EFFECT OF LOAD, ROTATION SPEED AND SLIP RATIO ON THE WEAR BEHAVIOUR OF PVD-COATED HOTVAR STEEL UNDER LUBRICATING CONDITIONS

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ABSTRACT

In this study, the effect of load and rotation speed on wear behaviour of the HOTVAR (Hot work) steel was investigated under lubricated abrasive conditions. The specimens were coated with titanium nitride (TiN) by physical vapour deposition (PVD) method on a small part of the heat-treated surface. Coating method was only applied to the ridge parts of the HOTVAR steel specimens. Average thickness of the TiN layer was determined as 1.89 μm. Disc–disc configuration was used during the wear tests. To determine the effect of load and rotation speed, the tests were carried out in 4 different loads and rotation speeds. As a result, it was observed that the mass loss values of the heat-treated specimen increase more than of the coated specimens, because there is an increasing effect of coating process on the hardness value of the specimens as the load increases. Similar to these mass loss results, roughness average (Ra) values of both specimens are close to each other in initial low load values, but later on the load value of 125 N, partial increases are observed. When the load increases to 175 N, Ra values of both specimens decrease and become similar. This is well explained by depletion of TiN layer during abrasive wear.

Keywords: PVD coating, nitriding, disc–disc wearing, abrasive wear, lubrication.

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AIMS AND BACKGROUND

Thin hard PVD coatings are today frequently used in order to improve the tribological performance of forming tools, cutting tools, and machine elements. In all these applications the surface roughness of the coated part is the most importance since it will affect the friction, wear and fatigue characteristics of the tribosystem[1]. In the past, hot-work tools were improved by a variety of surface engineering processes such as weld surfacing, thermal spraying, electrodeposition, etc. The PVD coatings have become the extremely important technological materials for several industrial applications.

Thin hard coatings are today employed in vast number of applications for reducing friction and wear of tools and mechanical components. PVD coatings have also been used for selected hot-working processes[2–4].

Many different developments of the hot work steels and tools that are made from them have been observed for the last 10 years. Metal working industries have shown interest in the improvement of tooling used in hot-working process: metal die casting, hot extrusion and hot forging. The PVD coatings have become the extremely important technological materials for several industrial applications; these coatings are successful in working processes. The PVD hard coatings are known for providing surfaces with enhanced tribological properties in terms of low friction and higher wear resistance[5,6].

PVD coating, such as, TiN, TiN/(Ti, Al)N and CrN coatings can reduce friction in tribological contacts and increase the abrasive wear resistance. In addition to the enhanced wear resistance, TiN coatings can also provide wear and oxidation resistance, especially at high temperatures[7,8].

The PVD techniques make it possible to extend by 50–100% the life of tools made of hot work steels[9,10].

The goal of this investigation is to determine usefulness of TiN PVD coatings deposition in order to improve wear resistance of tools made of hot work steels (HOTVAR steel). All the wear tests were performed under abrasive additive lubricated conditions at room temperature.

Investigation results including SEM will provide useful information to understanding and applying of these PVD coatings for improvement of wear resistance of tools made of hot work steels.

EXPERIMENTAL

Material. For experimental studies, specially alloyed HOTVAR steel was chosen because of its higher hardness, strength, hot wear resistance, toughness, thermal fatigue resistance and thermal conductivity.

