INVESTIGATING THE EFFECTS OF LASER STELLITE PAD WELDING ON THE SERVICE PROPERTIES OF VALVE STEELS

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Abstract

In the work the results of tests on 50H21G9N4 and H9S2 valve steels with pad welded stellite layers are presented. Basic properties such as tribological and erosion resistance as well as high temperature oxidation resistance were determined. Testing conditions were accepted with certain simplification owing to the complexity of mechanical and thermal load exhaust valves and, therefore, they do not reflect real operating conditions accurately. Specimens with and without laser, plasma and TIG pad welded stellite layers were subject to tests.

The conducted tests showed the highest tribological resistance of stellite layers under the conditions of dry friction in comparison with the material in the initial state as well as plasma and TIG pad welded stellite layers. The main mechanism of the abrasive wear of the surface layer is an adhesive wear by breaking the connections and adhesions that are being formed. The research on wear by abrasive erosion showed a smaller decrease in the mass of specimens with pad welded stellite layers in comparison with plasma and TIG pad welded stellite layers as well as the material in the initial form without the pad welded stellite layer.

The resistance of stellite layers to high temperature oxidation was showed in the research on heat resistance. Moreover, it was found that pad welding does not have any significant influence on the heat resistance of stellite layers.

Keywords: *internal combustion engine, exhaust valve, laser pad welding, surface layer, service proprieties*

1. Introduction

The development of internal combustion engines of modern motor vehicles is conditioned on the more and more growing environmental and economical requirements. Among the developmental trends concerning internal combustion engines it is noticeable that one is aiming at achieving higher and higher unit power at minimum fuel consumption. Operational reliability and a long service life of engine units are also of considerable importance. It is achieved by applying innovative technologies and structural materials.

Among engine subassemblies one may distinguish the distribution mechanism, the components of which operate under high thermal regimes and variable loads. One of the most loaded components of the distribution mechanism is the exhaust valve, which operates under specific conditions, namely at high temperatures, under an erosive and corrosive influence of exhaust gases and is exposed to wear as a result of the friction of mating surfaces. Operating conditions of exhaust valves are contingent on numerous factors that are related to the engine structure, the distribution mechanism, external and internal engine operation factors, fuel type and quality, operation character and operation intensity of the motor vehicle among other things [see references 1,2].

In order for the valve to cope with the abovementioned operating conditions under variable loads and be characterized by a long service life, it is necessary to carry out the valve construction process properly. The construction process involves strength calculations which determine the shape of the valve being constructed as well as material selection for the valve. Material selection in the valve construction process is the basic issue and that is why it is attempted to find solutions concerning material selection and their modification methods (i.e. achieving the desired service properties by creating surface layers) in order to meet structural requirements [see reference 3].

Techniques of creating surface layers with the use of a laser beam become more and more common. Laser stellite pad welding is one of the ways of modifying surface layer properties. Stellites, the material pad welded in the form of powders or wires, are used mainly for internal combustion engine valves which are heavily loaded. Stellites have high operational resistance at high temperatures, in an activated gas medium as well as abrasive wear and corrosion resistance [see reference 4].

One advantage of laser pad welding is a limited influence of the thermal effect of a laser beam on an object, as a result of which there occur low stresses and small deformations of a component after pad welding. Fast heat abstraction causes the formation of a very fine-grained structure of the padding weld of high metallurgical purity. Thanks to the possibilities of controlling the process, it is possible to reduce the substrate material fraction in the padding weld to approximately 4%, which allows obtaining a surface layer with desired properties already in the first layer of the padding weld. Using an optical fibre in order to feed the laser beam to the head makes it possible to automatize and robotize the welding process [see reference 5].

In work [6], there are presented the results of the research on the effect of pad welding conditions on the quality and shape of a stellite padding weld formed on the surface of valve steels. The research indicated a significant effect of the selection of pad welding parameters, especially the laser beam power density, on the shape of the padding weld and the quality of the metallurgical joint between the layer that was created and the substrate. There was observed a high correlation between the beam power density parameter and the parameter of the quantity of the powder being applied as well as of the thermal capacity of the pad welded components. The velocity parameter does not significantly affect the quality of the joint between the padding weld and the native material.

However, it has a considerable effect on the geometric dimensions of the padding weld, which may be used in the production technology by means of the aforementioned method and affect the process efficiency.

2. Research aims and subject areas

The aim of the research was to determine the basic service properties of components made of 50H21G9N4 and H9S2 steels with and without stellite layers that were laser, plasma or TIG pad welded. The research involved a study of tribological resistance under the conditions of dry friction and an erosive effect of an abrasive stream as well as of high temperature oxidation resistance.

