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ABRASIVE WEAR RESISTANCE OF FE_3AL AND STELLITE 6 COATINGS FOR THE PROTECTION OF VALVE SEATS SURFACES

Summary. The development of a technology that increases the service life of valve seats in CNG/LNG-powered vehicles requires the appropriate selection of material and the technology of its application. Commercially used valve seat materials show accelerated wear under operating conditions, especially in natural gas vehicle engines. The authors developed a new material concept and a new technological concept for the protection of the valve seat in CNG/LNG-powered vehicles. This article aims to present the first stage of tribological research. Two materials were used in the research: Stellite 6 alloy and Fe_3Al intermetal. A commonly used material for valve seats of combustion engines is Stellite 6. The Fe_3Al is the new proposed material coating for the protection of the valve seats of internal combustion engines. This article compares the abrasive wear resistance of these materials. The abrasion tests were performed on a T-11 pin-on-disc tester,

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and the counter-sample was steel S235JR. The test conditions were similar to those prevailing during the operation of the valves in the head of the internal combustion engine, without the influence of temperature. The obtained results indicate that the Fe_3Al intermetal is characterized by a lower coefficient of friction and lower wear intensity than Stellite 6. The results confirm that the Fe_3Al phase is a prospective material to be used as a protective material on the valve seat of vehicles.

Keywords: valve seat, abrasive wear, intermetal Fe_3Al, Stellite 6

1. INTRODUCTION

The analysis of the literature data [1, 2] shows the rapid development of the natural gas sector in road and sea transport. It can be concluded that the number of transport means using this type of fuel will constantly increase. Manufacturers now offer a wider range of new vehicles equipped with natural gas supply systems. The automotive market includes not only new vehicles but also vehicles operating diesel engines with the modification, adapting them to run on natural gas. The modification makes it possible to use natural gas fuel in vehicles that are not adapted to it at the factory [3, 4]. Literature data [3, 5] shows that the use of a gas installation in this type of vehicle changes the working environment of the vehicle structure elements. Lack of surface protection of these installation elements will require more frequent vehicle servicing, regulation of their operating parameters or even their early replacement.

1.1. Unsolved problem in CNG/LNG vehicles

One of the unsolved operational problems of natural gas engines and in engines with intense thermal operation is the accelerated wear of the seat of exhaust valves.

The most important feature that determines the operation of valve seats is the higher combustion temperature of gaseous fuel compared to conventional liquid fuel. Due to ever higher power and new emission standards, new materials that can withstand ever higher mechanical and thermal loads are sought.

Currently, in natural gas combustion engines, covered valves, for example, with Stellite or Inconel superalloys layer, are used [6, 7].

The authors of the [8-10] studies show that valve seat protection with Stellite and Inconel does not solve the problem of accelerated wear of the exhaust valve seat. The literature review [11] also does not indicate appropriate solutions. The main problem is the difficult and too expensive technology of producing the coating layer from new materials for relatively small, conical surfaces. Such surfaces are characteristic of valve seats. In particular, the problem concerns the protection of the exhaust valve in a diesel engine of a vehicle adapted to run on natural gas.

Work is underway to develop new materials with increased durability [12]. Depending on the technological requirements, these can be steels with high abrasion resistance, for example, surfaced, laser treated with coatings (for example, thermally sprayed composite coatings containing chromium, titanium and tungsten carbides) or alloys characterized by, for example, high durability at elevated temperatures [13].

Among the available commercial materials, our attention was drawn to the intermetallic phases. Their advantages, like corrosion resistance in an oxidizing environment, significant erosion resistance and relatively low density, make these materials prospective for use in the operating conditions of the exhaust valve seat. These properties suggest that intermetallic materials may be a better solution for the protection of a valve seat than the currently produced Stellite coatings [14-16]. The authors of this article decided to develop a technology for the protection of valve seat surfaces for vehicles powered by CNG/LNG.