Table 1. Chemical composition of the HOTVAR hot work tool steel

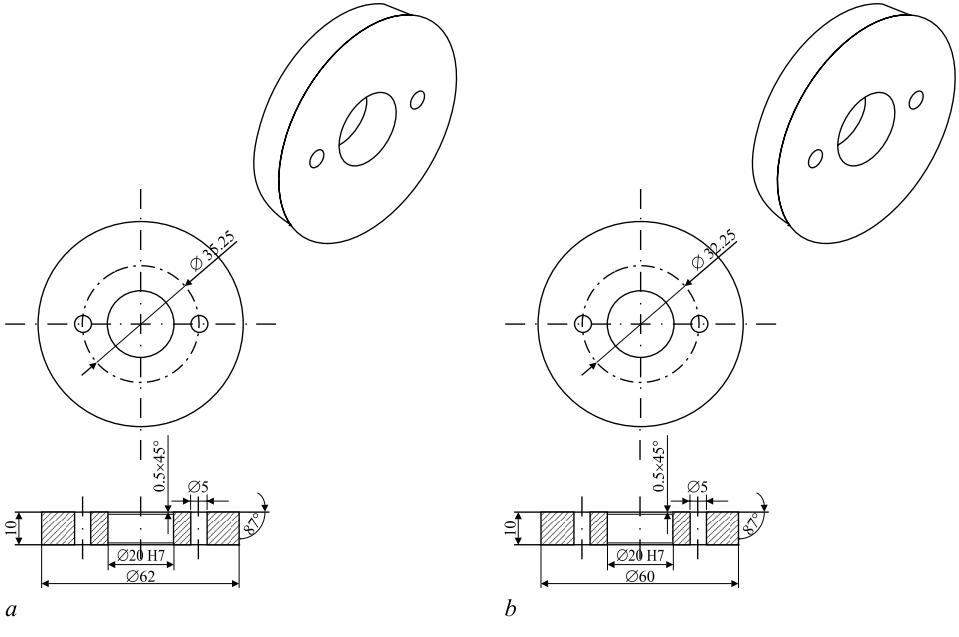
ISO/DIN	AISI	C (%)	Si (%)	Mn (%)	Cr (%)	Mo (%)	S (%)	Fe (%)
Patented	patented	0.55	1.00	0.75	2.60	2.25	0.85	Balance

Table 2. Mechanical and electrical properties of the HOTVAR hot work tool steel

Hardness (HB)	Modulus of elasticity (MPa)	Yield strength (MPa)	Tensile strength (MPa)
210	2.1×10^5	1820	2200

Chemical composition and mechanical and electrical properties of the HOTVAR steel are given in Tables 1 and 2, respectively.

Heat treatment procedure. The samples and wearer elements (discs) were prepared from HOTVAR rods. The dimensions of the samples and wearer discs are given in Fig. 1. Ridge parts of the specimens were 2% conically prepared. First, the heat treatment procedure was applied to specimens as seen in Fig. 2. After heat treatments, the surfaces of the specimen were polished and prepared for PVD coating process. The TiN-coated and heat-treated surfaces were tested and compared as a function of mass loss, roughness, friction coefficient, slip ratio and rotation speed.



a *b*

Fig. 1. Geometry of the sample (*a*), wearer disc (*b*)

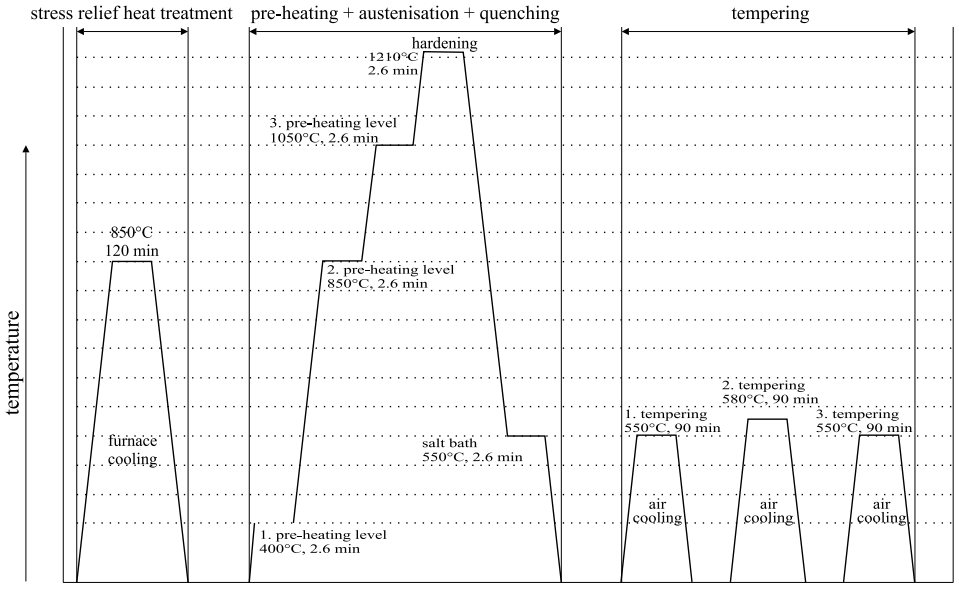


Fig. 2. Heat treatment procedure

TiN coating process. After heat treatment processes, the specimens were coated with TiN by PVD cathodic arc method. The coating method was only applied to the ridge parts of the HOTVAR specimens. Coating process was carried out by an AOA 4/500 PVD coating unit which has a plus bias power supply. The unit has 4 target and 4 gas inlets and its effective coating area is 600×800 mm^2.