The H9S2 steel is used for producing heavily loaded inlet valves and for less loaded exhaust valves of internal combustion engines of motorcars and motorcycles. The 50H21G9N4 steel is destined for heavily and very heavily loaded exhaust valves of internal combustion engines of motorcars and locomotives as well as for aircraft. It may also be used for thermal engineering equipment.

The materials being discussed belong to the group of valve steels, which are characterized by special properties. Valve steels have an increased abrasive wear resistance at high temperatures, are resistant to gas corrosion (especially to exhaust gases) and are heat-resisting up to the temperature of 850°C-900°C. The H9S2 steel maintains its good mechanical properties up to about 600°C, whereas the 50H21G9N4 steel maintains its good mechanical properties up to 800°C.

The chemical composition of steels in accordance with PN and the steels used in the research is presented in Tables 1 and 2.

Tab. 1. The chemical composition of the H9S2 steel

		Percentage of basic alloy elements [weight percentage]								
		C	Mn	Si	P_{max}	S_{max}	Cr	Ni	Mo	other elements
H9S2	according to PN	0.35-0.45	max 0.7	2-3	0.035	0.03	8-10	0.6	-	-
	specimens' composition analysis	0.43	0.5	2	0.033	0.024	9	0.4	-	-

Tab. 2. The chemical composition of the 50H21G9N4 steel

		Percentage of basic alloy elements [weight percentage]								
		C	Mn	Si	P_{max}	S_{max}	Cr	Ni	Mo	other elements
50H21G9N4	according to PN	0.47-0.57	8-11	max 0.5	0.03	0.05	20-22	3.25-4.5	-	N 0.38-0.5
	specimens' composition analysis	0.52	9.5	0.4	0.028	0. 036	20.5	4	-	0.43

3. A research on the service properties of valve steels

3.1. A research on the resistance of stellite layers to tribological wear under the conditions of dry friction

The tests on tribological wear were carried out at a sliding connection of frictional components with a linear contact (block-on-ring wear tester) under the conditions of dry friction. Stellite layers pad welded by three methods, namely laser, plasma and TIG pad welding were subject to tests. Additionally, tests were conducted on specimens made of a native material without the overlay after heat treatment in accordance with PN 71/H-86022. Test components were prepared in accordance with the requirements of the T-05 test stand, as shown in the schematics in Figure 1.

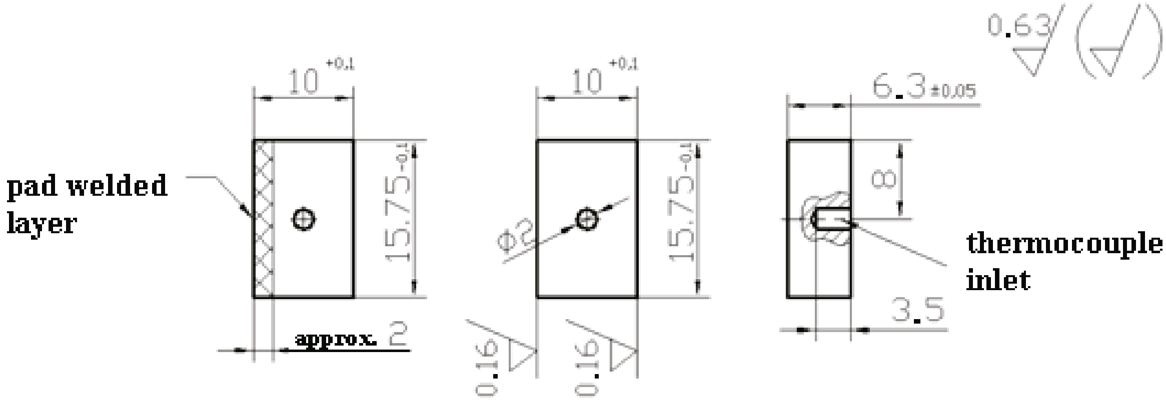


Fig.1. Tribological test specimens

The purpose of the test was to assess the expected increase in tribological wear resistance of the laser pad welded stellite layer in comparison with layers that were pad welded by other methods (plasma and TIG) and the material in the initial state. A ŁH 15 steel ring of the hardness of 64HRC was used as a counter-specimen.

Wear tests were conducted with the use of a T05 tribological machine (see Figure 2), which facilitated a continuous measurement of the linear displacement of the wear test specimen, friction force and friction pair temperature among other things. Additionally, wear was assesses by means of a gravimetric method by recording changes in the specimen's and the counter-specimen's mass prior to and after the test. What is more, the main wear mechanism in the tested tribological pair was identified.

Fig. 2. A tribological test stand (Tester T-05)

The tests were carried out under the following conditions of the sliding pair friction: contact load P=200N, friction path s=3000m, the relative velocity of frictional components was 1.6m/s.

