Influence of flame spraying on the mechanical and tribological properties of 42CrMo4 steel

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Abstract. Flame spraying is a thermal spray coating process that produces high quality surface coatings using heat, from the combustion of a fuel gas with oxygen. In the experimental part of the paper, laboratory tests were carried out on selected sprayed samples in terms of sample preparation for testing, measurement of chemical composition, recording of characteristic microstructures, measurement of hardness in the sample cross-section and tribological tests. Based on the analysis of the collected test results, it can be concluded that with increasing number of cycles at constant load, there is a mass loss of AISI431 (test sample 1) and Metco 350NS (test sample 2) coatings.

1. Introduction

Construction materials are subjected to harmful changes during their work, such as wear, material fatigue, corrosion, cracking, etc. The properties of surface coatings very often affect the durability of a particular tool or machine part in operation. For this reason, more and more attention is being paid to engineering and surface technologies. One of these technologies is thermal spraying [1-4], which belongs to the group of thermomechanical coatings, and among other coating and modification processes, they are surface finishing processes [5-7]. In publications [8, 9] mathematical modeling by (RSM) of different surface finishing processes and materials is shown.

Coatings have become essential for the protection of tools and machine parts and are now applied to about 70÷75 % of tools. In the past, attempts have been made to reduce the undesirable wear of materials by modifying the properties of the base material. However, today's approaches are such that the application of surface treatment processes is aimed at achieving properties at a higher level. The main objective is to increase wear resistance, reduce the coefficient of friction and increase corrosion resistance. The aim of this paper is to determine the dependence of the mass loss of the tested coatings on the number of applied cycles at constant load on selected spray samples by means of appropriate tests, such as chemical analysis, metallographic analysis, hardness flow analysis and analysis of tribological tests.

The planned tests and analyzes will provide information on the mechanical and tribological properties of the steel, which will be improved by heat treatment and flame spraying [10, 11]. Research of mechanical and tribological properties and different methods of processing technology of 42CrMo4 steel are presented in [12-14].

2. Properties of 42CrMo4 steel

The 42CrMo4 steel belongs to the group of low-alloy steels. It is known mainly for its good toughness, high torsional and dynamic strength. Moreover, thanks to the addition of alloying elements, it is very suitable for direct heat treatment by refining. Due to these properties, it is most often used for statically and dynamically loaded parts of vehicles, engines and machinery. Due to its good hardenability, it is also used for the production of parts with large cross-section, crankshafts, axles and gears. The main mechanical and physical properties of 42CrMo4 steel in the improved condition are listed in Table 1.

Table 1. *Mechanical and physical properties of 42CrMo4 steel in improved condition*

Property	Value
Modulus of elasticity E, MPa	$190 \div 210 \times 10^3$
Tensile strength R_m, MPa	$1100 \div 1300$
Conventional yield strength $R_{p0,2}$, MPa	900
Extension A, %	10
Contraction Z, %	40
Impact toughness K_v, J	35
Density ρ, g/mm^2	7,84

3. Experimental part

For the purposes of flame spraying and laboratory testing, a steel 42CrMo4 for the improvement was selected. The steel was improved to a value of 1000÷1100 MPa. The tests were performed on two test samples. Test sample 1 was sprayed with an AISI431 coating, while test sample 2 was sprayed with a Metco 350NS coating. Chemical analysis, metallographic analysis, hardness flow analysis and analysis of tribological tests were performed on the samples prepared and sprayed in this way.

3.1. Test plan

Table 2 shows the schedule of tests performed on the test samples of 42CrMo4 steel.

Table 2. *Laboratory testing plan*

Steel mark	Tests performed on 42CrMo4 steel					
	Heat treatment	Chemical analysis	Flame spraying	Metallography	Hardness HV0,5	Tribological tests
42CrMo4	+	+	+	+	+	+

3.2. *Heat treatment of 42CrMo4 steel*

The heat treatment scheme for 42CrMo4 steel consists of improvement, i.e. hardening and high temperature tempering. The steel is first heated to a temperature of 880 ºC, held at this temperature for about half an hour, and quenched in oil. This is followed by a high-temperature tempering at 560 ºC for 3 hours, after which the sample is cooled in a furnace (Fig. 1).

