Improvement of tribological properties of 440C steel in terms of applications in space mechanisms.

Rafał Przybyła, Maciej Ossowski**, Jerzy Grygorczuk*, Remigiusz Michalczewski***, Andrzej Czyżniewski****, Piotr Nolbrzak*****, Tadeusz Wierzchoń***

**Space Reseach Centre of the PAS*
Bartycka str. 18A, 00-716 Warsaw
***Warsaw University of Technology*
Wołoska str. 141, 02-507 Warsaw
****Institute for Sustainable Technologies NRI*
Pułaskiego str. 6/10, 26-600 Radom
*****Koszalin University of Technology*
Racławicka str. 15-17, 75-620 Koszalin
******Lodz University of Technology*
Stefanowskiego str. 1/15, 90-924 Lodz

Abstract

High strength steels, AISI 420, AISI431, 17/4PH, 17/7PH and few others are usually used in space mechanisms. The one of the most commonly used steels for tribological applications is AISI 440C. Despite its good tribological properties, there is a need to obtain longer service life and reliability, especially when used in bearings.

In the paper two different layers was used. The magnetron sputtering of MoS2 proceeded by low-temperature glow discharge-assisted nitriding. The second layers consists of magnetron sputtered Ti-C:H without nitriding.

Both solutions improved tribological properties of AISI 440C steel in comparison with untreated material.

1. Introduction

For over 35 years in the Space Research Centre of the Polish Academy of Sciences, the space instruments have been built. To be able to develop better and more reliable instruments, various research institutions have been invited to cooperation. Thanks to their experience and knowledge, it is possible to design space-based equipment in the interdisciplinary way. A breakthrough in the field of materials science and surface engineering was during the development of a thermal probe MUPUS [1]. Rosetta mission, in which all equipment on board the orbiter and lander had to perform its tasks flawlessly after 10 years of interplanetary travel. To meet the high demands of the mission was not only based by well mechanical development of the instrument, but also by the selection of appropriate materials as well as by shaping their properties in an optimal way. The success of the Polish instrument at this prestigious mission is also thanks to cooperation with the Department of Materials Science and Engineering at Warsaw University of Technology, where the processes of plasma nitriding of the MUPUS titanium parts were carried out. Since then, cooperation was Hold and developed [2].

We are currently in joint research focused on improving the tribological properties of materials used for space mechanisms. Examples of such materials are high-strength steels. Due to their high strength and good tribological properties, steels, in spite of its relatively high density, are widely used in the elements of friction couples, where there is a high load [3]. Examples of such friction couples are lead screws, harmonic drives or rolling bearings. To increase the service life and reliability of this type of machine elements, comparative tribological tests were carried in laboratory and simulated space conditions after different surface treatment. These studies were performed under the project ROLOKOS, whose aim is to develop new bearings for space applications.

The 440C stainless steel was used for testing due to the high popularity of the steel in the construction of space instruments, in particular, rolling bearings. In addition 440C steel is often used for tribological tests, which gives an opportunity to compare results with other institutions.

2. Tests in laboratory conditions

Tests in laboratory conditions were performed in The Institute for Sustainable Technologies – National Research Institute in Radom. The study was conducted in air at 20°C and a humidity of about 50% on ball-on-disc testing machine T10, shown in figure 1. The tribosystem consists of a stationary ball pressed at the required load P against the disk rotating at the defined speed n. The disk is made of the tested material. In case of testing of a surface coating, it is deposited on the disk. The tests are generally performed under dry friction conditions.
Two spatial configurations of the tribosystem are possible - vertical rotation and horizontal rotation axis of the disk, which is available after simply changing the load lever system. Optionally, one may use the KS-10 air conditioning chamber for the stabilization of humidity and temperature in the surroundings of the contact zone. The chamber is mounted directly onto the T-10 tribotester.

Figure 1: T-10 Ball-on-disk testing machine for evaluating friction and wear of thin coatings.

Tests were subjected to four different types of disc specimens: 440C steel without surface treatment, after plasma nitriding, after magnetron sputtering of Ti-C:H and after plasma nitriding and magnetron sputtering of MoS2. Counter specimens were ceramic balls made of two different materials: Si3N4 and ZrO2. In figures 2 and 3 there are friction coefficients and wear rates registered during the test with Si3N4 balls. In Figures 4 and 5 there are results during the tests with Si3N4 balls. Nitriding was done at Warsaw University of Technology, Ti-C:H magnetron sputtering was performed at Koszalin University of Technology and MoS2 magnetron sputtering was done at Lodz University of Technology.