On the basis of the obtained results, a comparative diagram of the mass changes of specimens and counter-specimens subject to the friction test was plotted (see Figure 3). The measurement of the mass decrement of specimens was made with the use of an analytical balance accurate to 0.0001g.

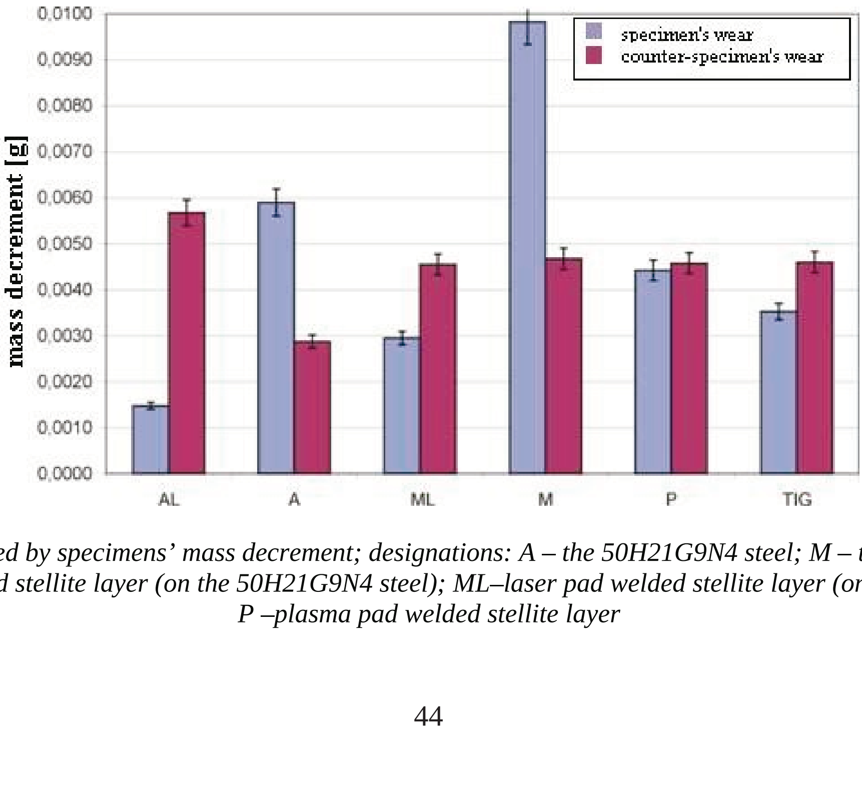


Fig. 3. Wear defined by specimens' mass decrement; designations: A – the 50H21G9N4 steel; M – the H9S2 steel; AL –laser pad welded stellite layer (on the 50H21G9N4 steel); ML–laser pad welded stellite layer (on the H9S2 steel); P –plasma pad welded stellite layer

It is noticeable in the diagram that there was a smaller mass decrement in the case of specimens with a laser pad welded stellite layer in comparison to the initial material and plasma and TIG pad welded layers. Specimens with laser pad welded stellite layers on the 50H21G9N4 steel (AL) and the H9S2 steel (ML) showed the smallest mass decrement. Plasma and TIG pad welded stellite layers were characterized by an insignificantly bigger mass decrement in comparison with the laser pad welded layer. The biggest mass decrement was recorded for specimens made of materials in the initial state (50H21G9N4 and H9S2 steels).

In Figure 4, there are presented the results of the research on material wear measured by a metric method as a function of a friction path. The H9S2 steel (M) showed the greatest wear out of the tested materials.

