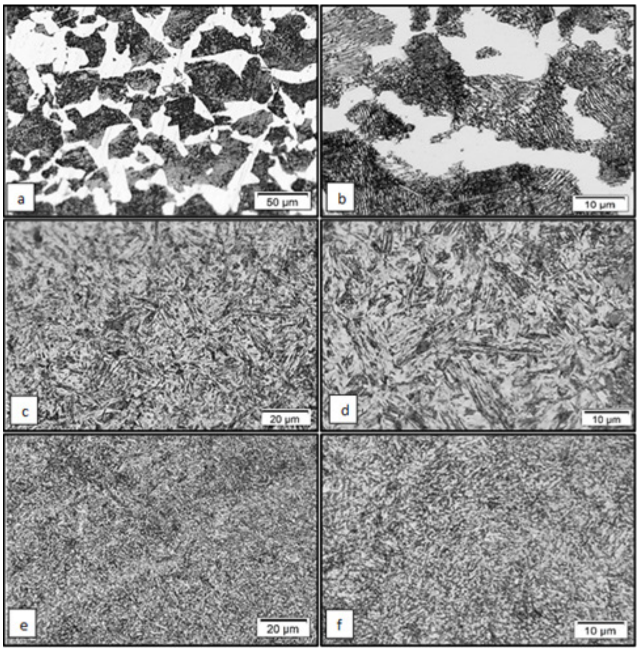

Figure 2 Optical microstructures obtained for AISI 1045 steel quenched in water cases. (a) Commercial condition at 50X. (b) Commercial condition at 100X. (c) Water quenched at 50X (d) Water quenched at 100X. (e) Quenched and Tempered at 50X, (f) Quenched and tempered at 100X.

The Fig. 3 shows the microstructures obtained to 50X and 100X magnifications. The figure to correspond to the steel quenched with machining fluid in the three concentrations studied. The figures 3a and 3b to correspond to Q_SOL1 condition and exhibits martensite in austenite (white zone). The figure 3c and 3d to correspond to Q_SOL2 condition and shows troostite (fine perlite at grain edges) on martensite background structure. The figures 3e and 3f to correspond to Q_SOL3 condition and exhibit sorbite (very fine perlite) and perlite structure.

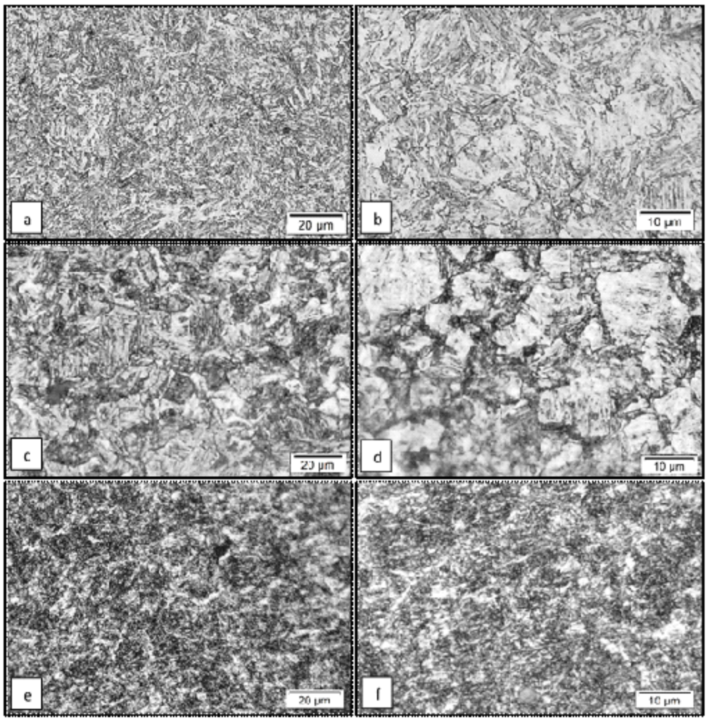

Figure 3 Optical microstructures obtained for AISI 1045 steel quenched in machining fluid at different concentrations. (a) Quenched in 10% machining fluid - 90% at 50X. (b) Quenched in 10% machining fluid - 90% water at 100X. (c) Quenched in 30% machining fluid - 70% water at 50X. (d) Quenched in 30% machining fluid - 70% water at 100X, (e) Quenched in 40% machining fluid - 60% water at 50X. (d) Quenched in 40% machining fluid - 60% water at 100X.