At the beginning, the specimens were heated to 350°C by an infrared heater. Then, they are heated and cleaned by glow discharge method for 60 min. After glow discharge, the pressure was lowered to 10^{-5} mbar for 2.5 min to start the bombardment step. During coating the pressure was lowered to 2.2×10^{-2} mbar.

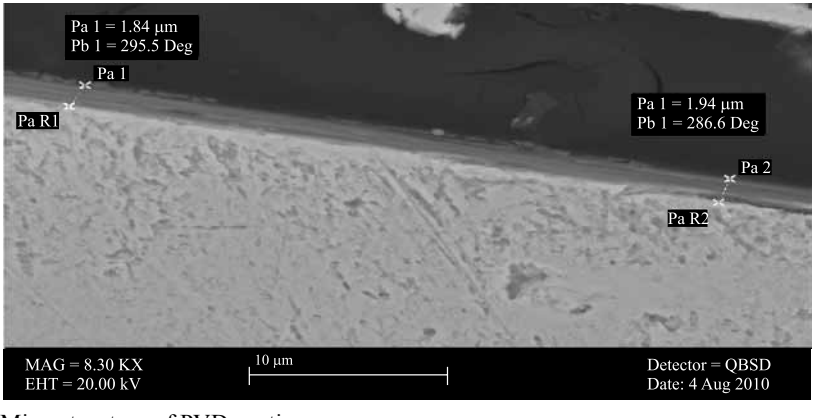


Fig. 3. Microstructure of PVD coating

Nitrogen gas was used during coating to form TiN layer. Average thickness of the TiN layer was determined as 1.89 μm as can be seen from the SEM micrograph in Fig. 3.

Wear tests. Disc–disc wear tests were carried out by the friction–wear test equipment. The test equipment and its base parts are shown in Fig. 4. In this test equipment it is able to carry out 2 types of configurations as disc–disc wearing mechanism. These configurations are shown in Fig. 4*b* and *c*, schematically. In the present wearing tests, the configuration (Fig. 4*c*) was used for additive abrasive lubricated conditions. The experimental system causes wear on the surfaces by relative sliding velocity driven by 2 parallel rods. The lower rod is directly subjected to the engine while the upper rod takes the motion from it by a gear mechanism. Slip ratio between the contact surfaces can be adjusted by using gears of different radius.

To determine the effect of the load, rotation speed and slip ratio, abrasive wear tests were carried out under 4 different loads (100, 125, 150 and 175 N), rotation speeds (200, 350, 500 and 650 rpm) and 5 slip ratios (1.79, 5, 8.7, 18.18 and 22%). All of the wearing tests were performed under abrasive lubricated conditions using the configuration of Fig. 4*c* and new discs were replaced during each experiments to eliminate the effect of surface damage.

During the abrasive wear tests, change of sliding distance and friction force values were recorded every second and they were transmitted to the computer by the help of a data logger. Tests under lubricated conditions were performed by adding 5% silica sand (57–65 mesh) to the Shell ® Premium Hydraulic Tellus 37 lubricant.



Fig. 4. Friction and wear test equipment (*a*), sample configuration for dry wear test (*b*) and sample configuration for lubricated abrasive test (*c*)

Before and after the wear tests, the wearer discs and samples were cleaned with low pressure air, washed with alcohol and they were all weighed to an accuracy of 10^{-5} g to determine the mass loss during abrasive wear. Additionally, surface roughness of the specimens was measured, too.

RESULTS

Effect of load on the wear behaviour. Mass losses of the PVD-coated samples of HOTVAR steel were lower than the uncoated samples although the wear tests were carried out under the same lubricated abrasive conditions. As seen in Fig. 5, TiN-coated samples are with higher wear resistance than those of uncoated samples. The mass losses were decreased because of the increasing load. Perhaps, the amount of the abrasive particles passing between the both samples decreased or the particle sizes become small by breaking during the wear tests.

Under different load values, surface roughness values of TiN-coated wearer discs (C) and heat-treated (HT) samples increase similarly versus increasing load. Figures 5, 6 and 7 show the change of mass loss, surface roughness and friction coefficient, respectively.