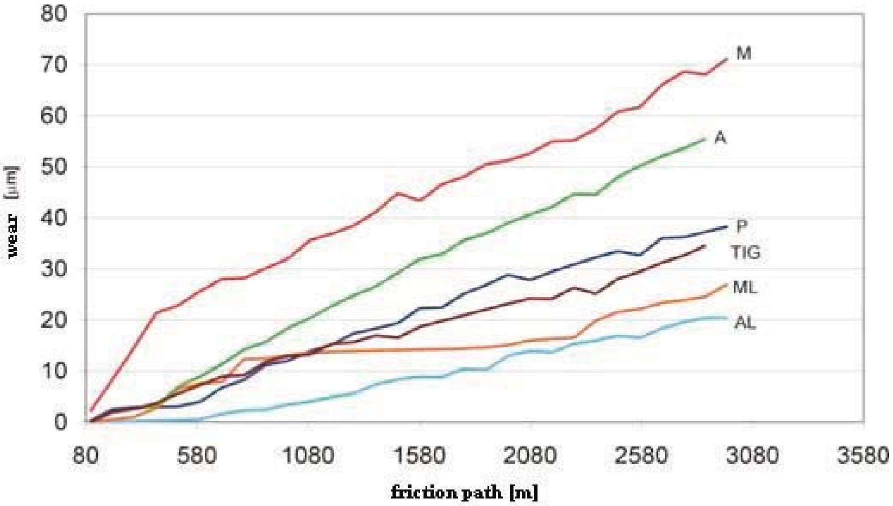
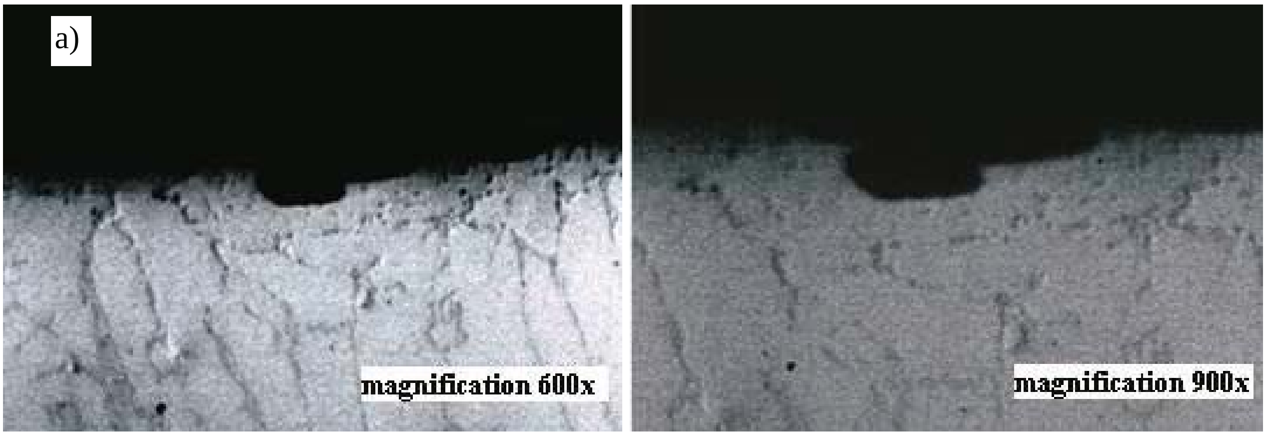


Fig. 4. Abrasive wear of specimens measured linearly as a function of a friction path.

On the basis of the diagram in Figure 4, it is possible to assess the intensity of the process during the test. All tested materials, except for (M) and (ML), are characterized by an approximately constant intensity of wear measured linearly (wear curves are approximately straight lines with a constant inclination angle). In the case of H9S2 steel (M) specimens, wear is more intense in the initial part of the test. Subsequently, the intensity decreases (a change in the inclination angle of the wear line). The stellite layer that was laser pad welded on the H9S2 steel (ML) shows a change in wear intensity as well. Both in the initial and the final phase of the experiment, there was observed an increase in wear intensity. The smallest wear was observed on specimens with a laser pad welded stellite layer (AL, ML) and a TIG pad welded stellite layer.

On the basis of the microscope images of friction surfaces and the images of the cross-sections of specimens that were taken after the wear test, it was found that the major mechanism was an adhesive wear of the first type [see references 7,8,9] (see Figure 5).



