Microstructure and tribological behavior of HVOF sprayed and laser treated CoCrTaAlCSiY coatings

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Abstract Co-based alloys are used over a wide range of application because of their excellent corrosion and wear properties. Especially the Stellites (Co-Cr-W) are well known and quite well researched. The CoCrTaAlCSiY is a new material on the field of thermal spray coatings and due to its composition was chosen for studding of tribological behavior. In this paper the HVOF sprayed and post heat treated coatings of CoCrTaAlCSiY are presented. Specimens were treated by a laser with two different laser parameters in order to reach different thickness of laser treated layers. Erosion test and linearly oscillating ball-on-flat test were applied to evaluate the wear behavior of CoCrTaAlCSiY coating. Microstructure of as-sprayed and heat treated coatings were also studied. The evaluation revealed a positive effect on wear coefficient for both laser treated coatings. A significant improvement of volume loss during erosion test was also observed for both laser treated coatings.

1. Introduction

Today's industry applications claim still higher demands on material properties and low purchase prices therefore materials with high wear and corrosion resistance are highly desirable. Their usage is in wide range of applications such as power generation, aerospace, chemical industry or medicine. There are the materials exposed to high mechanical load or corrosion environment or a combination of both. Only materials with excellent combination of mechanical and oxidation properties can fulfill such requirements but these special materials are quite expensive. That is why they are often applied on the surface of cheaper components as a coating material improving the surface properties.

Thermal spray coatings represent really good possibility how to combine low manufacturing costs and excellent material properties. The HVOF (High Velocity Oxygen Fuel spraying) is widely used method of thermal spraying. The main advantages of HVOF is preparation of coatings with low oxidation during the spraying process, high adhesion to substrate and low coating porosity [1].

Additional heat treatment of thermal spray coatings could lead to improvement of material properties. One of possible processes is laser heat treatment which is a technology that modifies the surface properties of materials. Usage of laser heat treatment in combination with thermal sprayed coatings results in elimination of oxides and porosity at the intersplat boundaries. Thus the internal coating cohesion is higher and subsequently the corrosion and wear resistance can be improved [2].

There exists a wide variety of wear resistant materials which differs in chemical composition and purpose of usage. The most commonly used wear resistant materials are composites of hard tungsten carbides WC or chromium carbides Cr_3C_2 (also a combination of both is possible) and Ni, Cr or Co-based metallic matrix (or a combination of these metals) where are the carbides distributed [1]. The Cr-based wear resistant materials with high content of chromium carbides

Cr_3C_2 are characterized by resistance to high temperatures. These Cr-based materials are represented by Cr_3C_2–25NiCr and Cr_3C_2–25CoNiCrAlY [3] [4]. The Ni-based alloys are generally based on the Ni-Cr solid solution. Typical representatives of such alloys for thermal spraying are NiCrBSi and Hastelloy C-276 [5].

And last but not least there is a family of Co-based alloys which are called Stellites, typically represented by Stellite 6 which is a Co-Cr-WC alloy [6] [7] [8]. One of the Co-based materials is CoCrTaAlCSiY which is a new material on the field of thermal spray coatings with the maximal operating temperature 1050 °C [9]. It is characterized by Co-based matrix with high content of Cr which provides oxidation resistance. On the other hand there is a considerable content of Al (7.5 wt.%) and Ta (8.2 wt.%), especially the effect of tantalum on the tribological behavior of HVOF sprayed coatings is not researched sufficiently. Addition of yttrium to the limit of 1 wt.% within Co-based alloys can enhance mechanical properties of upper oxidation layer which can cause improvement of wear resistance [10]. Tantalum is very reactive and carbide-forming element [11]. Tantalum is forming the tantalum carbide TaC which is harder than carbides Cr_3C_2 [10].

Target of this paper is to evaluate and describe results of laser heat treatment process which was applied on the HVOF sprayed coatings of CoCrTaAlCSiY material with the focus on mechanical properties and tribological behavior of the coatings. Two different laser parameters settings were selected in order to carry out coatings with different thickness of laser treated layers.