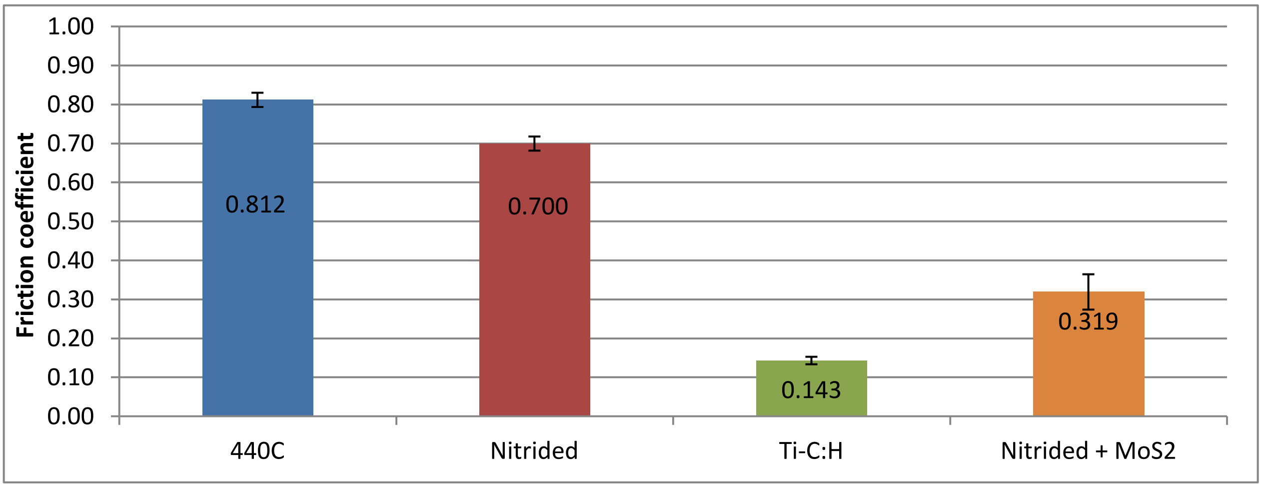

Figure 2: Friction coefficient of 440C discs in air against Si3N4 balls.

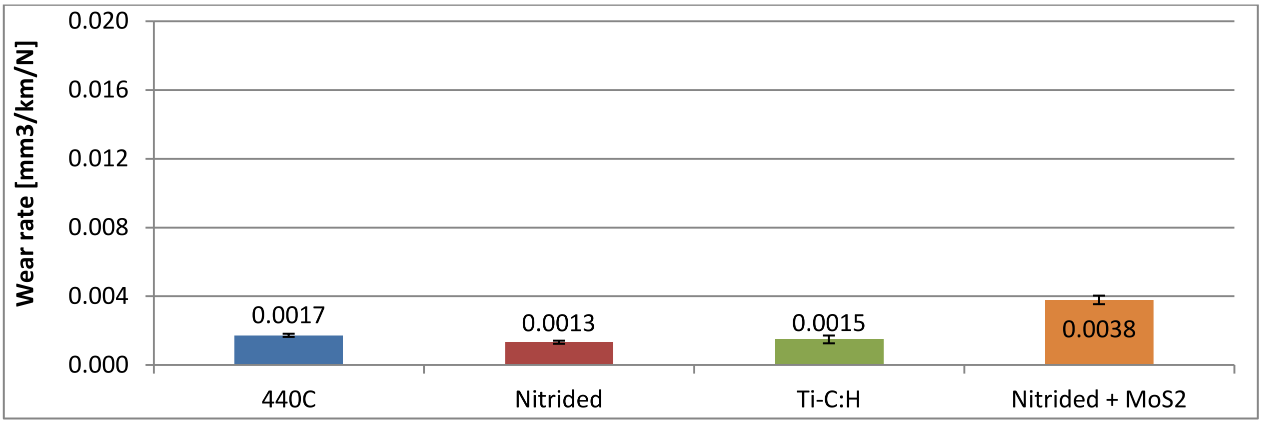

Figure 3: Wear rate of 440C discs in air against Si3N4 balls.