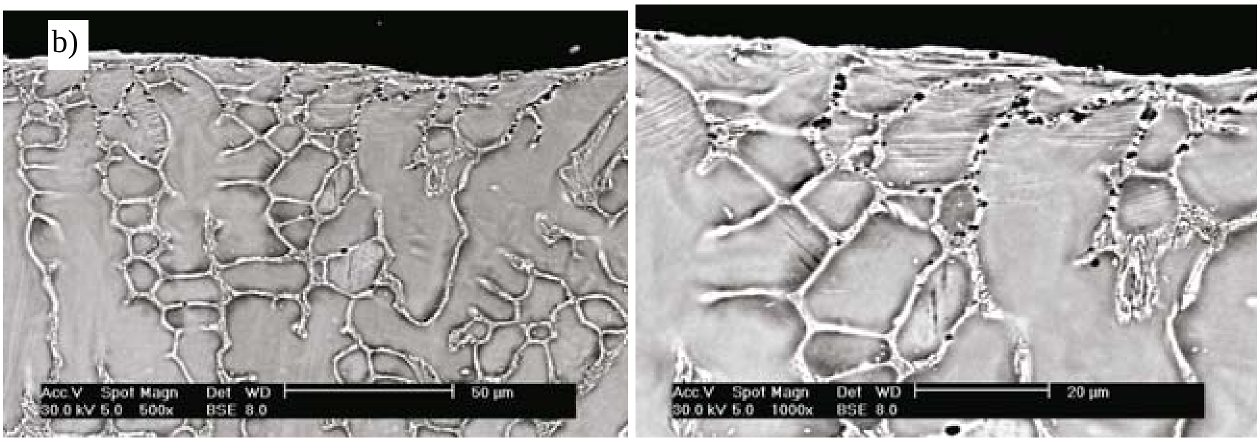


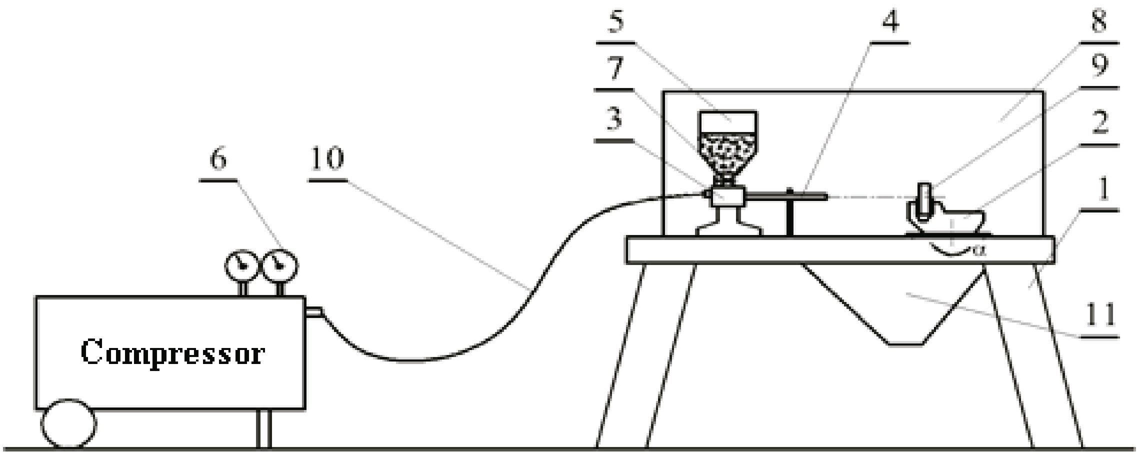
Fig. 5. Traces of adhesive tearing out as a result of grafting (a stellite layer on the 50H21G9N4 steel)

There was observed the presence of grafts of the micro-irregularities of surface and their subsequent abrasion, which resulted in the formation of braches on the specimen surface and smears of the specimen material on the counter-specimen. Moreover, a micro-machining mechanism that resulted from the smoothening of the irregularities of surface was observed on the H9S2 steel specimen.

3.2. Tests on wear caused by the erosive effect of an abrasive stream

Erosive tests were conducted on the basis of the ASTM G 76 standard on the test stand the ideological schematic of which is presented in Figure 6. The specimen surface subject to the action of an erosive stream had a dimension of 15x30mm and a thickness of 5 mm in the case of specimens with a pad welded layer. The layer was approximately 2-mm-thick. Prior to tests, the specimen surface was ground with the use of an abrasive paper with a granularity of 200 units.

The abrasive material that was used in tests was the EB 80 aloxite (a synthetic abrasive material on the base of an aluminium oxide with sharp-edged grains). The hardness of the material is more than 9 on a 10-grade Mohs scale.



1- a frame 2- a holder for fastening specimens 3- a pneumatic gun 4- an exhaust nozzle 5- an aloxite container 6- an operating pressure regulator 7- an abrasive material supply adjusting screw 8- a shield 9- a specimen

Fig. 6. A schematic of a test stand for erosive wear tests

Test specimens were oriented at the angles of α=90° and 45° to the exhaust nozzle axis. Measurement results were compiled in the diagrams of mass decrement (see Figure 7).