Ensuring the appropriate life cycle of valve seats in LNG and CNG powered vehicles is a significant problem [17]. Valve seats are subjected to various wear mechanisms, one of which is abrasive wear. It is estimated to be one of the most common sources of intensive wear of machine components. In the literature, we can find information that in industrial conditions, it accounts for about 50% of cases. The durability of this element of the vehicle affects both the passive safety of the vehicle and the safety of the environment. In the publications [7, 11], it was shown that in a drive unit in which the exhaust valve is damaged, there is a lack of tightness of the combustion chamber. The presented results of the damage are lower vehicle performance and increased emission of methane to the combustion system, and then to the atmosphere.

1.2. Aim of article

The previous section showed that the modification of the fuel system allows the use of natural gas in vehicles that are not factory-ready for it. The modification changes the working environment of the valve seat. Commercially used valve seat coating materials are not suitable for use in the new environment. Therefore, the main goal of the authors is to develop a new protective coating for valve seats. Thus, they chose the Fe_3Al intermetallic phase material.

In this article, the authors present one of the research tasks carried out under the Silesian University of Technology with grant number BK-277/RT1/2021. The task aims to assess whether the selected material meets the requirements of abrasive wear resistance. Abrasive wear is a major cause of valve seat degradation. In this article, the research question was put:

"Will the use of a new intermetallic coating material from the Fe_3Al phase increase the resistance to abrasive wear of valve seats?" For this purpose, the tribological properties of valve seat coating materials, such as the commercially used – Stellite 6 and the new proposed intermetallic material – Fe_3Al, were compared in laboratory tests. The durability of these materials was determined by testing the intensity of abrasive wear with a pin-disc tribometer [18]. The tests shown do not reflect all the factors affecting valve seat wear but may be a guideline for coating material selection for the protection of a seat valve.

2. EXPERIMENTAL PROCEDURE

The materials tested are Stellite 6 and intermetal Fe_3Al. Stellite 6 is an alloy of cobalt, chromium and tungsten, which is characterized by high hardness, brittleness, resistance to abrasion, high temperatures, and good corrosion resistance [19]. It is used as a material for surfacing parts working at elevated temperatures. It is commonly used on valve seats of internal combustion engines. Intermetal Fe_3Al is a material that is characterized by high resistance to oxidation and sulfidation [20]. Its limited use as a construction material was associated with a drop in strength above 600^0C. In recent years, the technology of producing intermetals has been improved by controlling the composition and microstructure. This material has been selected as one that can replace Stellite 6 as a construction material for valve seats in internal combustion engines. The tests were carried out on a T-11 pin-on-disc tester. The scheme of the friction pair is shown in Figure 1. The T-11 tester allows registering the friction force and linear wear. Based on the collected data, the friction coefficient and the wear intensity can be determined.

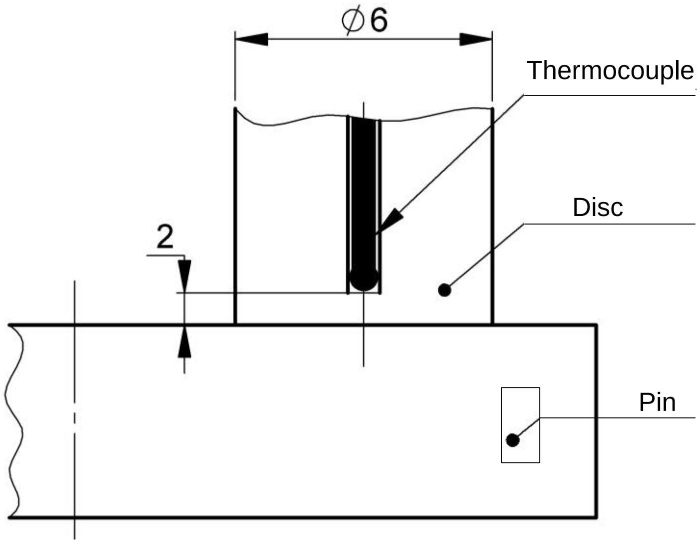


Fig. 1. View of the scheme of the friction pair, pin (Stellite 6) - disc (steel S235JR) during the test