2. Experimental procedures

2.1. Coatings preparation

The CoCrTaAlCSiY coatings were sprayed by HP/HVOF TAFA JP5000 spraying equipment in VZÚ Plzeň s.r.o. The grit blasted steel 11 523 plate with the dimensions 200 mm x 100 mm x 10 mm was used as a substrate. These dimensions were chosen to ensure sufficient cooling rates during laser treatment process. The powder F22 with a grain size 0.8-1 mm was used for grit blasting of substrates. For HVOF spraying was used commercially available gas atomized powder FST 469.001 with nominal chemical composition of 25 wt.% Cr, 8.2 wt.% Ta, 7.5 wt.% Al, 0.75 wt.% C, 0.7 wt.% Si, 0.75 wt.% Y and balanced Co. The laser treatment was applied using two different laser parameters (named LR1 and LR2). For the parameters LR1 was chosen the laser power 1070 W, specific energy 5.4 J/mm^2, traverse speed 16.7 mm/s and spot size 12 mm x 1 mm. The parameters LR2 are specified with laser power 1070 W, specific energy 17.8 J/mm^2, traverse speed 5 mm/s and spot size 12 mm x 1 mm. For laser treatment was used the HPDD 4 kW laser Coherent HighLight ISL-4000L with wave length 808 ± 10 nm. Preheating of the substrates up to 350 °C was performed in order to prevent coatings from high thermal gradient which could cause cracks in the coated layer. After laser treatment were the samples cooled in air atmosphere

2.2. Coatings analyses

The same experimental procedure was applied to as-sprayed coating and also to both laser treated specimens (with parameters LR1 and LR2). Automated LECO grinding and polishing equipment was used for grounding and polishing of the cross sections specimens. Quality of specimens polishing was continuously checked in optical microscope Nikon Epiphot 200 which was also used for optical micrographs of specimens microstructure. The microhardness was evaluated from cross sections by digital optical 3D microscope Hirox KH7700. Corresponding SEM images was prepared using the microscope EVO MA25 from Zeiss with LaB6 thermal filament and equipped by EDX detector SDD X-Max 20 Oxford Instruments.

The indents for microhardness measurement were made in 50 μm equidistant steps and started 50 μm below the coatings surface which resulted in 6 x 6 indentation matrix. The microhardness was evaluated by HV0.1 measurement and mean values are plotted in the graph in Figure 3.

Sliding wear resistance was evaluated using the linearly oscillating ball on flat wear test (ASTM G-133). Subsequently the wear coefficient (K) and coefficient of friction (COF) were determined at room temperature. The parameters of ASTM G-133 wear test were as follows: steel 100Cr6 counterpart (6 mm diameter ball), 25 N normal force, 5 Hz oscillating frequency, 10 mm stroke length, 1000 s testing time and 100 m total sliding distance. Three different measurements were applied for each specimen then the depth profile of each wear track was measured by profilometer KLA-Tencor P-6 Profiler at three different places and finally the total volume loss was calculated. Surfaces of specimens for ASTM G-133 wear test were at first ground and polished to ca. 0.04 ± 0.02 Ra value. Created wear tracks were observed in SEM in order to identify wear mechanism.

Abrasive wear resistance was evaluated using the dry sand rubber wheel test (ASTM G-65) and subsequently the wear coefficient (K) was determined at room temperature. The parameters of ASTM G-65 wear test were as follows: wheel diameter 231.89 mm, wheel width 12 mm, wheel hardness 65 Shore A, abrasive media Al_2O_3, size of abrasive particles 200 µm, load 22 N, feeding rate 500 g/min and 718 m total sliding distance. Surfaces of specimens for ASTM G-65 wear test were left without any treatment.

The erosion test (Figure 1) was carried out at VZÚ Plzeň s.r.o. with their own testing equipment. Principle of the erosion test is as follows: the reservoir at the top of the device provides a given constant amount of abrasive media (white corundum F70), the abrasive particles enter in between two rigidly connected rotating discs containing four accelerating channel, there are the abrasive particles accelerated by centrifugal forces and at the outlet of channels the particles stream encounter the specimens. The weight of specimens is several times measured and the weight loss is evaluated and because the density of tested material is known the volume loss can be determined.