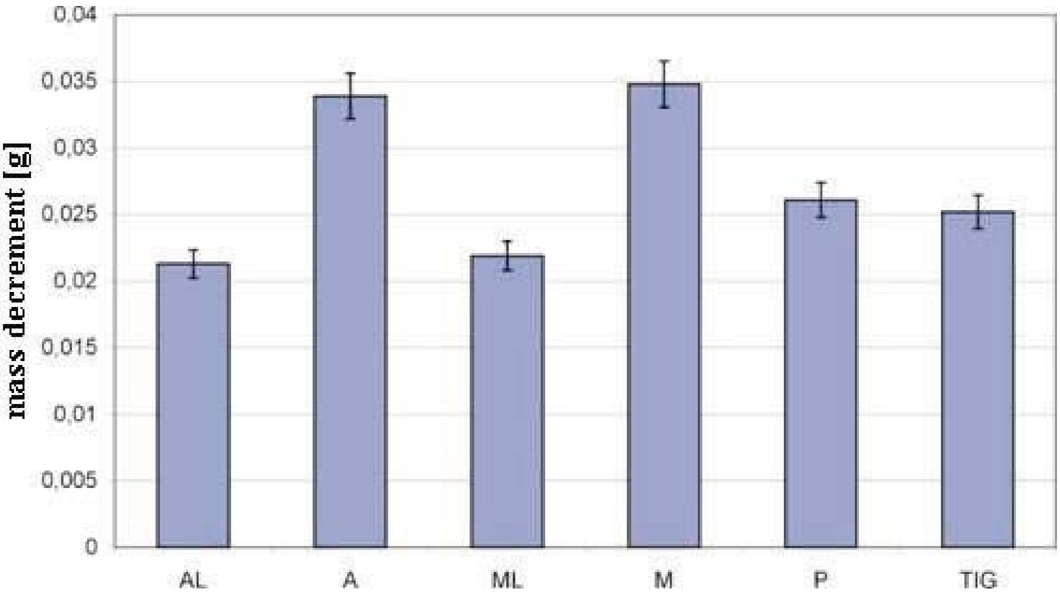


Fig. 7. Specimens' mass decrement in erosive wear tests

Specimens with a laser pad welded stellite layer had the smallest mass decrement in comparison with other material types. The biggest mass decrement was recorded for specimens made of valve steels in the initial state. Mass decrement of plasma and TIG pad welded stellite layers was bigger by 20% than of the laser pad welded layer.

Additionally, tests were carried out on specimens made of the 50H21G9N4 steel in the initial state which had a laser pad welded stellite layer. The specimens were oriented at the angle of $\alpha=45°$. The purpose of the test conducted at $\alpha=45°$ was to determine erosive wear (shearing erosion) [see reference 7] depending on the direction of an erosive stream, which partly reflects the effect of an exhaust gases stream on the surface of the faying face of a valve head (the inclination angle of the faying face of a valve head is 45°).

The effect of the erosive stream at 45° caused an increase in specimens' mass decrement (see Figure 8). The difference in the value of mass decrement under an erosive stream between the 50H21G9N4 steel in the initial state and the steel with a laser pad welded stellite layer increases for a smaller inclination angle ($\alpha=45°$) of the erosive stream.