The test samples were in the form of a cylinder with a diameter of 3.3 mm (Stellite 6) and 6 mm (intermetal Fe_3Al). The counter-sample was a target made of S235JR steel. The unit pressure in both cases was 1 MPa. The test time was set at 30 minutes. The slip velocity V_p = 0.5 m/s was assumed. Considering the adopted parameters, the rotational speed of the counter-sample was determined, n = 240 rpm. During the experiment, the value of friction force T was monitored, which allowed the identification of the friction coefficient μ:

$$\mu = \frac{T}{P}, \tag{1}$$

where: T – friction force, P – load of steel sample perpendicular to the surface of the silicate disc.

Pressure p_t calculated based on the formula:

$$p_t = \frac{4P}{\pi d^2} \left[\frac{N}{m^2}\right] \tag{2}$$

where: P – load force on the sample, d – sample diameter

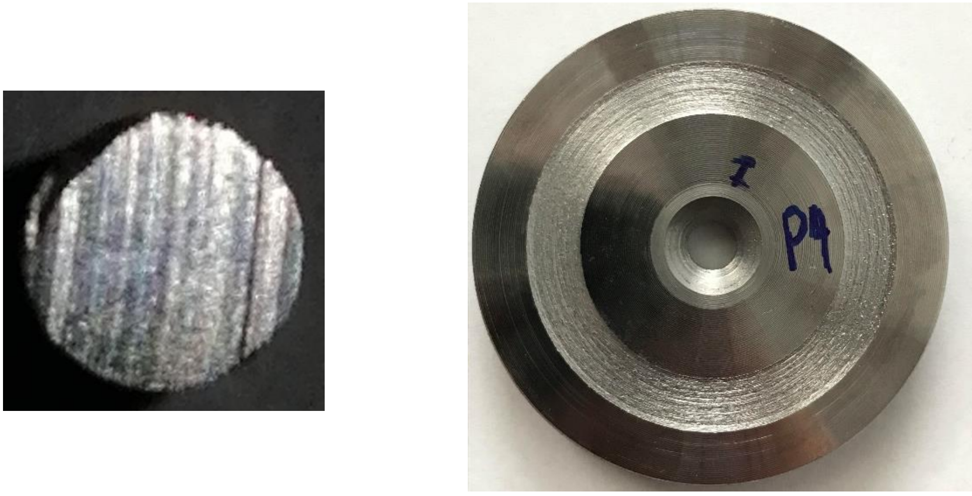
The measurement of the sample mass before and after the test allowed us to define the intensity of wear using the formula:

$$I = \frac{M_1 - M_2}{SF} \left[\frac{mg}{m^3}\right], \tag{3}$$

where: M_1 and M_2 – mass of the sample before and after the wear test [mg], S – distance the sample travelled under load [m], F – area of the sample's cross-section [m^2].