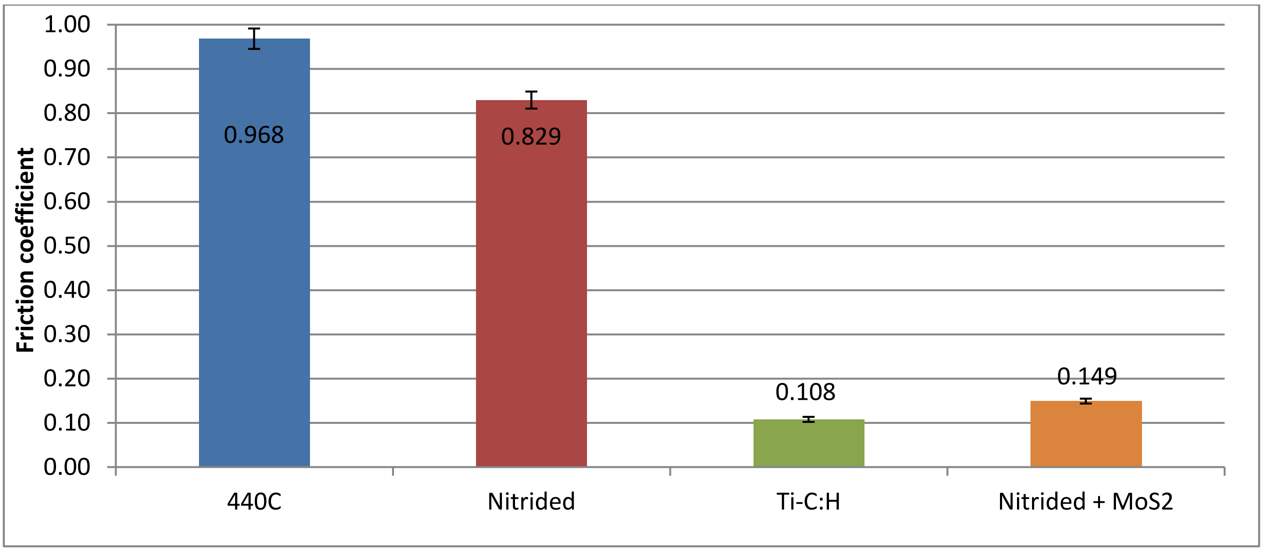

Figure 4: Friction coefficient of 440C discs in air against ZrO2 balls.

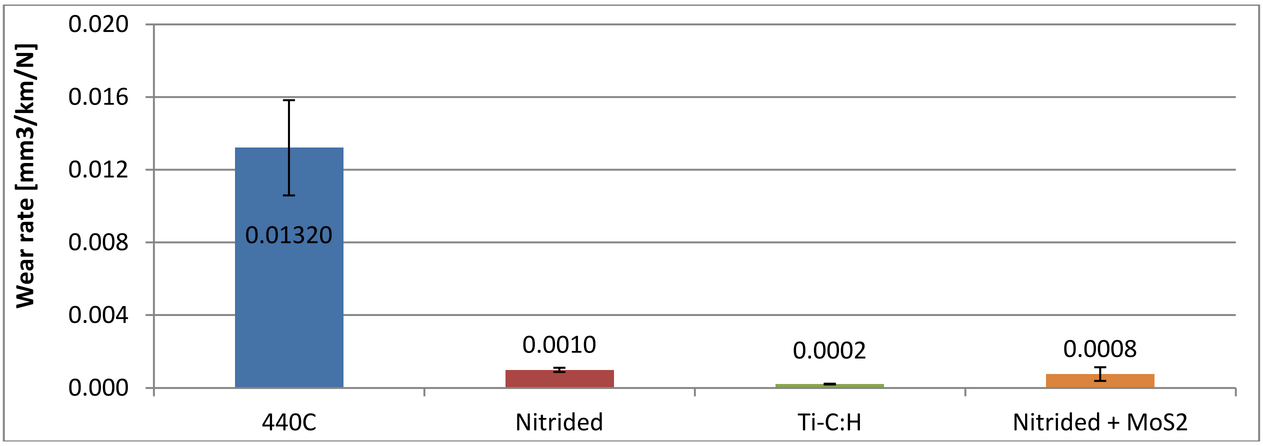

Figure 5: Wear rate of 440C discs in air against ZrO2 balls.

The lower coefficient of friction is obtained for Si3N4 balls for the untreated steel and for the steel after nitriding. For the steel with Ti-C:H and nitrided+MoS2 coatings, ZrO2 balls gives lower coefficient of friction. Looking at the results of wear rate, ZrO2 balls are better in all cases except untreated steel discs. It is understandable that in some papers where untreated steel is taken into account, the Si3N4 is described as recommended.

3. Tests in simulated space conditions

The Space Research Centre developed ball-on-disk tribometer for testing in simulated space conditions, see figure 6. This device is mounted in a vacuum chamber, which is provided with a pump set to enable the achievement of pressure at 5*10E-7 Pa. Tribometr has adjustable load between the ball and the disk. Changes of the load can be done remotely, also during the execution of the test. Additionally, the device has its own cold trap supplied by liquid nitrogen to cool the samples and their own electrical heater which enable carry out tests at temperatures ranging from -120°C to + 250°C. The speed between the friction pair elements is also adjustable and also can be changed remotely during the test.