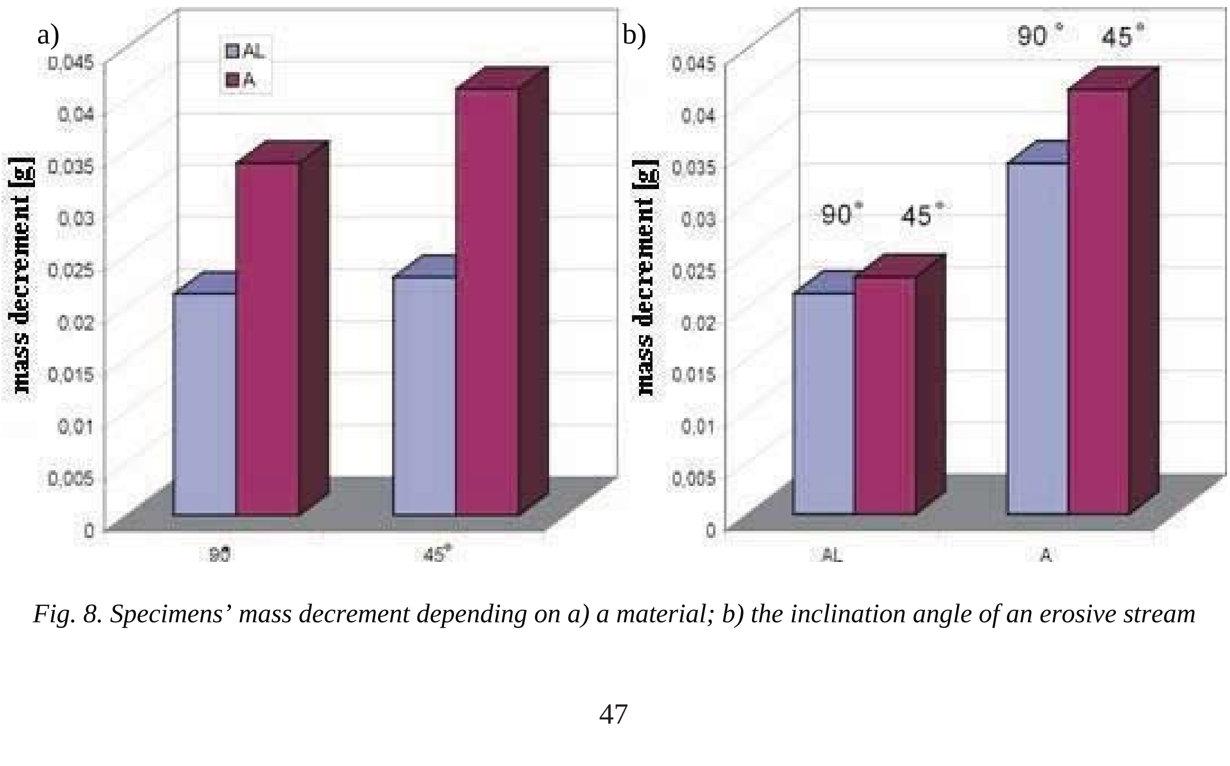


Fig. 8. Specimens' mass decrement depending on a) a material; b) the inclination angle of an erosive stream

The increase in the difference of mass decrement of specimens made of the 50H21G9N4 steel in the initial state (A) and with a pad welded stellite layer (AL) at a smaller angle of the abrasive stream (45°) indicates a higher resistance of the stellite layer. A higher resistance to erosion at small angles of attack is characteristic of hard and brittle materials [see reference 7].

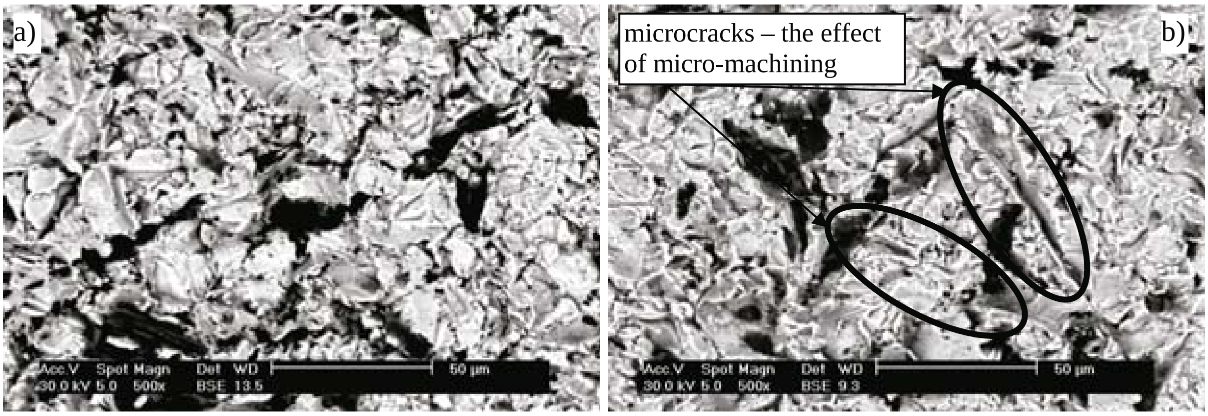


Fig. 9. Erosion traces: a) deformational erosion; angle α=90°, b) deformational-shearing erosion; angle α=45° (a stellite layer on the 50H21G9N4 steel)

The surface of specimens after the erosive tests at the stream angle of 90º shows a significant deformation of the surface layer (see Figure 9a). The layer was plastically deformed by aloxite particles of high kinetic energy striking against the surface. Deformation is smaller for the angle of 45º, however, there can be noticed cracks which indicate the occurrence of the mechanisms of micro-machining wear and ridging wear in addition to plastic deformations (see Figure 9b).

3.3. High temperature oxidation resistance tests

The assessment of the kinetics of high temperature oxidation of the stellite layer was carried out by a gravimetric method. The measurement consisted in holding specimens at a temperature of 900°C for 125 hours. During the annealing process, specimens' mass measurements were taken at specific intervals. On the basis of the obtained measurements, a diagram of the specimen's unit mass changes as a function of the experiment duration was plotted (see Figure 10).