3. RESULTS AND DISCUSSION

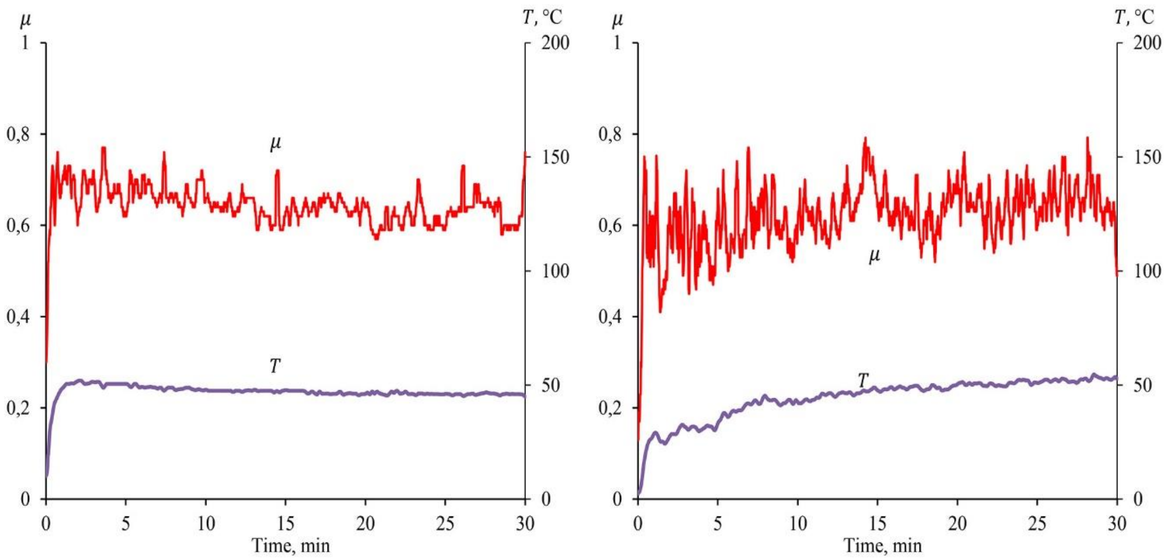
On the mandrel and the disc, we can observe signs of wear caused by abrasive wear. An exemplary view of the pin (Fe_3Al) and the disc (S235JR steel) is shown in Figures 2a, b.



a) b)

Fig. 2. View of the friction pair after the test:
a) pin made of Fe_3Al, b) disc made of steel S235JR

The materials were tested using an identical pressure of 1 MPa and an identical slip speed of 0.5 m/s. Each attempt was repeated three times. Figure 3a and b show examples of the friction coefficient and temperature curves of the tested materials.



a) b)

Fig. 3. Charts of the coefficient of friction and temperature: a) Stellite 6, b) intermetal Fe_3Al

We can observe that in the case of the friction pair of Stellite - steel S235JR, the temperature rises rapidly and reaches its maximum value after about 2 minutes of friction. However, in the case of the Fe_3Al intermetal, the temperature rises more gently and reaches its maximum value after 30 minutes of friction. Based on the tests performed, the mean values of the friction coefficient and the average temperature generated during the test for each of the tested materials were determined. Stellite 6 was characterized by an average value of the coefficient of friction of 0.69 and intermetal Fe_3Al 0.64. The mean values of the temperature at the contact were: Stellite 6 – 48^0C, intermetal Fe_3Al – 44.5^0C. The average values of the friction coefficients of the tested materials, calculated based on data from three tests, together with the standard deviation, are shown in Figure 4.

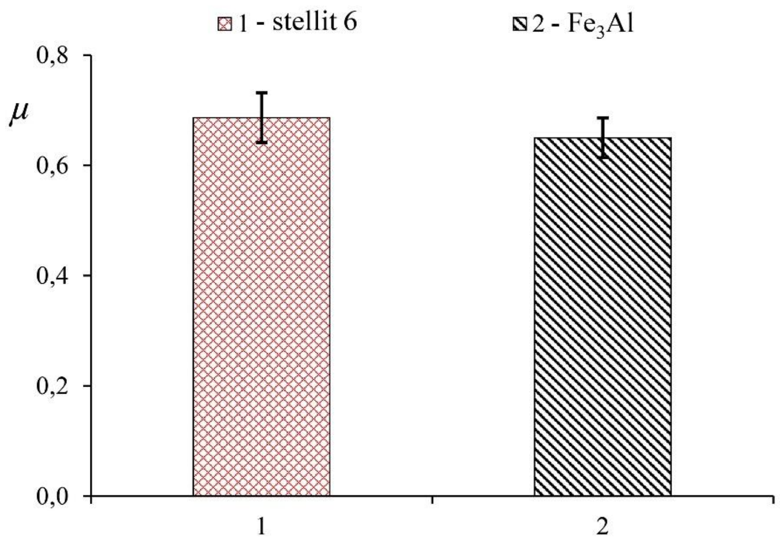


Fig. 4. Friction coefficient charts: 1 - Stellite 6, 2 - Fe_3Al

The average temperature values of the tested materials measured in the pin at a distance of about 2 mm from the contact surface are shown in Figure 5.

