Comparison of S 235 steel and DLC coated steel using Pin-on-disc method in dry sliding conditions against PA 6 countersurface

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Abstract. This study presents tribological tests of S 235 steel and DLC coated steel using the pin-on-disc test method, where these materials were the pins to compare it with each other. The counter surface was Polyamide 6 (PA 6) as the disc. Two kinds of loads were used in three levels: static weight loads and static weight loads supplemented with continuously changing load. Friction forces were measured in two directions, and the temperature was also measured near the contact zone. Two dimensions diagrams were used to present the results. The same parameters were set for the two tested materials for maximum comparability. The coefficient of friction and temperature were compared. After evaluating the test results; we concluded that in the case of DLC coated steel the coefficient of friction was lower. With the added vibration-load tests this difference was significantly higher at lower load levels. Regarding the temperature, with lower loads, the temperature values were the same. When higher loads were used, the temperature values were significantly lower using DLC coated steel.

1. Introduction
Nowadays coating has an increasing role. High-performance coating materials are available, and it is a frequently used technology to improve the performance of equipment, prolong the service life of critical parts and reduce the energy consumption of systems.

For instance, in case of cutting tools, or tool inserts the friction, wear and the life of the tool is a crucial factor. With high-performance coating materials, these factors also can be easily improved.

Physical vapor deposition (PVD) technology is an environmentally friendly surface treatment. Three commonly used coatings are also produced by this process which is the following: diamond-like carbon (DLC), graphite-like carbon (GNC) and chromium nitride (CrN) [6].

Diamond is a high-performance tool material with excellent tool life. The properties of the diamond are similar to the properties of the DLC [1]. DLC provides high hardness, low friction, and excellent chemical stability [5]. Diamond-like carbon films can be divided into two major categories according to their hydrogen content. These categories have similarities in tribological performance, but the films also behave differently in different tribological conditions [3].

Due to their good wear resistance and low friction coefficient DLC coatings have been studied intensively for many years and a great deal of research has been carried out in the field of tribology [4].
In the literature we found, researchers made tribological tests against metals and even against DLC [2], but we did not see any data against polymer countersurface. In this article, we studied the sliding properties of DLC coated steel against Polyamide 6 counter surface using the pin-on-disc test method.

2. Method

2.1. Materials

The pin-on-disc test method is a frequently used tribological test method. It is suitable for compare materials in continuously sliding systems. We chose this method because we wanted to compare two kinds of materials in a well controllable, continuously sliding system.

![S 235 steel specimen](image)

Figure 1. S 235 steel specimen

Two kinds of special shaped specimens were used as pins. The first type was a DLC coated AISI52100 ball bearing steel; the second was S 235 steel (Figure 1). The DLC coatings were produced by Oerlikon Balzers, in Hungary. The S 235 steel specimens were produced with the same geometry in our workshop. The height of the specimen was 5,3 mm; the contact surface was nearly a flat surface with diameter 21,5 mm, which is $363,05 \text{ mm}^2$. The surface roughness of the DLC coating was $Ra \, 0,04$. The sliding surface of the S 235 steel specimens was polished to reach the same value of surface roughness. A special specimen holder was made for the specimens. The material of the holder was Polyvinyl Chloride (PVC). PVC is a common and cheap polymer material. Usually, polymers have good thermal insulation ability, so the holder was suitable for measuring temperature during the tests. The holder is compatible with our pin-on-disc type tribological test device, which can be found in our institute’s workshop in Szent István University, Gödöllő.

