53rd Conference on Experimental Stress Analysis pp. 134–139
Český Krumlov, Czech Republic, June 1–4, 2015

Erosion Wear Resistance of Selected HVOF Sprayed Coatings

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Abstract: The paper involves the subject and the chosen results of up to now solving of work package "Development of advanced surface treatment of components used in parts of turbines working under the condition of operational temperatures of steam using the HP/HVOF technology of thermal spraying" of the Competence Centre project "Centre of Research and Experimental Development of Reliable Energy Production". The subject belongs to the field of material engineering and results of solving contribute to fulfilling the main project aim, which is a long time safeguarding of safe, reliable and financially available both classical thermal and nuclear sources of electric power, which consists in extending service life of existing and building new turbo generator blocks. The erosion wear resistance is one of the areas, which were observed. The impact of hard particles on the surface under variable impact angles was simulated in laboratory conditions using an in-house equipment. The wear resistance of selected HVOF sprayed hardmetal and super-alloy coatings was measured and the wear mechanism was evaluated. A strong influence of impact angle on both material volume loss and wear mechanism was monitored. The superior erosion wear properties of super-alloy coatings were proved, regardless the higher hardness of hardmetal coatings.

Keywords: HP/HVOF; Thermal Spray; Erosion Resistance; Impact Angle; Steam Turbine.

1 Introduction

The main aim of the "Centre of Research and Experimental Development of Reliable Energy Production" project [1] (in the framework of the Competence Centres Program of the Technology Agency of the Czech Republic [2]), the solving of which started in the year 2012 and will be in progress till the year 2019, is a long time safeguarding of safe, reliable and financially available both classical thermal and nuclear sources of electric power, which consists in extending the service life of existing and building new turbo generator blocks. Research and development of new technologies and materials will result in the increase in the ability of producers and operators of power-producing plants to compete. The project as a whole was introduced to professional public e.g. in [3–5]. Companies and research institutes involved in the project solving are Research and Testing Institute Plzeň (project applicant), Doosan Škoda Power, ČEZ, University of West Bohemia, Czech Technical University in Prague, MATERIAL AND METALLURGICAL RESEARCH, TES and ENERGOSERVIS Chomutov.

The project is solved in the framework of so called work packages (altogether 13) [1, 3, 6]. Work packages were set in such a way that they may lead to fulfilling the project main subject. The paper comprises the chosen results of up to now solving of work package "Development of advanced surface treatment of components used in parts of turbines working under the condition of operational temperatures of steam using the HP/HVOF technology of thermal spraying". The presented results are focused on the field of the evaluation of solid particle erosion of selected thermally sprayed coatings.

2 Thermal Spraying Tasks Solved in the Centre Competence Project

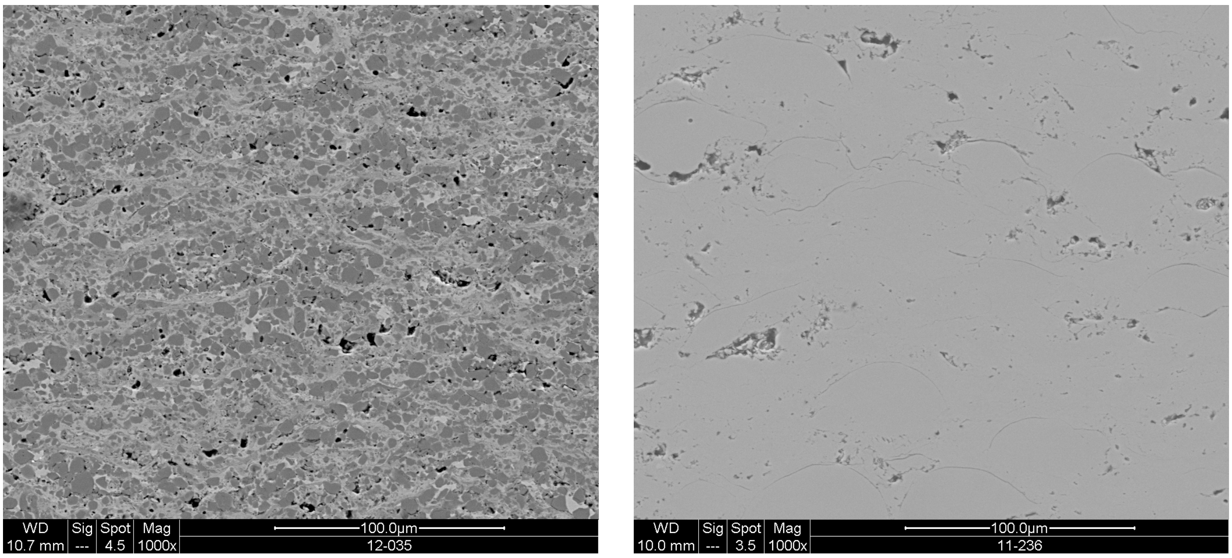
The purpose of solving the work package "Development of advanced surface treatment of components used in parts of turbines working under the condition of operational temperatures of steam using the HP/HVOF technology of thermal spraying" is increasing the reliability and extending the lifetime of components working at the environment of steam operational temperatures in steam turbines applying the HP/HVOF thermal spray technology. The research target is the identification of the best surface treatment method and the spraying process controls meeting the requirements typical for parts working in extreme environments under unstable operating conditions.