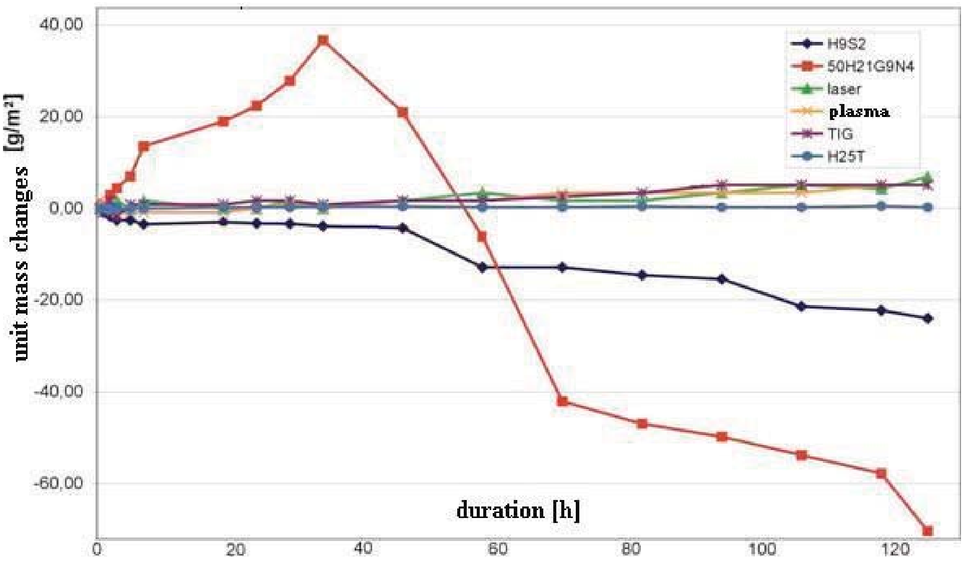


Fig. 10. Specimens' unit mass changes as a function of the duration of the experiment at the temperature of 900°C

Specimens with a stellite layer that was pad welded by different techniques were made in the shape of a cuboid of 24x16mm and a thickness of 3mm. The pad welded layer was minimum 2mm thick. Stellite layers were pad welded on the substrate made of the H25T heat-resisting steel, which has the highest resistance to high temperature oxidation.

The H9S2 steel showed a constant tendency to drop in mass. It is connected with the oxidation of the surface in a continuous manner during annealing and the scale that is formed has vaporization properties [see reference 10]. No rapid drop in mass was observed after the specimen had been cooled, which might indicate the stability of the formed film (lack of spalling). In turn, the 50H21G9N4 steel showed a constant growth of the oxide film up to the 40th hour of the experiment. However, after that time, the oxide layer became unstable and spalled intensively during measurements, which manifested in the form of significant and rapid specimen's drops in mass (see Figure 9). The phenomenon of oxide layer spalling is connected with the fact that the properties of the material and the oxide layer are dissimilar. The oxide layer comes off the material during cooling as a result of different coefficients of expansion. After 80 hours of annealing, the process of the oxide layer coming off stabilized and did not proceed as intensively as before. Stellite layers did not show a tendency to oxidize, which may indicate their high resistance to oxidation.

4. Summary and final conclusions

The use of stellite for lengthening the life of the faying face of a valve head of an internal combustion engine is validated by many years of research and practical applications. The conducted tests on the selected service properties of laser pad welded stellite layers made it possible to formulate the following conclusions:

1. Tribological research showed that the smallest mass decrement occurs in the case of specimens with a laser pad welded stellite layer under the conditions of dry friction. The wear is smaller in comparison with both the native material of the tested valve steels and layers pad welded by other techniques (plasma and TIG pad welding). By way of example, the specimen's mass decrement in tribological tests was 1.4 mg in the case of laser pad welding, 4.3 mg in the case of plasma pad welding and 3.5 mg in the case of TIG pad welding.
2. The analysis of the wear surface of mating components in tribological tests showed that wear in the tested association, in the case of stellite layers, is of an adhesive character. The wear mechanism was identified as the formation and braking of I-type graftings. For H9S2 and 50H21G9N4 materials, additional wear mechanisms, namely micro-machining and ridging were identified.
3. Erosive wear test results also validate the abovementioned higher resistance of laser pad welded stellite layers in comparison with the native material of the analyzed valve steels. A greater wear caused by the effect of an erosive stream was observed for specimens with plasma and TIG pad welded layers than for the laser pad welded layer. By way of example, in erosive tests, the mass wear of specimens was 2 mg in the case of laser pad welding, 2.6 mg in the case of plasma pad welding and 2.5 mg in the case of TIG pad welding.
4. Additional tests on the effect of an erosive stream oriented at the angle of 45° to the tested surface conducted on the 0H21G9N4 steel in the initial state and with a laser pad welded stellite layer showed a bigger difference of mass decrement between the tested materials in comparison with a perpendicular orientation of the erosive stream. The analysis of the surface topography after the erosive tests for the angle of the orientation of the erosive stream of 90° showed a considerable surface deformation caused by a dynamic interaction of aloxite particles with the specimen surface. For the angle of 45°, deformations are smaller and there are noticeable cracks which indicate the micro-machining of the surface by aloxite particles.

5. Heat resistance tests validated a high resistance of stellite layers to high temperature oxidation. No significant effect of a stellite layer pad welding technique on specimens' mass changes during annealing was noted. On the 50H21G9N4 steel, there appeared a large amount of oxides in the form of a layer which showed a tendency to spalling during the tests. Mass changes of H9S2 steel specimens at the temperature of the experiment indicate that there was formed an oxide layer that had vaporization properties.

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