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Abrasive resistance of HVOF thermally sprayed coatings based on alloys and cermets compared to nitrided stainless steel

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ABSTRACT

Purpose: This work is focused on the abrasion resistance comparison of alloy and cermet based coatings with nitrided stainless steel.

Design/methodology/approach: The coatings deposited on the steel substrates were subjected to the abrasion test according to a modified ASTM G-65 (Rubber Wheel/Dry Sand Abrasion Test). Al_2O_3 abrasive sand with the granularity of 212-250 μm was used as an abrasive material. Stellite 6, NiCrBSi, Hastelloy C-276, Cr_3C_2-NiCr, Cr_3C_2-CoNiCrAlY and TiMoCN-Ni powders were used to prepare several set of samples.

Findings: The obtained results show that the abrasion resistance is not directly proportional to the hardness. The difference in microstructure between cermet and alloy bases coatings in relation to their wear mechanism plays an important role.

Research limitations/implications: The HVOF thermal spraying technology (High Velocity Oxygen Fuel) is commonly used as a component surface protection against abrasive wear. Alloy and cermets based coatings therefore meet the requirements for high abrasion resistance.

Originality/value: The current trend in increase of operating temperature and steam parameters to improve steam turbine performance results in the operating temperatures which are close to the nitriding temperatures of steels limiting the use of this technology. For these reasons, the demand for alternative ways of functional surface protection is increasing, in particular to increase the abrasion resistance of component surfaces operating at high temperatures.

Keywords: HVOF; Coating; Abrasion resistance; Wear resistance; ASTM G-65; Nitriding

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PROPERTIES

1. Introduction

Nitriding is nowadays the most commonly used surface protection of components in energy industry. Unfortunately, this type of heat treatment loses its functional properties with time. Operating temperatures and steam pressures are being increased in order to improve the performance of steam turbines. These parameters are close to the nitriding temperatures of steels and limit the use of this technology. Consequently, the demand for alternative ways of functional surface protection increases, in particular to improve the surface abrasion resistance of components operating at high temperatures. The coatings deposited by HVOF (High Velocity Oxygen Fuel) technology are a suitable alternative to the nitriding process and meet the high demands for abrasion, corrosion and erosion resistance. HVOF technology is currently applied as a standard method of functional surface protection for a wide range of components in many industrial sectors [1]. The cermet coatings belong to the most widely used method of component surface protection; mainly due to their excellent mechanical properties [2]. Thermally sprayed Cr_3C_2-25%NiCr coatings are used in high temperature applications with regard to their excellent resistance to corrosion and oxidation [3]. Cr_3C_2-25%CoNiCrAlY coating provides an excellent protection against surface erosion and wear at high temperatures. This coating has also better oxidation resistance than Cr_3C_2-25%NiCr coating [4]. The experimental T10 coating has also been evaluated in this article. T10 coating is primarily suitable for energy and marine industry. There are also many alloy based coatings meeting the demanded requirements of the energy industry. The example of commercially used alloy based coatings is Stellite 6 characterized by excellent hardness, toughness and corrosion resistance. Stellite 6 based alloys have high melting point due to the presence of cobalt and chromium [5]. NiCrBSi based alloy is another material suitable for high temperature applications. This alloy is composed of very fine particles of precipitating carbides and borides in the nickel matrix. In practice, this coating is mainly used as a protection against abrasive wear even at elevated temperatures. These coatings belong to the group called self-fluxing alloys that are in many cases after spraying subsequently heat treated to improve their mechanical and physical properties [6]. The last evaluated coating is nickel, molybdenum and chromium alloy based coating which is commercially designated as Hastelloy C-276. This material exhibits excellent corrosion resistance, which is one of the most requested parameters in the selection of coatings for the energy industry. Based on this information, it is evident that these coatings are adequate substitutes for the previously mentioned nitriding. The advantage of functional coating application is that the noble material components can be replaced by less noble substrate with coating. The result of this substitution is to provide the components with required mechanical and corrosion properties and wear resistance with lower economic cost. Wear resistance is one of the most important features characterizing the properties of the resulting functional coatings. Current studies highlight the fact that abrasive wear occurs at about 50% of industrial applications [7]. Hardness is now a determining condition for the selection of suitable material, but it was shown that there cannot be found any correlation between harness and abrasive wear resistance. From this reason, hardness cannot be the only characteristics to decide about a suitable material, but possible mechanism of wear should be also taken into consideration. Consequently, this article is focused mainly on the comparison between the abrasion resistance of alloy and cermet coatings and the properties of nitrided material W.Nr. 1.4923.