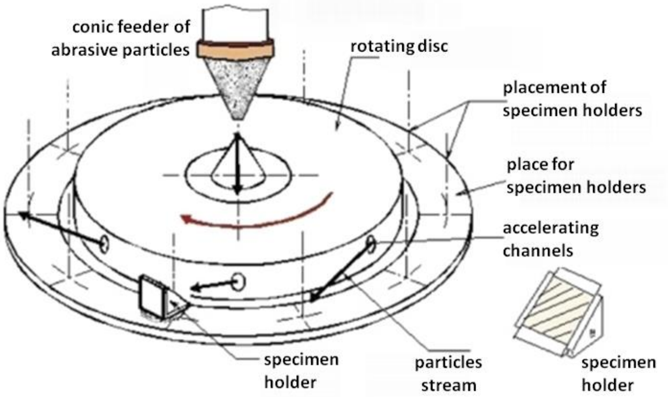

Figure 1. Schematic drawing of erosion test at VZÚ Plzeň s.r.o.

3. Results and discussion

3.1. Microstructure and microhardness

Microstructure of HVOF as-sprayed CoCrTaAlCSiY coating (Figure 2a) is characterized by dense web of splats and containing intersplat boundaries potentially lowering the coatings cohesion. For HVOF coatings is typical small amount of porosity in whole coating. The Al_2O_3 particles used for grit blasting can be occasionally observed on the substrate-coating interface.

Laser parameters LR1 (specific energy 5.4 J/mm^2) led to heat treatment of ca. third of coating thickness whereas LR2 (specific energy 17.8 J/mm^2) resulted in heat treatment of complete coating thickness. Both laser treatments (Figure 2b, 2c) led to decrease of internal coating porosity and final coatings are denser and more compact. Another consequence of laser treatment is that the coating surface is much smoother than as-sprayed coatings. The laser treated coating layer is characterized by recrystalized dendritic structure inside individual splats. In specimen with LR2 parameters (Figure 2c) is noticeable the upper coating layer where the microstructure was completely remelted. Additional effect of higher specific energy is that the porosity from substrate-coating interface propagated towards the coating surface.

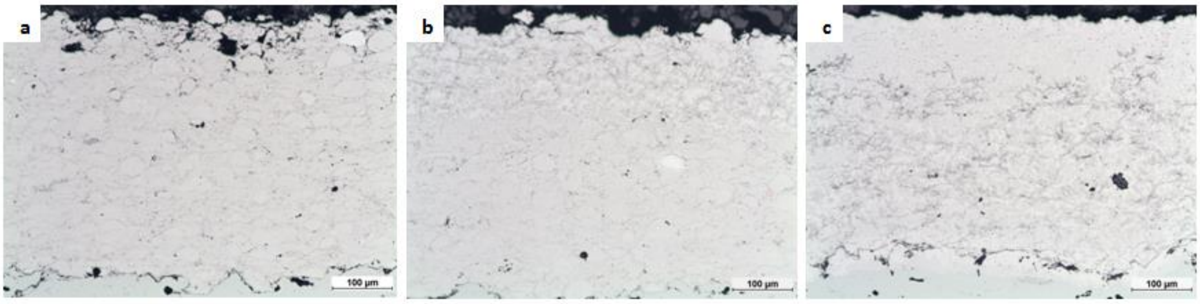

Figure 2. Optical micrographs of microstructure for HVOF CoCrTaAlCSiY coatings: (a) as-sprayed, (b) laser parameters LR1, (c) laser parameters LR2.

Results of microhardness measurement are shown in the graph in Figure 3. For both laser treated coatings (parameters LR1 and LR2) there is an increase of microhardness which is more evident for the LR1 with only partly laser treated coating. One of the reasons for microhardness improvement is perhaps the more compact coating with lower porosity than in the as-sprayed coating. Although scattering of values is quite high, there are two facts resulting from the microhardness measurement. First fact is the confirmation of laser treatment of whole coating thickens for parameters LR2 because in the layer near the substrate-coating interface are values lower than in as-sprayed specimen which is an effect of dilution of Fe from substrate material into coating. Second fact is that the microhardness of completely laser remelted coating (upper layer in LR2 specimen) is lower than the only laser treated coating which is typical for deeper layers.