A special material surface treatment consisting in thermal spray coating is expected to increase the material surface hardness, improve its wear resistance, and improve the surface sliding properties and material resistance towards high-temperature degradation. Selection of highly-resistant coatings based on hardmetal and super-alloy materials applied using the HP/HVOF technology enables to replace the conventional surface treatment by nitrogen hardening, which cannot be used for parts with operational temperatures exceeding 550 °C. Thermal spray technology may yield highly resistant surface coatings of a controlled thickness where the base material remains thermally unaffected. Thermal deformations and other adverse effects associated with welded-on surface layers or similar processes are eliminated. Additionally, the strictly controlled thickness of the thermal spray coatings enables to decrease the costs due to the part machining allowances. Thermal spray coatings created in this way are suitable for most demanding operational environments including those of extreme steam temperatures up to 850 °C. Main attention is paid to the type and quality of the surface coatings concerned and the evaluation methods that should give the true picture of the properties of the coatings under the service conditions.

3 Erosion Wear Resistance of Thermal Spray Coatings

Erosion by solid particles is a type of wear degradation process, in which solid particles entrained in fluid stream impact against the surface and induce wear by abrasion [7]. It can be found in many applications, not only in energy industry, at low or high temperature environments [7].

In this study, attention is paid to the evaluation of solid particle erosion of selected thermally sprayed coatings. Both hardmetal and super-alloy coatings were tested to compare them mutually. The influence of solid particle impact angle on the wear loss and wear mechanism is also studied and discussed.



(a) Cr_3C_2-25%NiCr HVOF sprayed coating

(b) Co-Cr-W super-alloy HVOF sprayed coating

Fig. 1: Scanning Electron Micrograph of thermal spray microstructures.

The microstructure of representative coatings is shown in Fig. 1. Due to the technology of thermal spraying, the microstructure of thermal spray coatings is lamellar, composed of individual particles (15-45 μm diameter), which were deformed by impacting the surface in semi-molten state to the disk-shape lamellas, so called "splats". Adhesion of the coating to the substrate and also the inner intersplat cohesion of the coating are given by the thermal spray process parameters and the coating material and are crucial for the coating wear resistance [8]. In both coatings, the minor porosity on the intersplat boundaries can be observed, typical for thermal spray coatings. In Fig. 1a, the cross section of hardmetal coating Cr_3C_2-25%NiCr is shown. In the

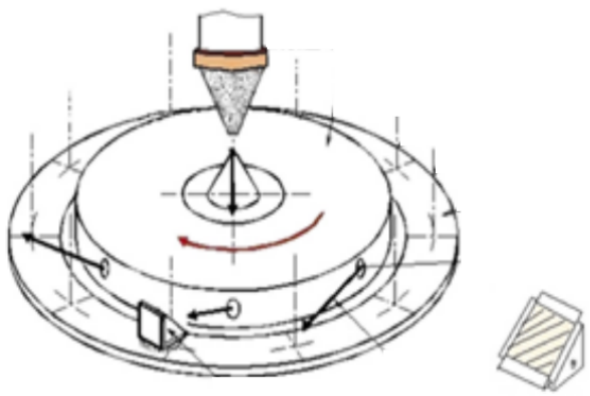
Tab. 1: Basic properties of the evaluated HVOF coatings.