2. Experiment

This section is focused on the comparison between the abrasion resistance of cermet and alloy based coatings (HVOF) and nitrided stainless steel and subsequently on the determination of coating structure influence on the wear mechanism.

The coatings were prepared using HVOF thermal spraying technology system TAFA JP-5000 in VZÚ Plzeň s.r.o. The evaluated coatings were based on hard metals – Cr_3C_2-25%NiCr, Cr_3C_2-25%CoNiCrAlY, experimental T10 (TiMoCN-Ni); and alloys – Stellite 6, NiCrBSi, Hastelloy C-276. W.Nr. 1.0570 steel in the size of 75x25x5 mm was selected as substrate material. The average coating thickness was 300 μm.

The samples of nitrided stainless steel were prepared in the department of heat treatment, VZÚ Plzeň s.r.o,. Two sets of nitrided specimens were prepared. The surface activation with TiH was used by the samples labeled Exp.1 and Exp.2 samples were without the surface activation. W.Nr. 1.4923 was used as the material for specimens.

Abrasive resistance of above mentioned coatings was evaluated by a modified method according to ASTM G-65. The principle of this method is described in detail in the publication [8]. The test result is the volume loss, possibly also the wear rate of material depending on the specific test conditions. Materials exhibiting higher abrasive wear resistance are characterized by lower volume loss. The brief description of the test is as follows: abrasive particles with defined grain size and hardness are injected between the rotating wheel fitted with a rubber band of certain hardness and a sample which is pressed with a defined force to the wheel. The first test result is the weight loss of the tested material. The weight loss is then converted to the volume loss in order to compare materials of different densities.

The conditions selected for coatings evaluation were as follows: a rubber disc with the diameter of 231.89 mm was pressed against the sample with a defined force of 22 N at constant speed of 200 rev/min. Synthetic white corundum with the grain size of 212-250 µm was used as an abrasive material. The quantity of corundum injected between the sample and the disc was 440 g/min and the sand moisture did not exceed 0.5% of the total weight. Weight losses were measured on a digital scale Sartorius TE214S OCE with the accuracy of 0.0001 g. Tests were carried out at the temperature of 22 ± 2°C [9].

The microstructure in coating cross section and the surface morphology after the abrasion test was evaluated by SEM microscopy. Microhardness was measured using the Vickers indenter with 300 g load applied for 10 seconds ($HV_{0.3}$). The resulting value is the average of seven measurements. The density was determined by the Archimedes principle. The surface hardness was measured according to Rockwell (HR15N). The resulting value is the average of five measurements.

3. Results and discussion

The measured values of mechanical properties of the coatings and the nitrided stainless steel are shown in Table 1.

Abrasive wear resistance was analyzed by selected coatings. The relation between the volume loss and the abrasive track for each coating is shown in Figure 1. The wear rate Wr is defined as the linear straight line direction of each coating, see Fig. 1. All obtained values are summarized in Table 1.