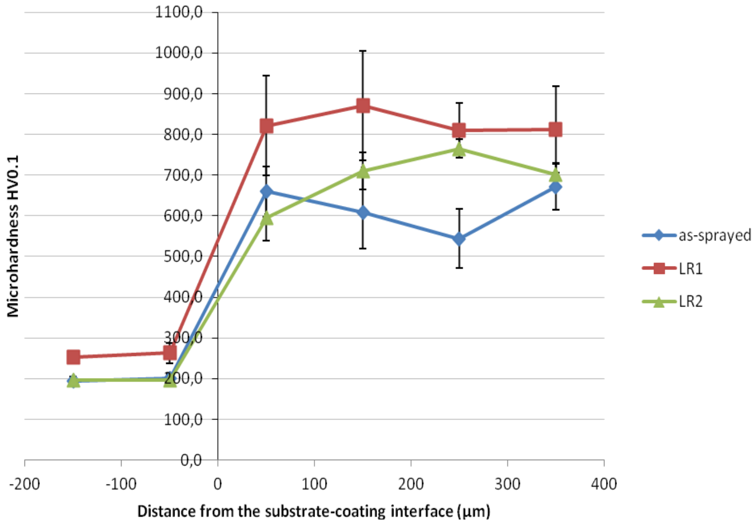

Figure 3. Dependence of microhardness HV0.1 on distance from the substrate-coating interface.

3.2. *Wear and abrasion resistance*

Graphs in Figure 4 revealed results of the sliding wear resistance measurement. Coefficient of friction (COF) which was evaluated according the ASTM G-133 remains the same for parameters LR2 as for the as-sprayed coating whereas the COF for LR1 parameters shows slight reduction. In wear coefficient (K) can be observed evident trend of decreasing K with increasing amount of laser treated coating layer. The completely laser remelted coating layer (Figure 2c) is beneficial for wear resistance of CoCrTaAlCSiY coating. It could be explained by vanishing of intersplat boundaries in laser remelted layer which avoided delamination of entire splats during wear test.

SEM images of wear tracks after ASTM G-133 are in Figure 5. The main wear mechanism of all specimens is abrasion and for the as-sprayed coating (Figure 5a) was additionally revealed partial delamination of individual splats as a consequence of intersplat decohesion (Figure 2a). Both wear mechanisms contributed to higher K for as-sprayed coating despite its lower microhardness.

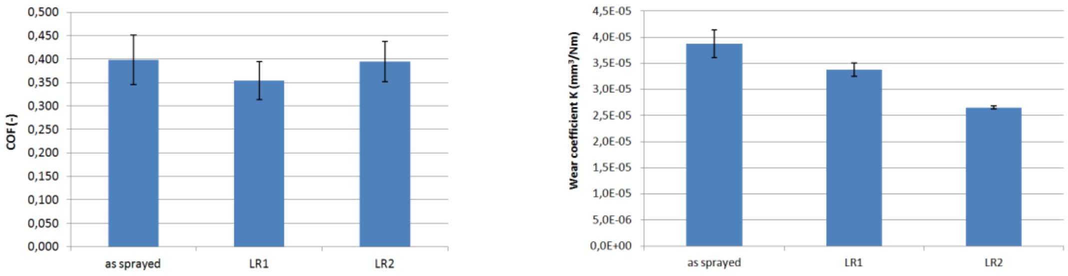

Figure 4. Coefficient of friction (COF) and wear coefficient K evaluated from ASTM G-133.