The material of the disc was Polyamide 6 (PA 6). It was 100 mm in diameter with 12 mm thickness. In this setup, the disc was the softer material. After every test, the sliding surface was damaged. To get better results, the damaged surface was removed after every test, using a conventional lathe machine. Therefore, the surface roughness of the disc was always different. In sliding systems, the surface roughness is a significant factor. Surface roughness values were measured on a Mitutoyo SJ-201 device. Table 1. shows the surface roughness values for each test. The parameters of the tests are described in detail in the next chapter.
Table 1. Average surface roughness (Rₐ) values of the PA 6 disc

| Test  | Value (µm) |
|-------|------------|
| Test 1| 0,75       |
| Test 2| 0,76       |
| Test 3| 0,84       |
| Test 4| 0,78       |
| Test 5| 1,03       |
| Test 6| 1,24       |
| Test 7| 1,08       |
| Test 8| 0,92       |
| Test 9| 0,92       |
| Test 10| 0,83     |
| Test 11| 0,83      |
| Test 12| 1,05      |

2.2. Parameters of the tests

To reach better comparability, the same parameters were set to each test on both types of specimens. Table 2. shows the parameters of all tests.

Table 2. Parameters of the tests

| Test | Material of specimen* | Diameter of sliding path [mm] | Sliding velocity [m/s] | Static Load [MPa] | Vibration load** [MPa] | Sliding distance [m] | Ambient temperature [°C] |
|------|------------------------|-------------------------------|-----------------------|-------------------|-----------------------|-----------------------|--------------------------|
| 1    | DLC                    | 60                            | 0,5                   | 0,055             | - ±0,04               | 1000                  | 26                       |
| 2    | DLC                    |                               |                       | 0,055             | - ±0,04               | 1000                  |                          |
| 3    | S 235                  |                               |                       | 0,055             | - ±0,04               | 1000                  |                          |
| 4    | S 235                  |                               |                       | 0,11              | - ±0,04               | 1000                  |                          |
| 5    | DLC                    |                               |                       | 0,11              | - ±0,04               | 1000                  |                          |
| 6    | DLC                    |                               |                       | 0,11              | - ±0,04               | 1000                  |                          |
| 7    | S 235                  |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |
| 8    | S 235                  |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |
| 9    | DLC                    |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |
| 10   | DLC                    |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |
| 11   | S 235                  |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |
| 12   | S 235                  |                               |                       | 0,165             | - ±0,04               | 1000                  |                          |

* 'DLC' means DLC coated DIN 1.3505 steel, and 'S 235' means S 235 steel
** 'Vibration load' is explained in detail below

We can separate three different load levels regarding the ‘Static Load’ values in table 2.

In the case of Test 10, the sliding distance was only 600 m. With those parameters, the temperature went too high and raised continuously. The test was stopped to prevent damaging the holder and the measuring system.

The vibration load is provided by a so-called vibration unit device. It is suitable for producing continuously changing loads to the contact surface only in a normal direction. In case of this experiment, once the unit was turned off, or it worked at 28 Hz, added ±0,04 MPa to the static, normal direction load. Special dead weights were made to providing the static loads (figure 2.)
Three loads were used. First without vibration load, then with the continuously changing vibration load. The vibration unit and the system provided the first type of normal direction force, which was 20N. With one of the dead weights, the force increased to 40N, and after applying the second dead weight, the force was 60N. Regarding the sliding surface of the specimens, the loads were calculated.

The measurements always run at dry sliding conditions.

2.3. Method

Figure 2. shows the pin-on-disc type tribological test device.

In Fig. 3, we can see the special holder. There is a magnet in the bottom of the holder to keep the specimen on the place when fixing the holder to the testing device. After the holder was fixed to the device, we must adjust the screw to prevent any movement of the specimen during the measurements.

We can also see a groove at the bottom of the holder. In this groove the temperature sensor takes place. We cannot measure the temperature directly in the contact zone. The temperature was measured...
on the opposite side from the contact zone of the specimens. Thermal conductive paste was used for more precise results. This method is suitable to compare the investigated materials.

In figure 4 we can see the disc, the holder and the specimen after a test. After the correct input parameters applied to the system, the contact surfaces were cleaned with methylated spirit. In the following, we reset the force measuring sensors. Before commencing the test, we initialized parameters on the computer. The strain gauges found on the force measuring sensor and the type Spider 8 measuring amplifier are connected by wire converting the analog signals to digital, which are then transmitted to the computer. The chart-like visualization of the digital signals was achieved with software called Catman. The measuring frequency was 5 Hz in all cases.