3.3. Chemical composition testing of 42CrMo4 steel

The chemical composition was tested on 42CrMo4 steel. The composition of the steel used for the laboratory tests was determined by chemical analysis. A spectrometric method was used to determine the chemical composition. The results of the declared and tested chemical composition of 42CrMo4 steel are shown in Table 3.

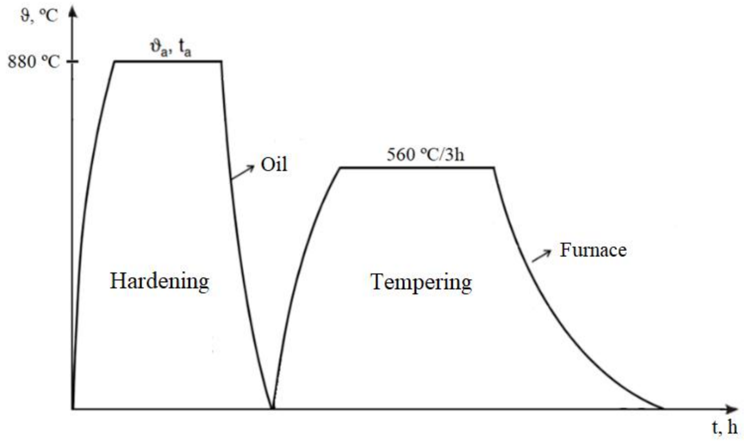


Figure 1. *Heat treatment diagram of 42CrMo4 steel*

Table 3. *Tested and declared chemical composition of 42CrMo4 steel*

<table>
<tr><td rowspan="6">42CrMo4 steel</td><td colspan="7">Tested chemical composition, %</td></tr>
<tr><td>C</td><td>Si</td><td>Mn</td><td>P</td><td>S</td><td>Cr</td><td>Mo</td></tr>
<tr><td>0,382</td><td>0,383</td><td>0,728</td><td>0,024</td><td>0,001</td><td>0,931</td><td>0,245</td></tr>
<tr><td colspan="7">Declared chemical composition, %</td></tr>
<tr><td>C</td><td>Si</td><td>Mn</td><td>P</td><td>S</td><td>Cr</td><td>Mo</td></tr>
<tr><td>0,38 ÷ 0,45</td><td>≤ 0,40</td><td>0,60 ÷ 0,90</td><td>≤ 0,035</td><td>≤ 0,035</td><td>0,90 ÷ 1,20</td><td>0,15 ÷ 0,30</td></tr>
</table>

3.4. *Flame spraying procedure*

After heat treatment, it is necessary to prepare the surface of the material in order to successfully carry out flame spraying. The preparation consists of turning, milling, grinding and degreasing processes. The dimensions of the test samples are shown in Fig. 2.

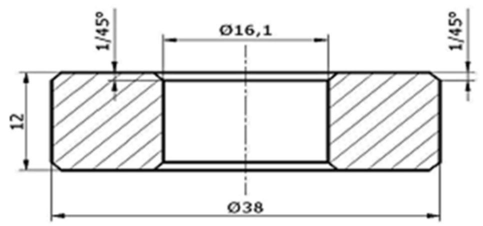
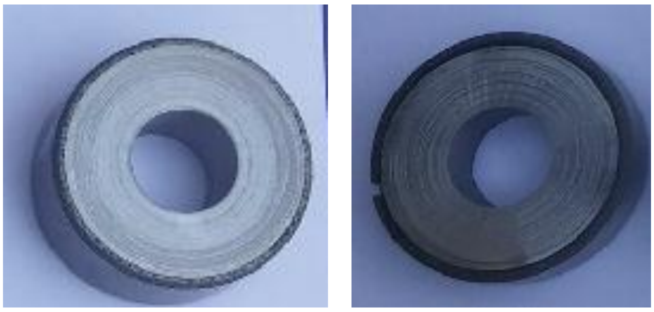


Figure 2. *Dimensions of test samples*

After preparation by flame spraying, two test samples were prepared for laboratory testing, Figure 3.



a) b)