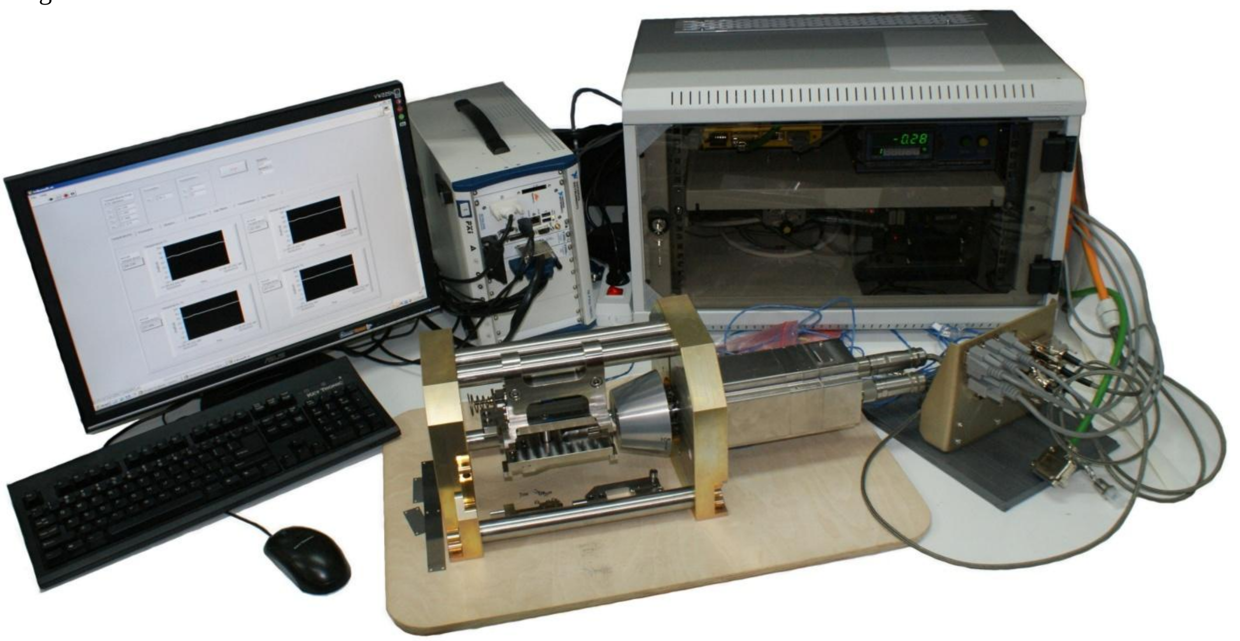

Figure 6. Tribometer for tests in simulated space conditions.

3.1 Tests in vacuum at room temperature

The same experiments as in laboratory conditions were carried out in vacuum at a temperature of 20°C. In the drawings 7,8,9,10 are the results.

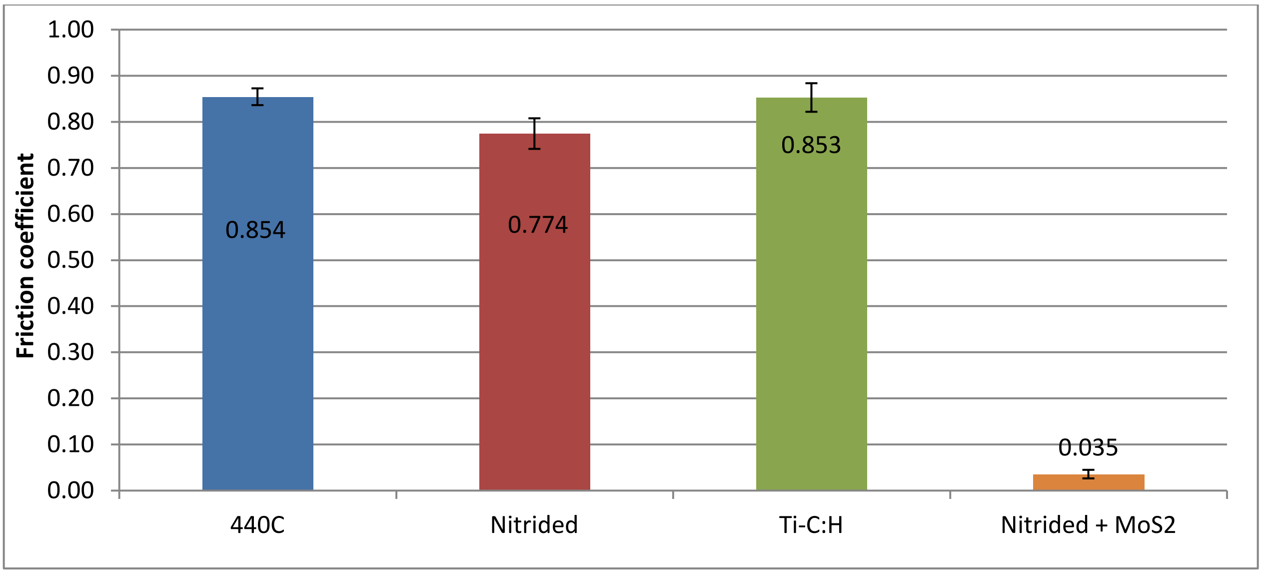

Figure 7: Friction coefficient of 440C discs in vacuum against Si3N4 balls.