The graph in Fig. 1 shows that Cr_3C_2-25%NiCr coating exhibited the highest abrasive wear resistance of all coatings deposited by thermal spraying. The results of this coating are followed by T10 and Cr_3C_2-CoNiCrAlY coatings results. As expected, Stellite 6 and Hastelloy C-276 coatings showed lower abrasive wear resistance and NiCrBSi showed the lowest resistance to abrasive wear. The graph in Fig. 1 can evoke the assumption that Stellite 6 exhibited the lowest abrasion wear resistance, but this coating has the high volume loss only in the first test cycle. The reason is that in terms of abrasion resistance, the straight line direction (Wr) is the determining factor. The results recorded in the Table. 1 show that this coating has lower Wr value, and therefore the wear is slower than by NiCrBSi, but faster than by nitrided steel Exp. 1. While comparing the nitrided stainless steel, the samples without surface activation exhibit higher abrasive wear resistance. This surface treatment is in terms of abrasion resistance comparable with NiCrBSi coating and more resistant than Stellite 6 coating. The stainless steel with surface activation (using TiH) showed a very low Wr value. The abrasion resistance of evaluated surface treatments does not correspond in some cases with the values of hardness. This occurs especially by alloy based coatings.

Table 1.
Mechanical properties of coatings

Coating	Roughness R_a	HR15N	$HV_{0.3}$	Wr , mm^3/m
Cr_3C_2-25%NiCr	4.1 ± 0.5	89.1 ± 2.1	847 ± 35	0.00561
Cr_3C_2-CoNiCrAlY	5.2 ± 0.3	87.9 ± 2.6	894 ± 76	0.00831
TiMoCN-Ni	2.9 ± 0.2	91.7 ± 1.2	689 ± 43	0.00765
Stellite 6	6.9 ± 0.4	82.8 ± 3.1	626 ± 53	0.03212
Hastelloy C-276	8.2 ± 1.0	81.3 ± 2.2	463 ± 35	0.02108
NiCrBSi	6.7 ± 1.0	87.8 ± 1.8	815 ± 59	0.03598
Nitridedsteel Exp. 1	4.1 ± 0.6	71.1 ± 0.8	804 ± 23	0.03641
Nitridedsteel Exp. 2	1.3 ± 0.2	90.3 ± 0.4	836 ± 9	0.02572