Coating material	Surface hardness HR15 N	HRC	Microhardness HV0.3	Specific density [g/cm^3]
Cr_3C_2-25%NiCr	89.37 ± 1.45	58.4	930 ± 92	6.685
Cr_3C_2-25%CoNiCrAlY	87.98 ± 2.60	55	894 ± 75	6.479
TiMoCN-29%Ni	84.94 ± 1.99	49	689 ± 43	5.894
Stellite 6	82.82 ± 3.10	43.5	650 ± 75	8.296
NiCrBSi	87.77 ± 1.83	55	815 ± 58	7.176

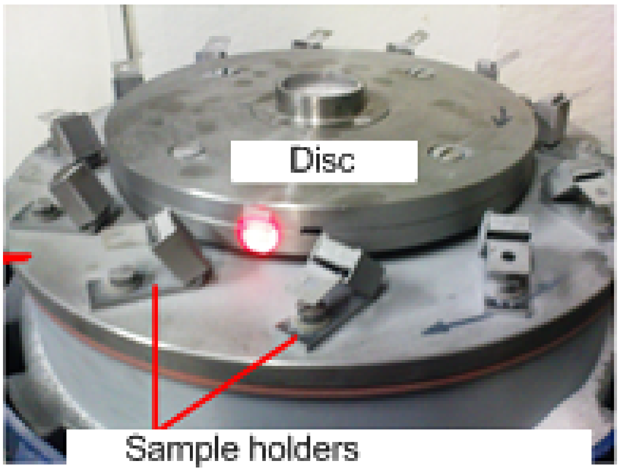
case of hardmetal, each splat consists of hard CrC particles embedded in the tough matrix. While hard carbide particles are responsible for high hardness and abrasion wear resistance, a tough matrix is needed to bond the carbides together and transform the erosion impact energy into plastic deformation. In Fig. 1b, the super-alloy (Co-Cr-W) coating's microstructure is shown. Only the splat boundaries and minor porosity in the coating can be seen. The intersplat microstructure consists of the Co-based solid solution. No separate hard particles can be observed. Hardness of such a coating is lower compared to the hardmetal coatings, but its toughness is much higher.

3.1 Erosion Wear Testing Equipment and Parameters

Equipment for solid particle erosion wear testing was designed and manufactured. It makes use of the centrifugal construction for the generation of kinetic energy of solid particles, impinging the surface of the coated samples (Fig. 2). The sample holders enable to adjust the particles impact angle.



(a) scheme of centrifugal solid particle erosion test [9]



(b) centrifugal solid particle erosion test device

Fig. 2: Design of solid particle erosion wear test equipment.

On the basis of previous studies [10, 11], test parameters suitable for HVOF coatings were chosen. Al_2O_3 (212-250 μm size range) abrasive particles were used, 47 mm/s circumferential velocity of rotating disc was set, the exposition time was 2 minutes. Four different angles of abrasive particles impact were set: 90°, 60°, 30°, 15°. The erosion wear mass loss was determined by weighing the samples before and after the test, and was converted into the volume loss using coating materials specific density (Tab. 1). The wear mechanisms were analyzed after the test using the Scanning Electron Microscopy.

3.2 Tested Coatings Materials

Five coating materials were sprayed and tested. The choice of the materials was motivated by its purpose in terms of the solved project. All tested coating materials were wear resistant and should have stood the high temperature environment. The level of their wear resistivity under different load conditions is one of the merits of the solved project. Three kinds of hardmetal (typical Cr_3C_2-25%NiCr, less used Cr_3C_2-25%CoNiCrAlY and experimental TiMoCN-29%Ni) and two alloy coatings (Co-based Stellite 6 and Ni-based NiCrBSi) were sprayed onto the carbon steel substrate (20 × 15 × 4 mm) using the HVOF spraying technology (the JP-5000 spraying system). The standard procedure of substrate samples preparation and spraying used in the Research and Testing Institute Plzeň was applied. Average thickness of the coatings was 0.4-0.5 mm, their basic mechanical properties are summarized in Tab. 1.

3.3 Measured Results

The volume losses, measured after the solid particle erosion test under 4 different angles of particle impact, are summarized in Fig. 3. It is evident that a perpendicular impact of abrasive particles causes the highest erosion wear, while during the impact under the lowest angle the lowest volume loss was measured. Similar tendency is valid, with respect to the scatter of the measured values, for all 5 evaluated coatings. The wear mechanism differs for the perpendicular and the lowangle impact. While for the low-angle impact the wear mechanism is more similar to the abrasion, the perpendicular impact causes cracking and the loss of a bigger part of the coating material due to the combination of coating material strain hardening, brittleness and impact fatigue loading. A different character of wear mechanism is demonstrated in Fig. 4 and 5.