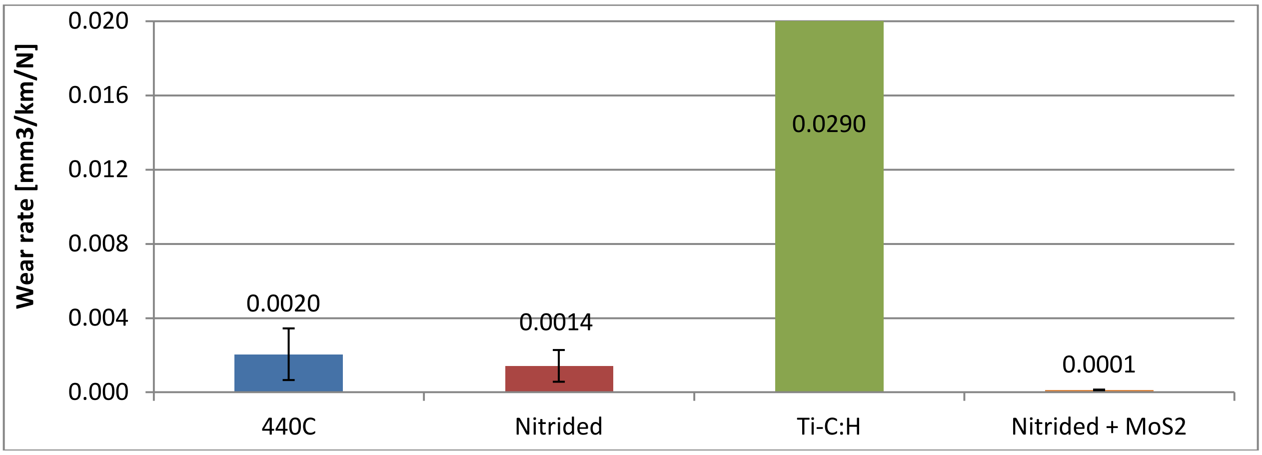

Figure 8: Wear rate of 440C discs in vacuum against Si3N4 balls.

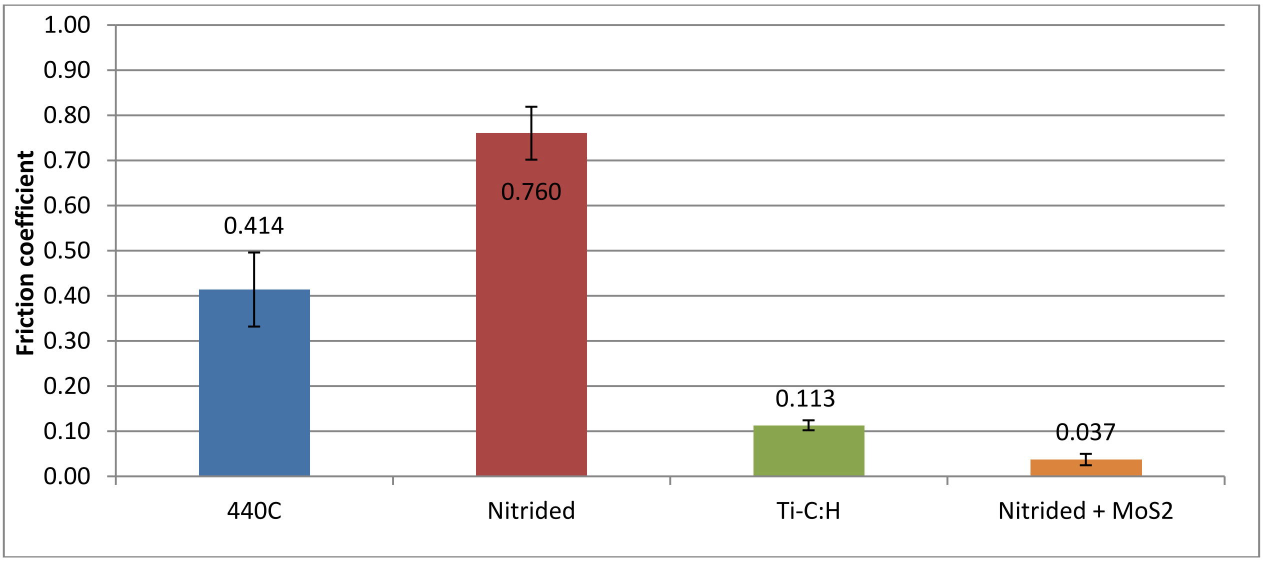

Figure 9: Friction coefficient of 440C discs in vacuum against ZrO2 balls.