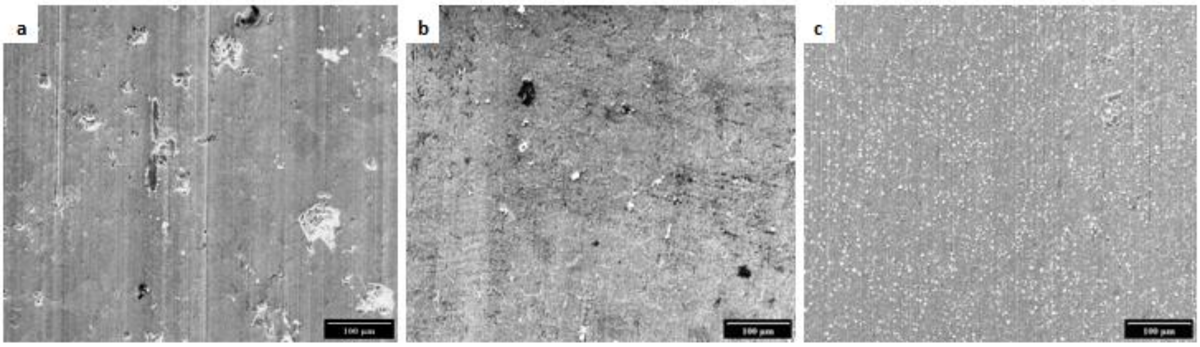

Figure 5. SEM of wear tracks for HVOF CoCrTaAlCSiY coatings: (a) as-sprayed, (b) laser parameters LR1, (c) laser parameters LR2.

Abrasive wear resistance was evaluated according the ASTM G-65 and the wear coefficient is plotted in Figure 6a. The beneficial effect of completely laser remelted coating layer was confirmed for LR2 parameters whereas parameters LR1 show slightly increased K which correspond to microhardness measurement.

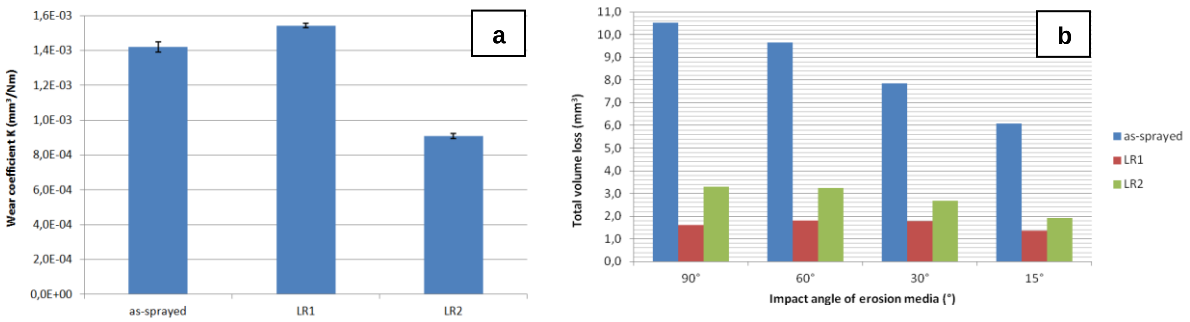

Figure 6. (a) Wear coefficient K evaluated from ASTM G-65 and (b) volume losses dependent on the impact angle of erosion media.

3.3. *Erosion resistance*

Total volume losses with dependency to impact angle of erosion media are reported in graph in Figure 6b. There is a significant improvement of erosion behavior for both laser treatment coatings. It could be explained as a consequence of enhanced internal coating cohesion and elimination of porosity after laser treatment. The reduction of volume losses is more pronounced for LR1 parameters which could be a consequence of higher microhardness, it means that more erosion particles reflect from the coating surface without any interaction with it. The tendency of decreasing volume losses with decreasing impact angle of erosion media is more or less evident for all specimens.

4. Conclusion

The aim of this study was to reveal tribological behavior of HVOF sprayed and laser treated CoCrTaAlCSiY coatings. An improvement of sliding wear resistance was proved for both laser parameters compared to as-sprayed coating. The specimen with parameters LR2 (higher specific energy) is characterized by significant reduction of wear coefficient which was also proved by ASTM G-65 wear test. The erosion test revealed beneficial influence of enhanced internal coating cohesion and elimination of porosity inside laser treated coatings. The consequence is markable reduction of volume losses for both laser parameters and all impact angles of erosion media. Enhanced erosion and wear behavior of both laser treated parameters is accompanied by higher microhardness. Further tests and especially the XRD analyses should be applied to reveal the phase composition of CoCrTaAlCSiY coatings.

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