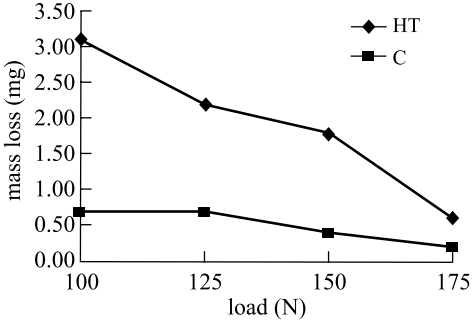


Fig. 5. Change of mass loss by load

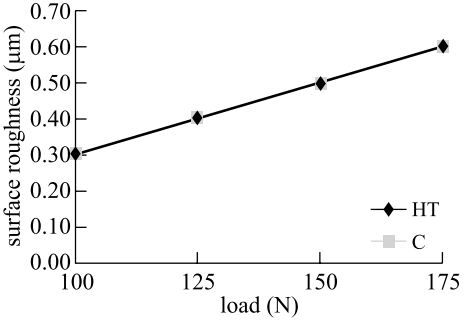


Fig. 6. Change of surface roughness by load

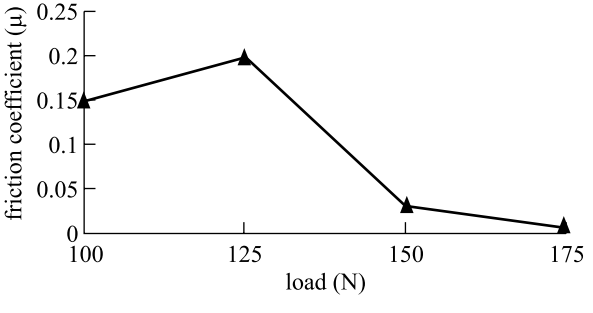


Fig. 7. Variation of friction coefficient according to the load

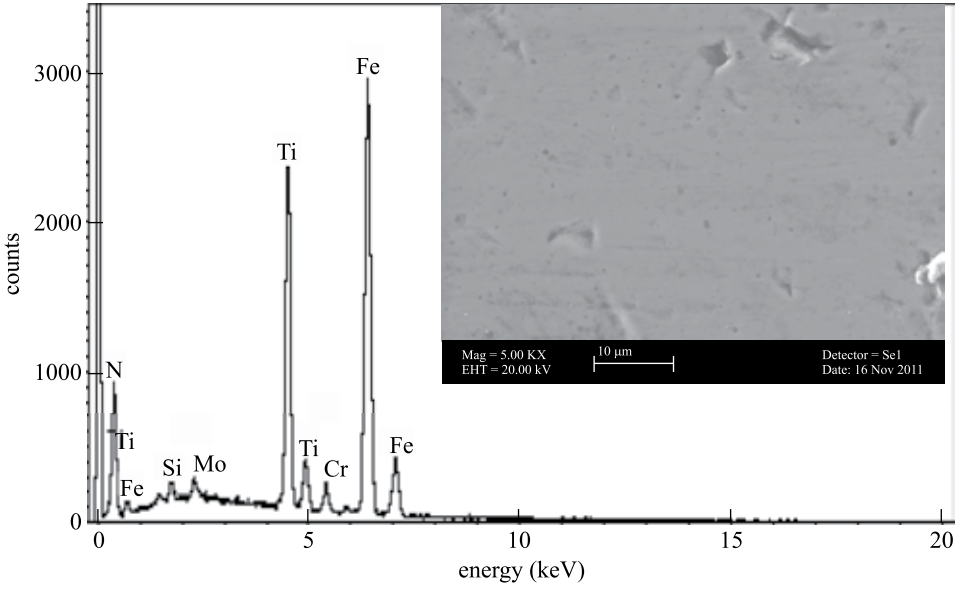


Fig. 8. ED-X analysis of wearer sample surface by PVD TiN-coated (C) and its SEM imaging before wearing test