During the tests, all data and the prepared diagrams were monitored and displayed on the screen in real time. After completing the test, all data were saved in the appropriate file for later processing, using a spreadsheet.

The contact surfaces of the disc were re-machined after every single run.

3. Results

During the entire tests, the computer registered the friction forces, the rotation speed of the disc, and the temperature of the specimens from the opposite side in the function of sliding distance. Comparative diagrams were made in Microsoft Excel to illustrate the results. In figure 5. we can see the results of Test 1, 2, 3 and 4 in one diagram. In these four cases, the static load was the same (Table 2.). With this method, the differences between the two examined material, and the effect of the vibration load also can be seen.

![Coefficient of friction and temperature (Test 1-4)](image)

**Figure 5.** The coefficient of friction and temperature of Test 1-4

In figure 5. we can see the vibration load has a more significant effect on S 235 steel specimens. The coefficient of friction (Cof.) values were the highest and lowest in the case of S 235 steel. With these parameters, vibration has a negative effect on the S 235 steel specimen regarding the Cof. value. However, after the running in period (700 m) the Cof. values reached the steady-state in all four cases.

In the case of temperature curves, there were no significant differences between the four tests. The Cof. curves are not as smooth as the temperature curves. In a continuously sliding system, this is a
common phenomenon, so-called stick-slip. The materials are stick together in the contact zone, then suddenly move again

![Coefficient of friction and temperature (Test 5-8)](image)

**Figure 6.** The coefficient of friction and temperature of Test 5-8

Figure 6 shows the results of Test 5, 6, 7 and 8. In this diagram different scale was used regarding the Cof. value to get a better visualisation. In case of this load level, we can see the vibration strongly influenced the Cof. and temperature curves of S 235 steel specimens. Without vibration load, the Cof. curve is nearly steady-state during the measurement. With the supplemented vibration load, the Cof. values are much higher. After the running in period there is a short steady-state part of the curve. After this phase the Cof. highly increases. The temperature curves run together except in case of S 235 steel specimen with vibration load.

We can see the DLC coated specimens are not influenced strongly by the vibration in this setup. There is a non-significant difference between the Cof. curves. Both curves are nearly steady-state during the tests

![Coefficient of friction and temperature (Test 9-12)](image)

**Figure 7.** The coefficient of friction and temperature of Test 9-12
Figure 7 shows the third comparative diagram with the highest loads in this experiment. Without the vibration load, the measured values were lower with the DLC coated specimen. However, both curves were progressive, while the curves of the S 235 steel were regressive. With vibration load, the shapes of the curves were the same regarding the two examined materials, but the Cof. and temperature values of S 235 steel were lower during the test. In this load level with the added vibration load, the temperature went too high in case of the DLC coated material. The measurement was stopped to prevent damaging the measuring system. The vibration load was strongly and positively influenced the S 235 steel curves.

4. Conclusions

In this experiment two kind of specimens were used to compare them with each other in dry, continuously sliding conditions. The counter surface was PA 6. Two types of loads were applied on three levels. The specimens were tested with the same parameters. From the comparative diagrams, we can see the differences.

At the first level of loads, there are no significant differences. Both the Cof. and temperature curves reach the steady-state after about 700 m. With the second level of loads, all values are increasing during the whole test. In this level, the S 235 steel has the highest values of Cof. and temperature with the supplemented vibration load. The sliding properties of the DLC coated steel material were not influenced significantly by the vibration load.

At the third level of load, without the supplemented vibration load the DLC coated steel produced more favourable values in the examined interval. With vibration, the temperature curve of the DLC coated material increased to an extremely high value, while with the same parameters the S 235 steel produced favourable values. After about 700 m the curve reached the steady-state.

As a further result, we found that this test method is suitable for compare materials under sliding conditions.

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