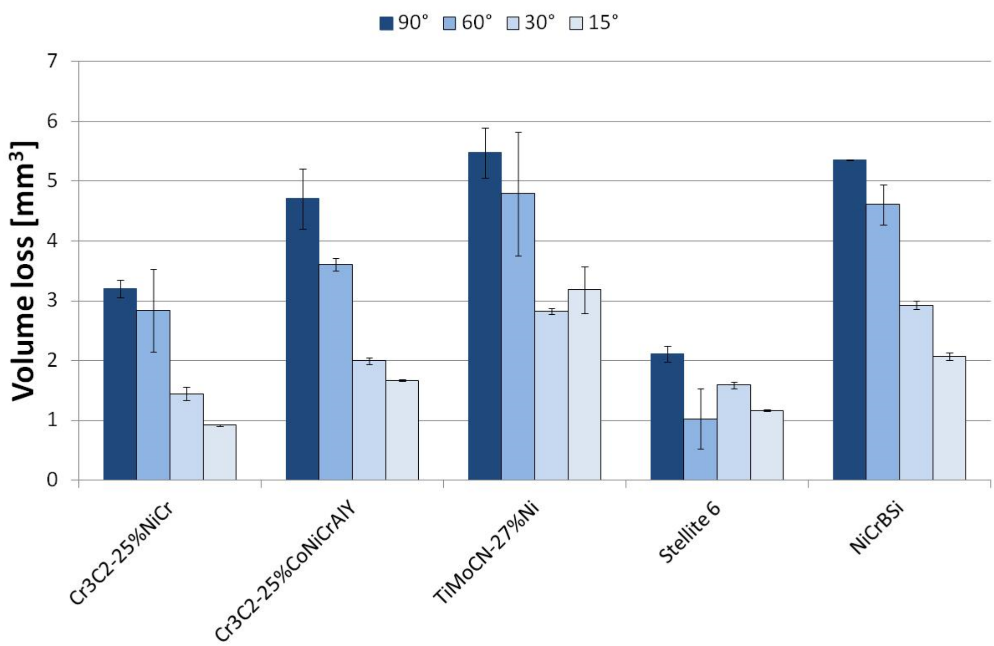
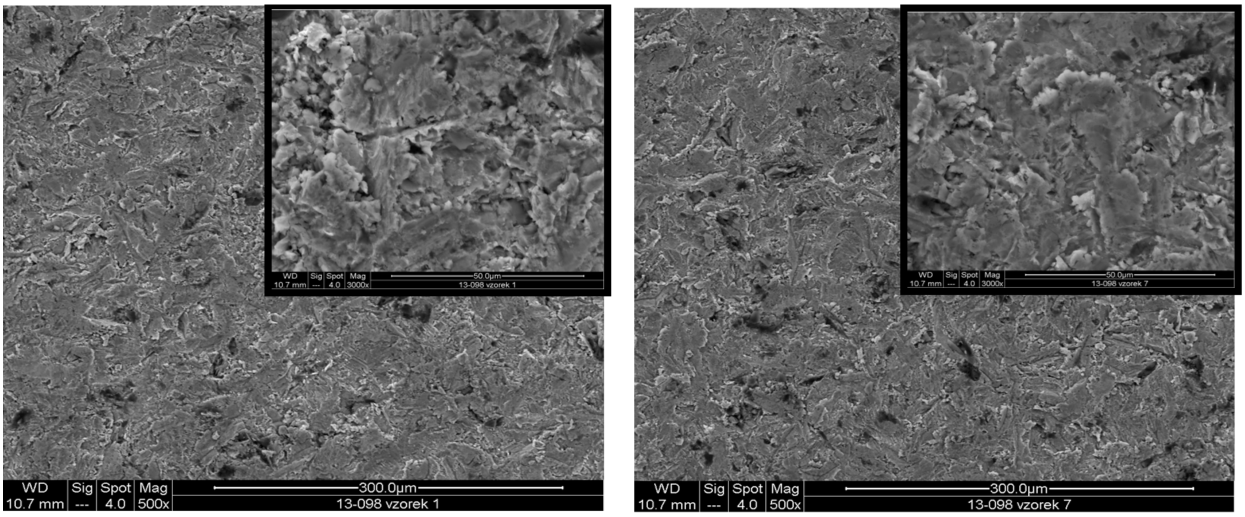


Fig. 3: Measured volume loss in dependence on the impingement angle.

It is necessary to note that the measured results of solid particle erosion wear cannot be directly correlated to the measured coatings hardness values (see Tab. 1).