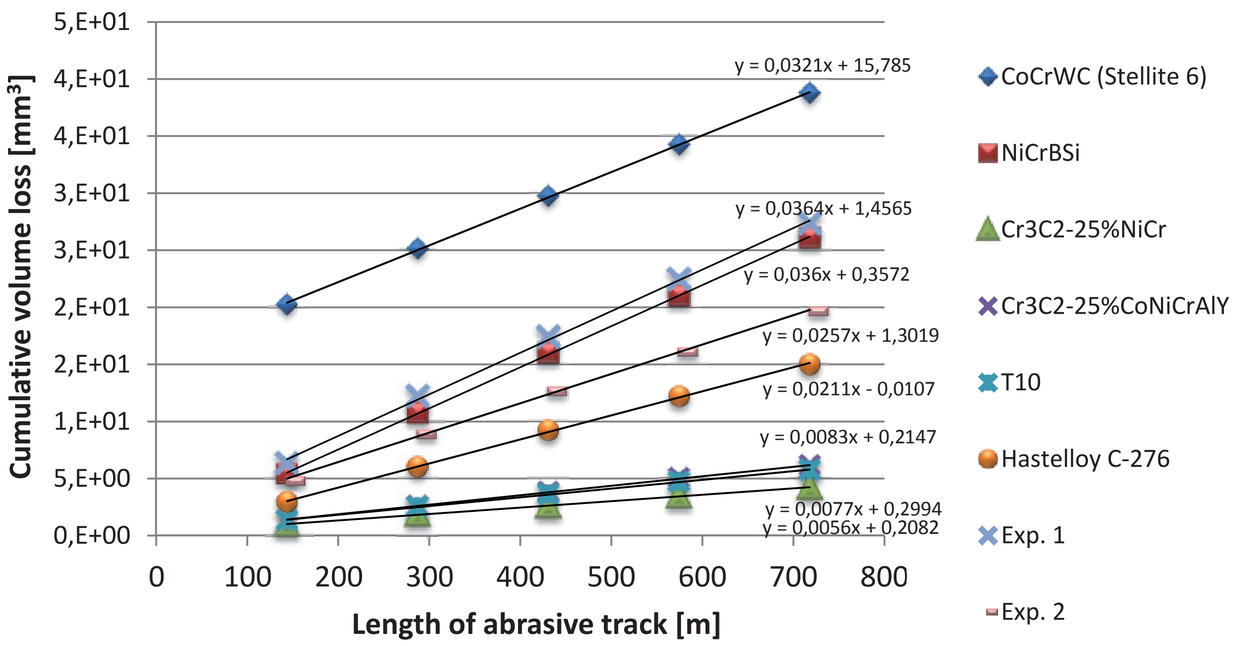

Fig. 1. Abrasive wear comparison of evaluated surface treatments

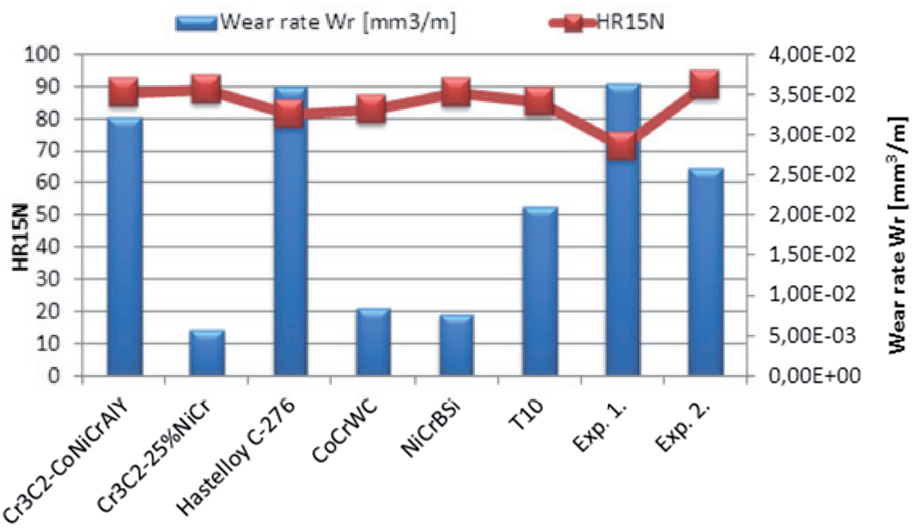

Fig. 2. Dependence of the wear rate on the hardness HR15N

Basic mechanical properties of selected coatings are summarized in Tab. 1. Fig. 2 and Fig. 3 show the dependence of wear rate on hardness HR15N and $HV_{0.3}$ for all evaluated surface treatments. The Fig. 4 shows the surface morphology of coatings and nitrided steel after the wear in the middle of the abrasion track. These photographs further clarify the wear mechanisms of evaluated surface treatments. The uniform distribution of carbides throughout the matrix prevents abrasion wear in cermet coatings, which is proportional to the strength of carbide-matrix bond. For this reason, alloy based coatings have higher abrasion rate than cermet coatings due to the absence of carbide phases.

Grain size evaluation was carried out according to EURONORM 103 with the result of 4.5 to 5.5. The size of austenitic grain size for standard nitriding steel of class 15 was evaluated with the result of 5 or finer. This grain size of stainless steels is considered to be a borderline and in some cases the nitriding process does not reaches the desired properties. We assume that this fact particularly caused low abrasion resistance of tested nitrided steel.