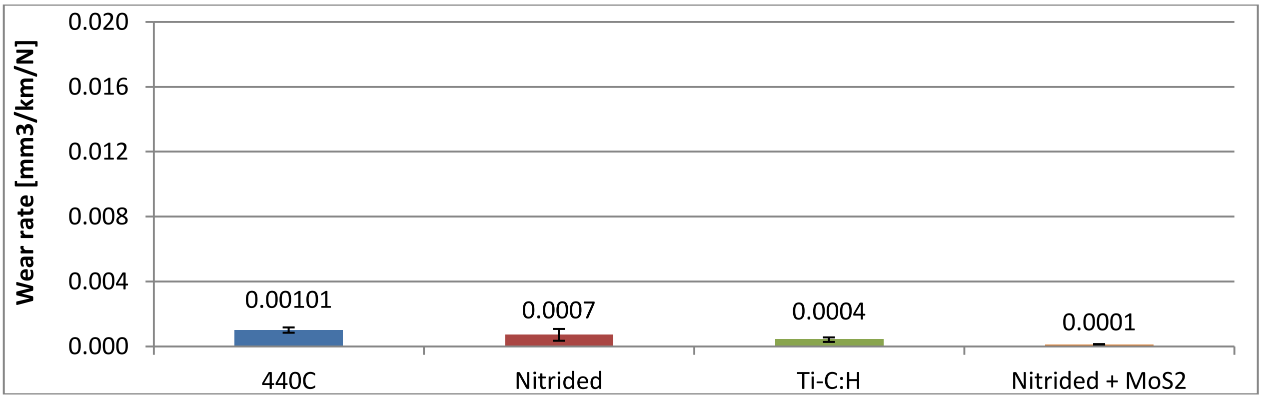

Figure 10: Wear rate of 440C discs in vacuum against ZrO2 balls.

The coefficient of friction for the counter body made of Si3N4 in a vacuum does not significantly increase for the steel and nitride steel, increased significantly for steel with a layer of Ti-C:H and decreased significantly for the nitrided layer of MoS2. Wear for Si3N4 ball almost does not changed in vacuum but dramatically increased for Ti-C:H and significantly decreased for MoS2.

The friction coefficient for ZrO2 decreased for almost all discs, the greatest change can be noticed for MoS2 and for untreated steel, minor change for nitride steel and only slight increase for Ti-C:H coating.

The wear rate dropped in almost all cases except Ti-C:H, nevertheless in all cases is low.

Taking into account results from tests conducted in vacuum, again ZrO2 balls gives lower friction coefficients and wear rates. For all types of tested discs.

3.2 Research in vacuum at -80°C

Based on studies in laboratory conditions and in the vacuum it was decided to continue tests only with ZrO2 balls. Results of tests in vacuum at -80°C are presented in figures 11 and 12.