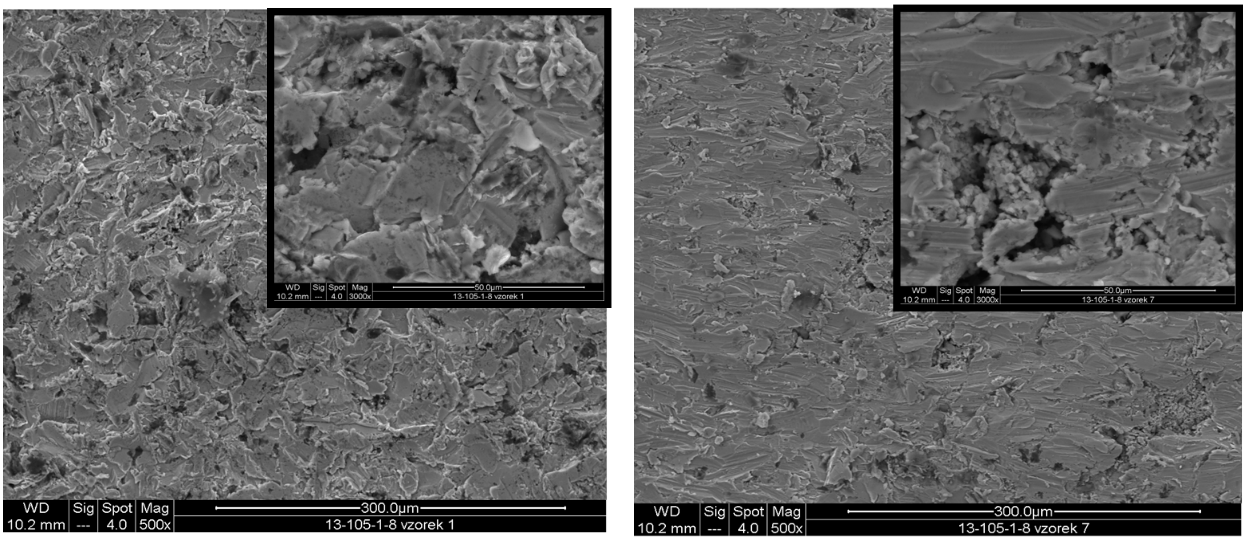
The hardness can be considered to be a guide only in the case of materials with similar nature, e.g. hardmetals. At the low-angle erosion, which occurs through abrasion mechanism, the hardmetals benefit from the wear resistance of hard particles, embedded in the matrix (carbides, nitrides). The amount of the carbides, their size in correlation to the size of abrasive particles and finally the strength of carbide-matrix bonding play an important role [12]. In such a condition, the hardness can predict the wear resistance. In the case of perpendicular impact of abrasive particles, the wear mechanism changes but the main microstructural parameters are similar – size and distribution of carbide, the strength of the carbide-matrix bonding, but also the ability of the matrix to accommodate the impact fatigue loading. In the case of poor intersplat cohesion whole splats can be released from the coating and a high erosion wear can occur.

In the group of super-alloy coatings represented by NiCrBSi and Stellite coating the hardness cannot be used for the erosion wear estimation. Even if the measured hardness values are higher for NiCrBSi, the erosion wear resistance of Stellite 6 is the highest of all the measured coatings, particularly for the perpendicular impact angle. The Stellite coatings are designed to have a high erosion wear resistance and were previously recommended for the application on the surface of turbine blades and pumps [13]. The Co-based solid solution can accommodate a high amount of impact energy without undesirable strain hardening leading to the brittleness and the fatigue.



(a) 90° impact angle (b) 15° impact angle

Fig. 4: Solid particle erosion wear mechanism in dependence on the impact angle for Cr_3C_2-25%NiCr coating.



(a) 90° impact angle (b) 15° impact angle

Fig. 5: Solid particle erosion wear mechanism in dependence on the impact angle for Stellite 6 coating.

4 Conclusion

The paper contains the chosen results of up to now solving of work package “Development of advanced surface treatment of components used in parts of turbines working under the condition of operational temperatures of steam using the HP/HVOF technology of thermal spraying”, which is part of the eight-year project “Centre of Research and Experimental Development of Reliable Energy Production”. Attention is paid to the evaluation of solid particle erosion of selected thermally sprayed coatings.

The result of research and development of new technologies and materials, in which eight companies are involved (Research and Testing Institute Plzeň, Doosan Škoda Power, ČEZ, University of West Bohemia, Czech Technical University in Prague, MATERIAL AND METALLURGICAL RESEARCH, TES and ENERGOSERVIS Chomutov), will a better competitiveness of producers and operators of power-producing plants.

Acknowledgement

The paper has originated in the framework of the solution of the "Competence Centres" program of the Technology Agency of the Czech Republic, project number TE01020068.

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