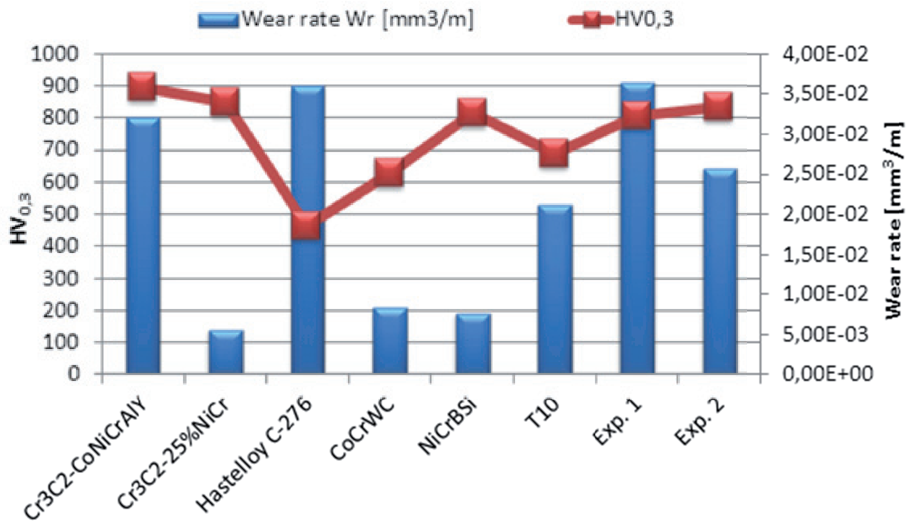

Fig. 3. Dependence of the wear rate on microhardness $HV_{0.3}$

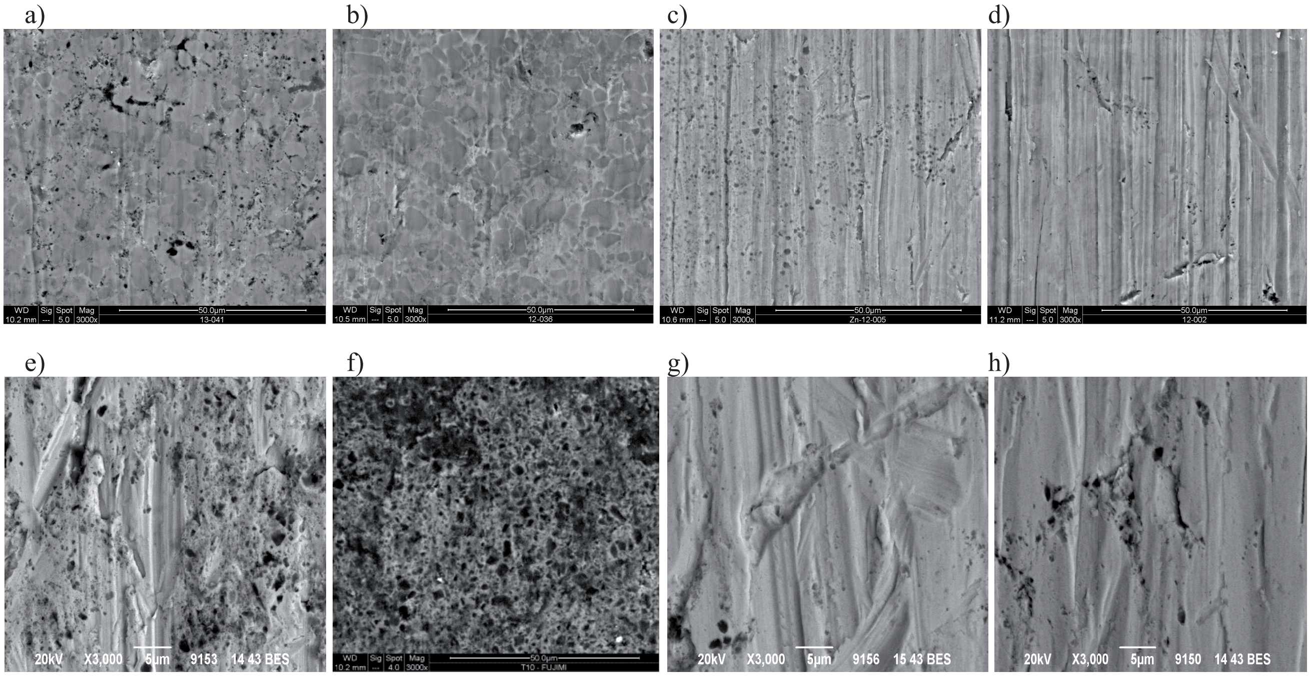

Fig. 4. Surface morphology of individual coatings after wear in the middle of the abrasion track a) Cr_3C_2-CoNiCrAlY, b) Cr_3C_2-NiCr, c) NiCrBSi, d) Stellite 6, e) Hastelloy C-276, f)-Ni TiMoCN, g) Nitrided Steel Exp. 1, h) Nitrided steel Exp. 2, 3000x magnification, SEM (Mix)

4. Conclusions

- As expected, it was confirmed that the cermet coatings show higher abrasion wear resistance than alloy based coatings.
- The obtained results apparently show that the abrasion wear resistance is proportional to the hardness.
- It was found that hardness HR15N can be used in case of cermet coating only as an orientation indicator for the abrasive wear resistance determination. However, according to the results obtained, we can state that the correlation between hardness and abrasion resistance is not possible in the case of alloy based coatings. A similar conclusion can be drawn also in connection with the use of micro-hardness $HV_{0.3}$ as an indicator to determine the abrasion resistance of coatings.
- Furthermore, particularly the difference in micro-structure of cermet and alloy based coatings and of stainless steel plays a very important role in relation to the wear mechanism. Carbides uniformly distributed in the matrix prevent abrasion in the case of the cermet coatings. The abrasive wear rate is determined by the strength of carbide-matrix bond. For this reason, alloy based coatings exhibit higher abrasion than cermet coatings due to the absence of carbide phases.