Figure 3. *Representation of test samples*
a) coating AISI431 (test sample 1); b) coating Metco 350NS (test sample 2)

After turning and milling, the surface must be thoroughly cleaned and degreased so that the coatings applied by flame spraying can be well applied to the surface. Degreasing was performed with a highly volatile degreasing agent. Surface preparation is followed by flame spraying. Two different coatings are applied to the 1.2 mm thick base material by flame spraying. One coating is AISI431 (test sample 1) and the other is Metco 350NS (test sample 2). The AISI431 coating is most commonly used for gasket assembly and disassembly, in boiler tubes, chemical industry, pump parts, etc. It is suitable for use at temperatures up to 500 ºC and has high corrosion resistance. The hardness of the coatings is about 270 HV. The Metco 350NS coating is most commonly used for bearings, and the coating hardnesses are 600 HV. Both coatings are also used for quick repairs and touch-ups. These coatings are characterized by a microporous structure and very good retention of the oil film. Since they are non-rusting materials, they can also be used for repairs exposed to the corrosive influence of aggressive media. The declared chemical compositions of the tested coatings are listed in Tables 4 and 5.

Table 4. *Declared chemical composition of the coating AISI431 (test sample 1)*

Chemical composition, %					
C	Cr	Mn	Ni	Si	Fe
0,18	17	0,18	2	0,30	ostatak

Table 5. *Declared chemical composition of the coating Metco 350NS (test sample 2)*

Chemical composition, %			
C	Mo	Mn	Fe
2 ÷ 3	16 ÷ 18	0,25	residue

In order to apply the flame spraying process to the test samples, they must first be preheated. Preheating is carried out with a gas flame usually 40° above ambient temperature. After preheating, the flame spraying process begins. Spraying is carried out with a gun, Figure 4.

Figure 4. *Flame spray gun*

The speed of the gun is 11 mm/s, while the rotation speed of the samples is 220 rpm. The distance of the gun from the samples is 150 mm and for the last layer 200 mm. Oxygen at a pressure of 4 bar, acetylene at 0.7 bar and air at 0.8 bar are supplied to the gun through cables. The powder is in a bottle, which is attached to the gun and enters the gun by gravity. The powder flies in a wide jet, and air is used to direct and focus the powder to the smallest possible point. Air is also used as a cooling medium, i.e. to prevent preheating of the samples and to clean the samples in intermediate phases. Therefore, it is very important to maintain the intermediate temperature to avoid the formation of oxides. The intermediate temperature is usually 70÷120 ºC. It should always be as cold as possible, because the greater the difference between the final temperature and the preheating temperature, the greater the residual stresses. The flame spraying procedure was carried out in 6 passes. After the procedure, the samples should be cooled slowly. The cooling was done in volcanic sand. For larger samples, a non-combustible cloth is used in which the samples are wrapped.

3.5. *Metallographic tests*

In order to perform metallographic studies and analysis of the base material and the sprayed coatings, the samples must first be etched in a suitable medium. The samples were etched in nital (3%) for 3 to 5 seconds.

3.5.1. *Microstructure characteristics of the test sample 1*

The basic structure of the base material consists of bainite and martensite age hardening. After heat treatment, quenching and tempering at high temperatures, hardening martensite is formed. In addition to bainite and martensite, residual austenite (approx. 10%) and various precipitates (cementite and chromium carbides) are also present (Fig. 5).

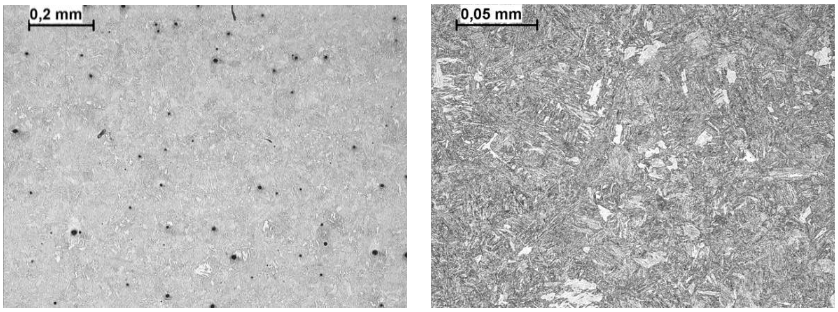


Figure 5. *Microstructure of basic material of the test sample 1*

The microstructure of the AISI431 coating is coarse-grained. The hardened coarse grains are clearly visible. It can also be observed that there was no complete melting of the coating material and also no penetration. White round grains represent undissolved elements, and precipitates are also present. The high porosity of the sprayed coating is expressed (Fig. 6).