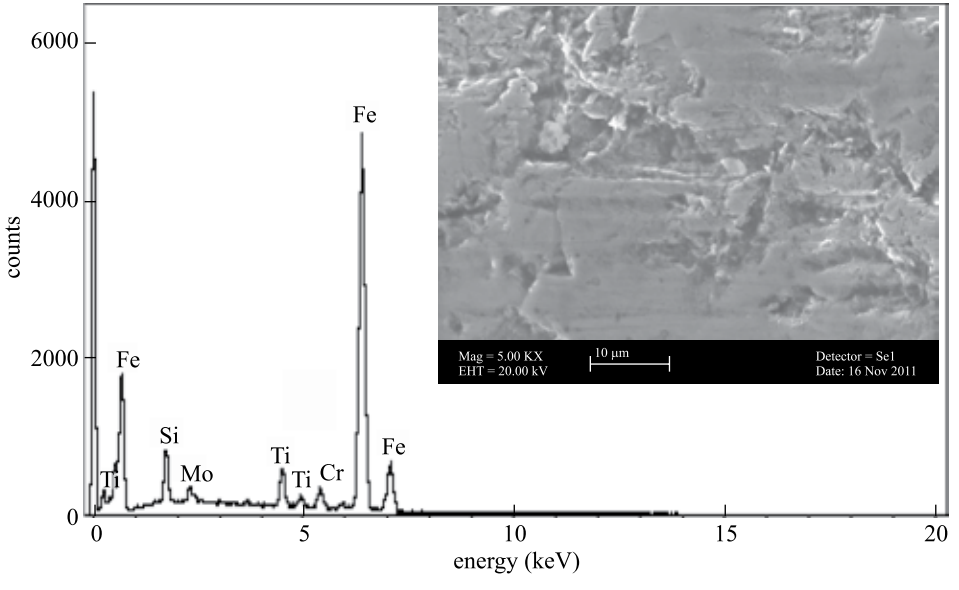


Fig. 9. ED-X analysis of worn surface of wearer sample (C) and its SEM imaging after the wearing test

Figures 8 and 9 show the ED-X analyses and SEM pictures before and after wearing tests. Figure 9 shows clearly the mass losses at the end of the wearing

tests. It also shows the ED-X and SEM imaging after the wearing test that some of TiN coating was remained on the worn surface. If the wearing test continues, the values of mass losses for both samples can be equal because of the complete removal of the TiN coating from the surface. As shown in Fig. 7, the friction coefficient for TiN follows similar trends as in mass losses. There may be 2 reasons for the decrease of the the friction coefficient. One of them is load and another one is abrasive particle. For the 1st one, plastic deformation might be low as test load increases during the wearing tests and the 2nd one, the lubricated abrasive particle might be entered in a small amount between samples. So, the friction coefficient might be decreased from this reason. Similar situation is shown in Fig. 14.

Effect of rotation speed on the wear behaviour. Then analysing the slopes on Fig. 10, mass losses of coated samples were lower than the uncoated samples because of the TiN layer. Minimum and maximum values of the samples of the heat treatment (HT) are between 0.1 and 3.1 mg, respectively. Same values of the coating samples (C) are between 0.1 and 5.3. To compare the mass losses for the both samples, mass loss values of the coating sample are generally lower than other samples as seen in Fig. 10. It can be seen in Figs 10 and 11 that mass loss and

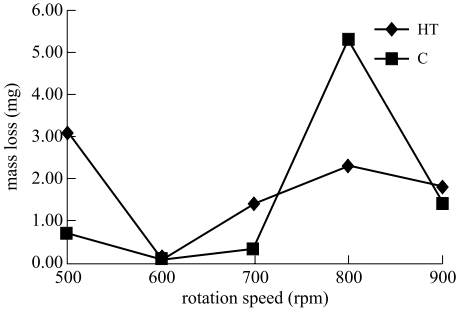


Fig. 10. Change of mass loss by rotation speed

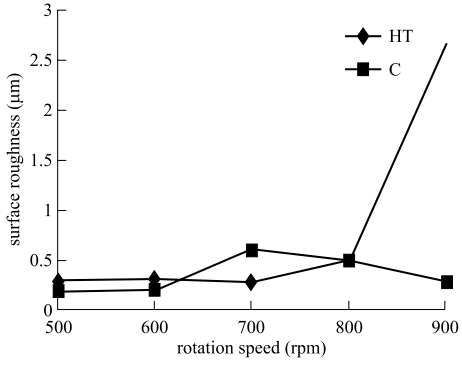


Fig. 11. Change of surface roughness

surface roughness values increase with the rise of rotation speed after abrasive wear tests which performed at a constant load of 100 N. But it was observed that surface roughness values of the heat-treated samples are higher than that of the TiN-coated wearer discs. This is because the samples are affected by the abrasive particles more than the TiN-coated surfaces.