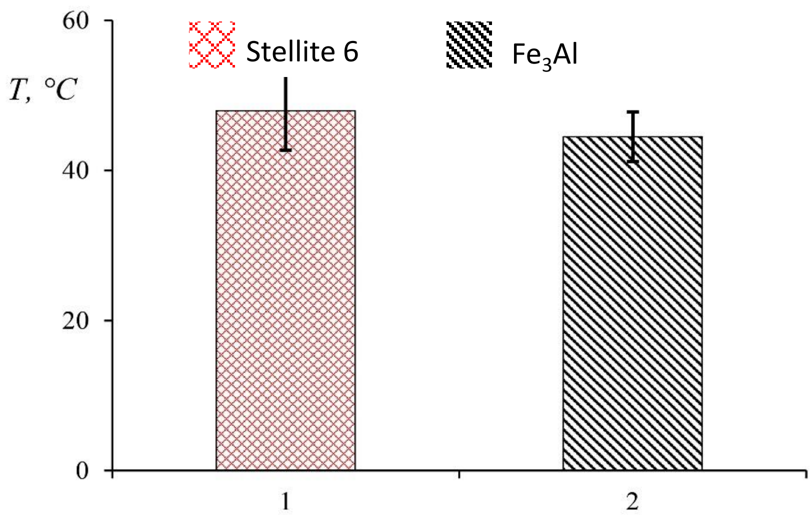


Fig. 5. Average temperature charts: 1 - Stellite 6, 2 - Fe_3Al

Based on the loss of spindle mass, friction path and transverse surface of the spindle, average values of the wear intensity of the tested materials were determined. Stellite 6 was characterized by an average wear intensity equal to 1560 mg/m^3 and intermetal Fe_3Al 1463 mg/m^3. The comparison of the obtained values with the standard deviation is shown in Figure 6.

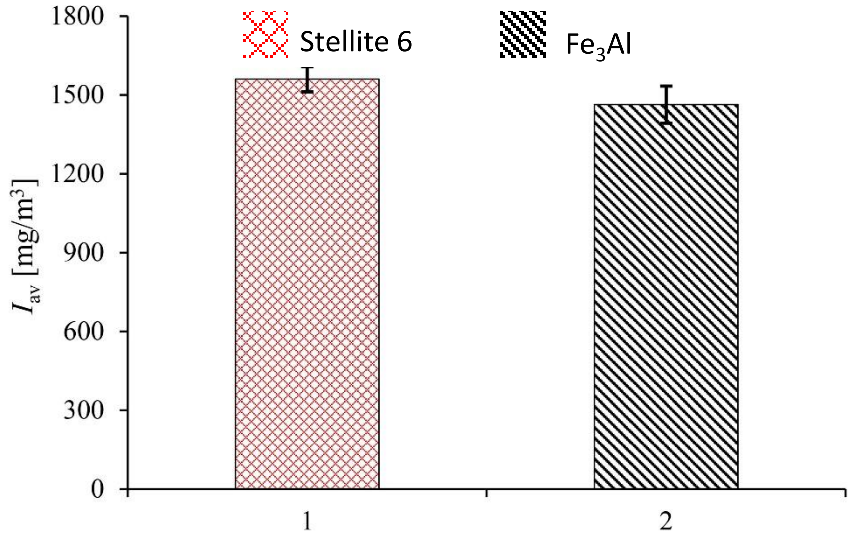


Fig. 6. Wear intensity charts: 1 - Stellite 6, 2 - Fe_3Al

Analyzing the obtained results, we can conclude that the average values of the three tests: coefficient of friction, temperature and wear intensity, indicate that the Fe_3Al intermetal is characterized by better tribological properties.

Figure 7 shows the surface view of the tested materials. The surface structure in both cases is different.