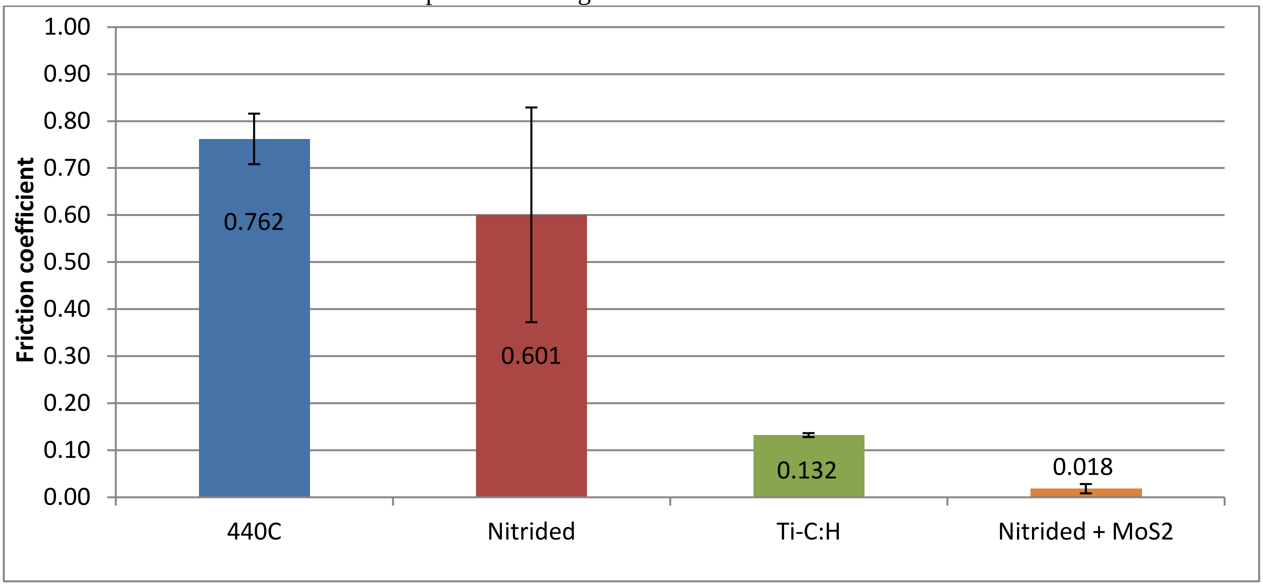

Figure 11: Friction coefficient of 440C discs in vacuum at -80°C against ZrO2 balls.

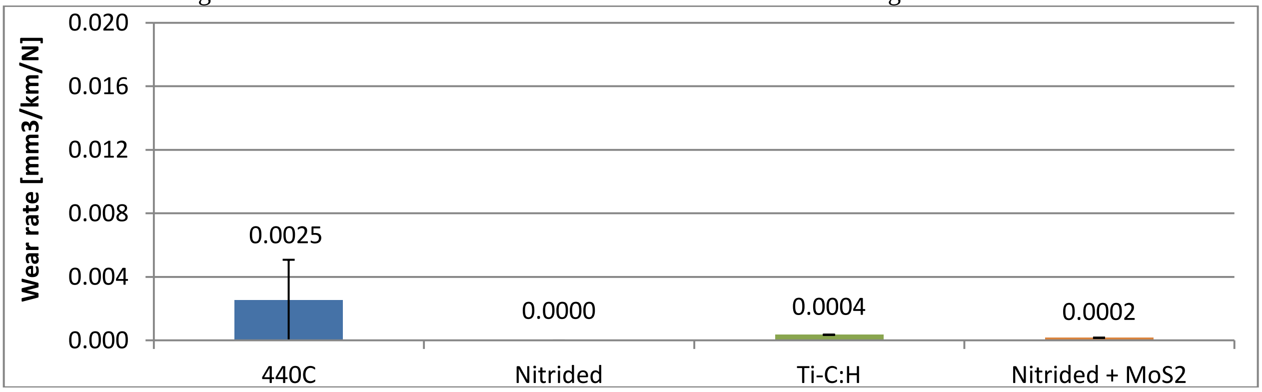

Figure 12: Wear rate of 440C discs in vacuum at -80°C against ZrO2 balls.

Friction coefficient for untreated material is higher than in vacuum at room temperature but sill lower than in the laboratory condition. For nitride steel is lower than in previous tests but there are larger variations between each specimen. Low temperature slightly increases the friction coefficient for Ti-C:H coating. For nitrided discs with MoS2 coating this test gives the lower friction coefficient than in the previous tests. Wear rate is higher than in vacuum tests, similar to wear rate in the air. Rest of the discs almost does not show wear.

3.3 Research in vacuum at 120°C

Results of tests in vacuum at +120°C are presented in figures 13 and 14.