Effect of slip ratio on the wear behaviour. As in the previous conditions, the mass loss of coated samples was lower than that of uncoated samples. According to the variation of the slip ratios, minimum and maximum mass loss values of the samples of the heat treatment (HT) are between 1.2 and 6.1 mg, respec-

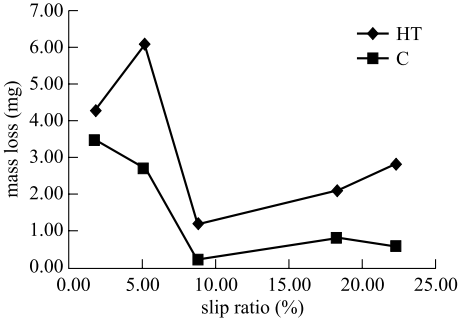


Fig. 12. Change of mass loss by slip ratio

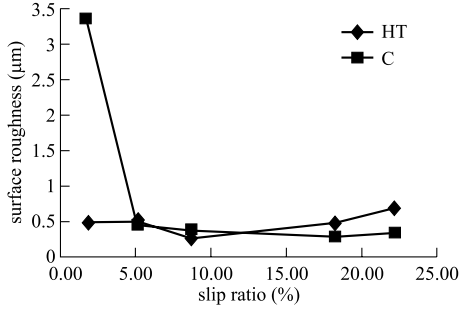


Fig. 13. Change of surface roughness by slip ratio

tively. Same values of the coating samples (C) are between 0.2 and 3.5, respectively, as seen in Fig. 12. To explore the effect of slip ratio on the mass loss, load, time and rotation speed values were remained constant as 125 N, 15 min and 600 rpm, respectively. Abrasive wear test was conducted under slip ratios varying from 1.79 to 22 %. Figures 12, 13 and 14 show the change of mass loss, surface roughness and friction coefficient according to the variations of the slip ratio. Mass loss of the TiN-coated (C) specimens was lower than of the samples of heat treatment (HT) under lubricated abrasive conditions. Similarly, the surface roughness for both samples is closer to the each other as shown in Fig. 13.

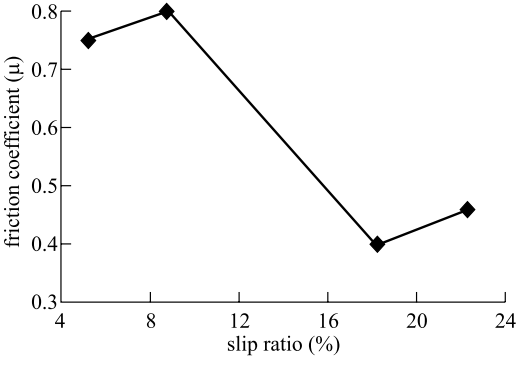


Fig. 14. Variation of friction coefficient according to the slip ratio

Figures 5, 10 and 12 show the mass loss values of both samples which are very close to each other depending on the test conditions. The main reason is that the TiN coating layer of AISI H10 steel is removed by the abrasive particles during tests.

CONCLUSIONS

During the wear tests, hot work steel samples were used. First, they were subjected to the heat treatments and then some small portion of the surface was coated by TiN PVD method. The wear tests were carried out using the disc–disc wear mechanism using the test configuration as shown in Fig. 4*c* under lubricating abrasive conditions. The following points were concluded at the end of wear tests.

1. When the load is increased, the difference of the mass losses of the wearer samples (C-TiN coating by PVD) was reduced according to the samples (HT-heat-treated) towards to the end of tests. At the beginning the mass loss was higher because of the TiN-coated sample. This decreasing case may be occurred during the test because the TiN layer was continuing to remove from the surface. Then, the amount of mass loss for both samples almost gets equal after removing all TiN layer. From the point of surface roughness, it was showed parallel properties for both samples and increased linearly. Both curves were superpositioned on sit each other at elevated load values.

The trend of the friction coefficient was decreased as the test load increased. The main reason may be probably the lubricated abrasive particles. Those lubricated abrasive particles might be entered between samples in a low amount.

2. At increasing the rotational speeds, the mass loss values for both samples (C-TiN and HT-heat-treated) showed very close behaviour shape.

Regarding the surface roughness (R_a) of both samples, the differences of R_a values were not so high. In spite of some deviations, R_a value of C and HT samples were approximately constant. These deviations of the mass loss and surface roughness may come from the amount of the particles during the wearing tests.

3. There is a decrease of the mass loss value both for the C and HT samples in slip ratios. Again, small deviation occurred for HT sample as the main reason might be abrasive particle sizes. R_a values of both samples were very close to each other. The variations of R_a values continued as constant approximation.

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