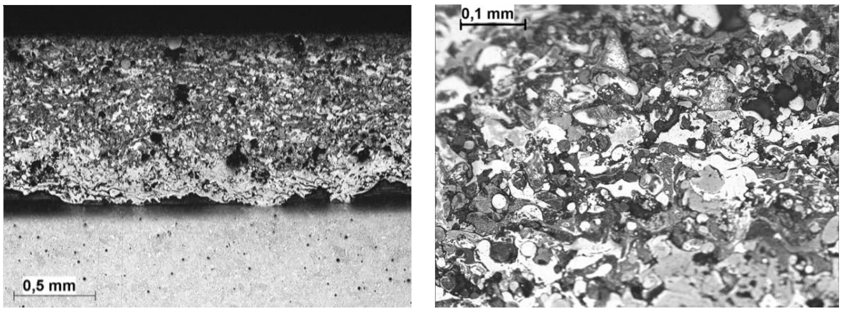


Figure 6. *Microstructure of the coating AISI 431 (test sample 1)*

3.5.2. *Microstructure characteristics of the test sample 2*

The basic structure of the parent material in this case consists of martensite and bainite. There is less retained austenite in the microstructure, but more precipitated precipitates compared to the microstructure of the base material of test sample 1 (Fig. 7).

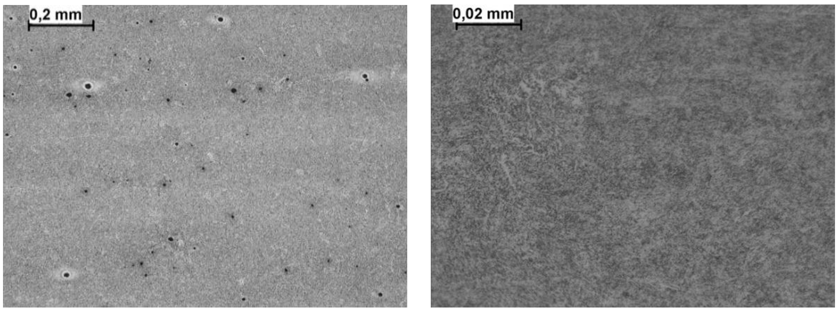


Figure 7. *Microstructure of basic material of the test sample 2*

The microstructure of the Metco 350NS coating is layered and compact. Undissolved elements are present, but in a much lower percentage than in the AISI431 coating. The coating is more homogeneous and penetration is low (Fig. 8).

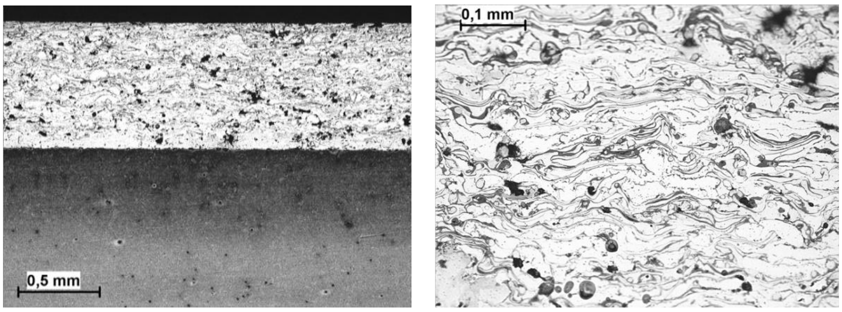


Figure 8. *Microstructure of the coating Metco 350NS (test sample 2)*

3.6. *Hardness test*

To obtain a complete picture of the mechanical properties, the hardness values must be measured on the cross section of the samples after the metallographic tests. The hardness was measured according to the Vickers method HV0.5. The values of the measured hardnesses of test sample 1 are listed in Table 6, while the values of the measured hardnesses of test sample 2 are listed in Table 7.