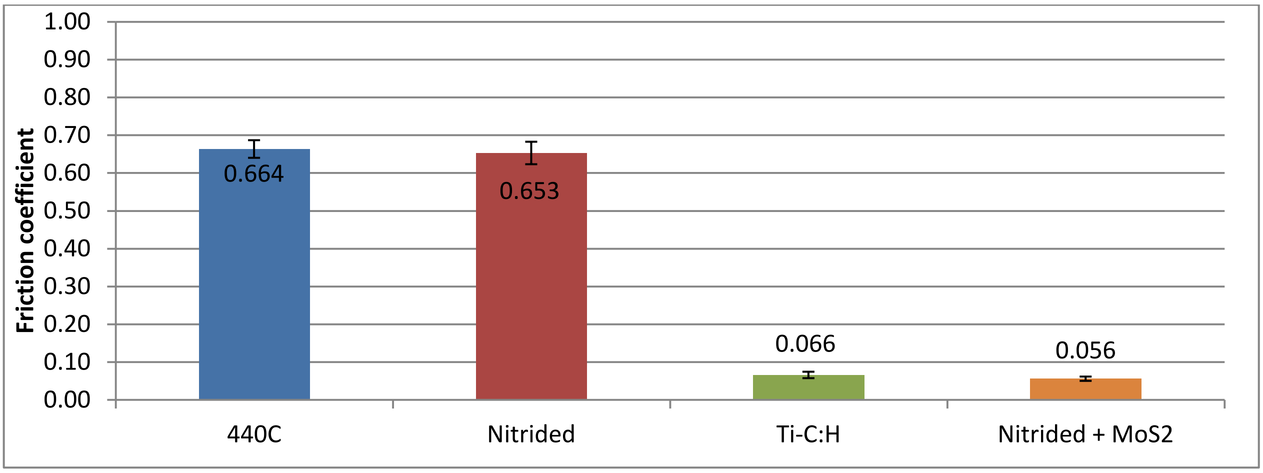

Figure 13: Friction coefficient of 440C discs in vacuum at +120°C against ZrO2 balls.

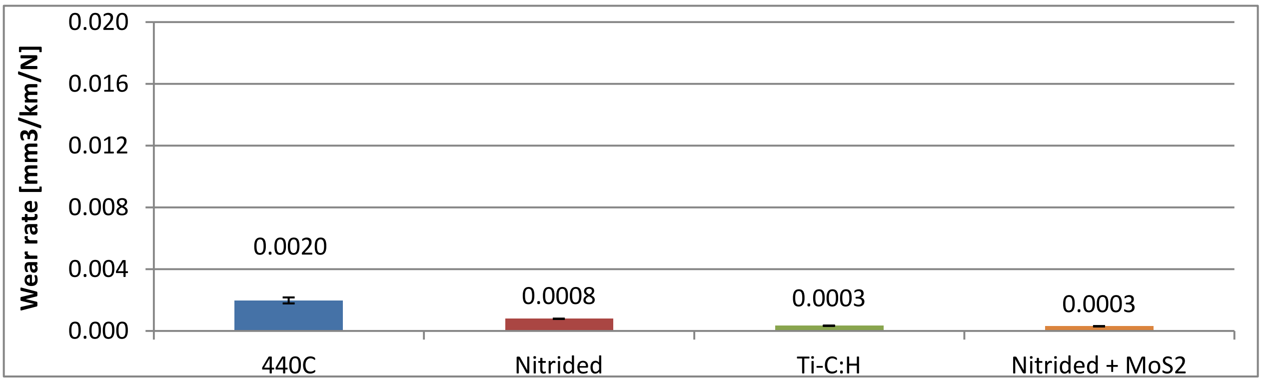

Figure 14: Wear rate of 440C discs in vacuum at +120°C against ZrO2 balls.

For untreated steel discs the friction coefficient is higher than in vacuum but still lower than in the laboratory conditions. Nitrided steel gives stable and lower friction coefficient than in air and in vacuum. Discs with Ti-C:H gives lower friction coefficient than in air and vacuum. Nitrided discs with MoS2 coating gives lower friction coefficient than in air but higher than in vacuum condition. Wear rates are almost the same as in the low temperature the greatest change is between nitrided discs. Also wear rates are similar to wear rates in room temperature except disc without treatment.

4. Conclusions

Tribological tests of layers and coatings prepared on 440C steel discs, were conducted against ball specimens made of two different ceramic materials. The tests were performed in the laboratory and in simulated conditions of space considering both a vacuum and temperature. The studies established that ZrO2 works better with the steel than Si3N4. Furthermore it confirmed that the composite layer (nitrided steel with MoS2 coating) significantly improves wear resistance and reduces the coefficient of friction with respect to the untreated material in air, vacuum and in all ranges of temperatures. The Ti-C:H gives the best results from tribological point of view in air which is also important from the functional testing and storage point of view and gives comparable results with composite layer with MoS2 coating in high temperatures.

References

[1] Grygorczuk, J., Banaszkiewicz, M., Seweryn, K., Spohn, T. 2007. MUPUS insertion device for the Rosetta mission. In: *Journal of Telecommunications and Information Technology*. Vol. 1, p. 50 – 53.

[2] J. Grygorczuk, M. Dobrowolski, L. Wisniewski, M. Banaszkiewicz, M. Ciesielska, B. Kedziora, K. Seweryn, R. Wawrzaszek, T. Wierzchon, M. Trzaska, M. Ossowski. 2011. ADVANCED MECHANISMS AND TRIBOLOGICAL TESTS OF THE HAMMERING SAMPLING DEVICE CHOMIK. *ESMATS 2011*.

[3] ESR Technology Ltd.. 2007. SPACE TRIBOLOGY HANDBOOK 4TH EDITION.