As is know, the high hardness of metals is important to reduction of the coefficient of friction value. In this case, the AISI 1045 steel (ductile behavior), was quenched in water, which allowed the increase in hardness average from 17 HRC to 58 HRC . This hardness was the reason for the coefficient of friction was reduced from 0.5 to 0.31 on average. The increase in hardness is due to the presence of martensite as the main microstructure evidenced in figure 2c. However, the increases in hardness allow increasing the fragility. This fragility can be caused for the high increase of residual stresses in the material, producing the increase in the loss of material during the contact and movement. This value increased from 0.0157 g to 0.0585 g. According to the literature, as consequence of hardening thermal treatments, such as quenching in water, the transformation to martensite induces high residual stresses. This stresses auspicious the irregular behavior of the mechanical properties and the brittleness of the material. For this reason, is necessary the heat treatment of tempering. In this treatment, the residual stresses are minimized or eliminated in spite to reduction of the hardness reached.

In this study, the steel quenched in water was tempered obtaining tempered martensitic structure (figure 2e) and reducing the hardness from 58 HRC to 38 HRC. As expected, the increase in ductility allow the increase of the coefficient of friction from 0.31 to 0.37, thus, the reduction of fragility to allow to that the mass lossed was reduced from 0.0585 g to 0.0192 g. The conditions obtained suggest and to confirm that increase the hardness of material allow decreasing the coefficient of friction. However, high hardness could generate high residual stresses allowing increase the loss mass. For this reason, it is very important to carry out the tempered treatment.

On the other hand, the hardening of the steel also can be done by quenching in mineral, vegetable, animal or synthetic oils [4]. In this way, the machining fluid is traditionally a substance based on mineral or synthetic oil. This mixture is applied pure or in emulsion with water in order to favor the transfer of heat produced in the machining process. The results obtained in quenching with mixture 90% water – 10% machining fluid, showed that the coefficient of friction was reduced until 0.33 values (comparated with commercial condition sample). In this case, the hardness was 57 HRC and the microstructure obtained was martensite. These results were close to those obtained for quenched in water, although the value of lossed mass was lower.

The results with quenching in mixture 70% water - 30% machining oil, allowed reaching a coefficient of friction of 0.35 and a hardness value of 35 HRC. This hardness value is near to water quenching and tempering hardness value. The microstructure found in this condition is predominantly perlite fine at grain edges (troostite) in martensite background, however, the value of the mass lossed for this condition was the same to achieve in the quenching of 90% water - 10% machining oil. The quenching carried out with mixture 60% water - 40% machining oil, reached a coefficient of friction of 0.39 as well as an average hardness of 30 HRC. The microstructure obtained is pearlite accompanied with regions of perlite very fine (sorbite). The hardness value reached is the lowest of all quenched conditions. The microstructure identified suggests an intermediate ductility condition. The value of lossed mass was 0.0180 g, this value is practically the same reached in the condition of quenching in water and tempering.

Finally, the total of experiments showed that for to obtain low coefficient of friction was necessary to realize the quenching in water or in mixture with the high water and low machining oil, obtaining martensite like principal microstructure, however, the conditions achieved (high hardness and martensite microstructure) allow to obtain high mass loss (wear) condition. For to reduce the wear is very important to tempering the steel quenched, in this way the martensitic structure would to reduce the residual stresses and hardness. The results of this work suggests that a great alternative to the quenched and after tempered in the ASISI 1045 steel is the use of the mixture of water and machining fluid like quenching media, especially in the proportion 60% water-40% machining fluid. This mixture allowed obtain wear and coefficient of friction values at same levels that the quenched in water and tempered case. This behavior is consequence of the heat extraction capacity. In the quenching in water case the high heat extraction rate of substance allowed to short cooling times and the obtaining structures to increase the hardeness and reduce the toughness (very brittle) [8, 13-16]. How explainned for Kabasko 2013 [17], the martensite transformation start at temperatures less that 350C for most carbon steel, then to use substances with high cooling rate enable the transformation of martensite, while the use of substances based on petroleum oil (case of machining fluids) who have low cooling rate and may to reduce the martensite transformation and to allow the obtaining the toughness structures like fine perlite (sorbite and troostite) that prevent high residual stresses and cracks.

4. CONCLUSION

In this work, experimental results have allowed to analyse and demonstrate the influence of the quenching media during the hardened of steel AISI 1045 and the coefficient of friction and dry wear behavior. Traditionally the medium carbon steels are hardened using water like coolant media. This substance has high heat extraction rate and allow the martensitic transformation in the microstructure, thus it favors the high hardness in the material and the low coefficient of friction value. However, the high velocity of transformation of the microstructure using water, allow to the increase of the residual stresses allowing high dry wear. This suggests that in order to reduce of dry wear, the tempering treatment should be carried out in order to reduce the residual stresses and the fragility of the structure. However, according to results is possible skip the tempering treatment using mixture of water and machining fluid like coolant substance in the quenching treatment. The machining fluid presents a lower rate of heat extraction allowing obtaining toughness structures different from the martensite. The use of water and machining fluid in the 60%-40% proportion allowed obtain low wear, intermedia hardness and intermediate coefficient of friction value.

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