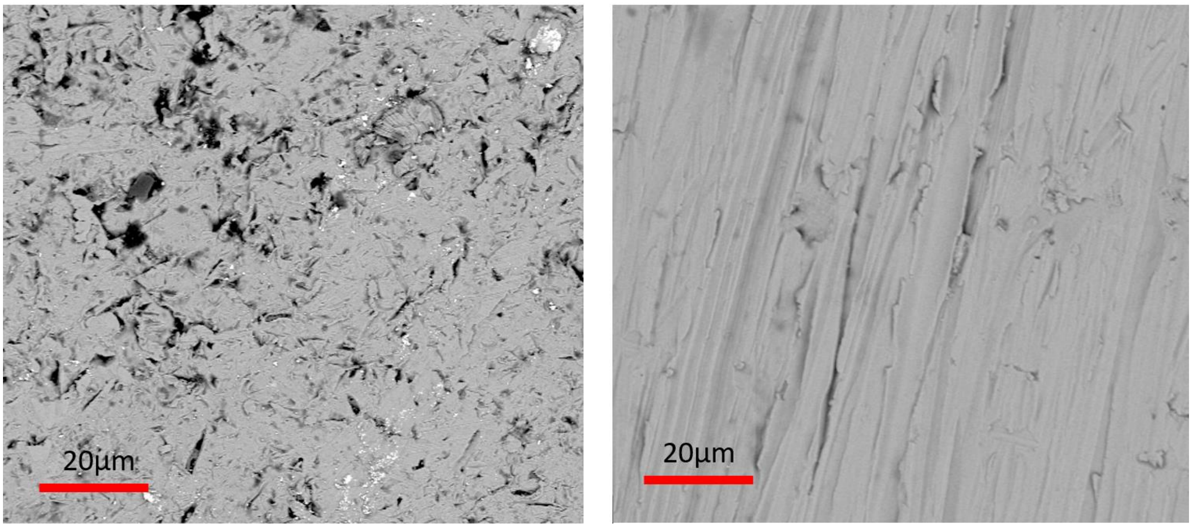


Fig. 7. Surfaces of tested materials: 1 - Fe_3Al, 2 - Stellite 6

In the case of Stellite 6, we can see clear traces of plastic deformation. Alternatively, in the case of intermetal, we see small gaps and scratches on the surface.

The conducted research allowed for the tribological evaluation of Stellite 6 and the Fe_3Al intermetal. All recorded parameters showed better tribological properties of the Fe_3Al intermetal.

4. CONCLUSION

The development of a technology that increases the service life of valve seats in CNG/LNG-powered vehicles requires the appropriate selection of material and technology. This article presents one of the research stages of a grant (number BK-277/RT1/2021), including the results of the tribological tests of the selected intermetallic material. Based on the presented research, it can be concluded that the proposed material for the protection of the seat valve is a good solution. The material has better tribological properties in the test conditions than the commercially used Stellite 6.

Analyzing the obtained results, we can conclude:

- intermetal Fe_3Al in the applied test conditions is characterized by a friction coefficient lower by about 7% compared to Stellite 6,
- intermetal Fe_3Al in the applied test conditions is characterized by a wear intensity lower by about 6% compared to Stellite 6,
- the temperature generated in the sliding contact in the case of the friction pair Stellite 6 - steel S235JR reaches its maximum value after about 2 minutes and remains constant throughout the test,
- the temperature generated in the sliding contact in the intermetal Fe_3Al friction pair - S235JR steel increases during the test and reaches its maximum value after 30 minutes (at the end of the test).

At this stage of the research, the results cannot be applied to the actual operating conditions of the valve seat. The tests were carried out at a room temperature of 24°C. Both materials operate at elevated temperatures in most applications. In the future, tribological tests should be carried out considering elevated temperatures, at which the tested materials may show completely different tribological properties. Further investigations should also include laboratory and operational tests of the finished intermetallic coatings.

Acknowledgement

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