Table 6. *Hardness measurement results of test sample 1*

Ordinal number of measurements	Distance from the surface, mm		Hardness, HV0,5
1.	0,25	Coating AISI431	318
2.	0,5		245
3.	0,75		216
4.	1	Basic material 42CrMo4	341
5.	1,25		339
6.	1,5		325
7.	2		328
8.	3		331
9.	5		322
10.	10		326

Table 7. *Hardness measurement results of test sample 2*

Ordinal number of measurements	Distance from the surface, mm		Hardness, HV0,5
1.	0,25	Coating Metco 350NS	627
2.	0,5		601
3.	0,75		544
4.	1	Basic material 42CrMo4	328
5.	1,25		323
6.	1,5		334
7.	2		330
8.	3		341
9.	5		326
10.	10		329

3.7. *Tribological tests*

Tribological tests were performed on an AISI431 coating (test sample 1) and on a Metco 350NS coating (test sample 2). Mass loss of the tested coatings was monitored during the test. During the test, the coatings were loaded with a constant force of 250 g, varying the number of cycles from 100; 200; 500; 1000; 2000, while 80 grit sandpaper was used as the abrasive. The initial mass of test sample 1 was 91.43 g, while the initial mass of test sample 2 was 94.47 g. The tests were performed on a Taber Abraser device (Fig. 9).

Figure 9. *Tribological testing device*

The results of the mass loss of the tested coatings are shown in Table 8.

Table 8. *Mass loss results of AISI431 and Metco 350NS coatings*

Type of coating	Number of cycles				
	100	200	500	1000	2000
	Mass loss Δm, g				
AISI431	0,0011	0,0020	0,0046	0,0091	0,0188
Metco 350NS	0,0004	0,0007	0,0015	0,0029	0,0056

4. Research results and discussion

The test plan (Table 2), indicates the scope and sequence of the tests, which range from chemical and metallographic analysis of the base material and coatings, to analysis of the hardness flow measured by the HV0.5 method, to analysis of the tribological tests. The heat treatment of the steel to improve 42CrMo4 consisted of hardening and high-temperature tempering for 3 hours and cooling in a furnace, Figure 3.1. By analyzing the results obtained by testing the chemical composition of the test samples, it was determined to be 42CrMo4 steel (Table 3). Metallographic tests were performed on the base material and coatings of test samples 1 and 2. Visually, test sample 1 exhibited better adhesion of the AISI431 coating. However, the metallographic tests showed that test specimen 2, which was successful by spraying the Metco 350NS coating, had much better adhesion, homogenization and penetration compared to test sample 1. Another interesting fact is that both test samples were made from the same base material and heat treated together, and there is much less retained austenite but more precipitates in test sample 2 compared to test sample 1. The hardness of the base material of test samples 1 and 2 corresponds to the microstructure of the improved steel 42CrMo4 obtained by heat treatment and its value is ≈ 330 HV0.5. The hardness of the coating AISI431 - test sample 1 (≈ 260 HV0.5) was much lower than the hardness of the coating Metco 350NS - test sample 2 (≈ 590 HV0.5). For selected conditions of tribological tests, the mass loss of AISI 431 and Metco 350NS coatings as a function of variable number of cycles and constant load is presented (Table 8). The analysis of the obtained results showed that with increasing number of cycles, with constant load, there was a mass loss of coating AISI431 (test sample 1) and Metco 350NS (test sample 2), noting that slightly greater mass loss had coating AISI431 (test sample 1).

5. Conclusion

In order to protect certain tools and machine parts from various influences, the process of thermal spraying is used. This process has a very wide application, mainly due to the wide range of materials that can be sprayed. Another important feature is the speed of execution and the fact that the base material does not change its structure, since only its surface is heated. For the thermal spraying process to be successful, the test surface must be prepared to a high quality and certain process parameters must be matched. Since thermal spraying is a process that is still being improved, it can be assumed that this process will find even more applications in various fields in the future.

Analysis of the collected test results suggests that the AISI431 coating continuously shows a higher mass loss than the Metco 350NS coating with increasing number of cycles at constant load.

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