- Finally, it would be interesting to conduct in future research a re-measurement of nitrided steel with a grain size of at least factor 7. The main reason for re-measurements is to exclude the possibility of insufficient grain size in case of evaluated the nitrided steel, which would result in the decreased levels of abrasion resistance.

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References

[1] P. Pawlowski, The Science and Engineering of Thermal Spray Coatings, Whiley Chichester, UK, 1995, 327.

[2] F. Zahálka, R. Enžl, Žárově stříkané povlaky - moderní technologie povrchových ochran, Technik, 2005.

[3] T.S. Sidhu, S. Prakash, R.D. Agrawal, Characterizations and Hot Corrosion Resistance of Cr_3C_2-NiCr Coating on Ni-base Super alloys in an Aggressive Environment, Journal of Thermal Spray Technology 15/4 (2006) 811-816.

[4] Flame Spray Technologies, Powders, April 2008, http://www.fst.nl/ [online], [17. 1. 2013], http://www.fst.nl/upload/documents/PDF%20for%20download/FST_Powders_1105.pdf

[5] T.S. Sidhu, S. Prakash, R.D. Agrawal, A Comparative Study of Hot Corrosion Resistance of HVOF Sprayed NiCrBSi and Stellite-6 Coated Ni-Base Superalloyat 900°C, Materials Science and Engineering: A445-446 (2007) 210-218.

[6] J.M. Miguel, J.M. Guilemany, S. Vizcaino, Tribological study of NiCrBSi coating obtained by different processes, Tribology International 36/3 (2003) 181-187.

[7] T.S. Eyre, Wear characteristic of metals, Tribology International 9/5 (1976) 203-212.

[8] A.N.J. Stevenson, I. Hutchings, Development of the dry sand/rubber wheel abrasion test, Wear 195 (1996) 232-240.

[9] ASTM Standard G65 – 04, 2010, "Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus," ASTM International, West Conshohocken, PA, 2010, DOI: 10.1520/G0065-04R10.