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# Influence of Machining Process on Surface Integrity of Plasma Coating

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***Abstract*****—**For the required function of components with the thermal spray coating, it is necessary to perform additional machining of the coated surface. The paper deals with assessing the surface integrity of Metco 2042, a plasma sprayed coating, after its machining. The selected plasma sprayed coating serves as an abradable sealing coating in a jet engine. Therefore, the spray and its surface must meet high quality and functional requirements. Plasma sprayed coatings are characterized by lamellar structure, which requires a special approach to their machining. Therefore, the experimental part involves the set-up of special cutting tools and cutting parameters under which the applied coating was machined. For the assessment of suitably set machining parameters, selected parameters of surface integrity were measured and evaluated during the experiment. To determine the size of surface irregularities and the effect of the selected machining technology on the sprayed coating surface, the surface roughness parameters Ra and Rz were measured. Furthermore, the measurement of sprayed coating surface hardness by the HR 15 Y method before and after machining process was used to determine the surface strengthening. The changes of strengthening were detected after the machining. The impact of chosen cutting parameters on the surface roughness after the machining was not proven.

***Keywords*****—**Machining, plasma sprayed coating, surface integrity, strengthening.

## I. INTRODUCTION

THERMAL spray technology is a particle process in which effectively functional coatings are formed on the surface of parts with a thickness of approximately 50 μm. This technology is among the gradually evolving surface treatment technologies helping to create coatings with specific properties. Thermal spraying differs from other technologies by creating coatings that are not based on the deposition of individual atoms or ions. It involves the spraying of whole melted (or partially melted) droplets of material that only stick to surfaces located in the droplet trajectory. The structure of thermal-sprayed coatings is thus more or less heterogeneous, anisotropic, with microscopic pores and microcracks, irrespective of the spraying method and the material used. When applying thermal coating, the material in the form of a powder or wire is conveyed to a device (burner) where it is melted and accelerated towards the surface of the part. After the impact of the molten or partially molten particle, the particle spreads on the surface of the part and quickly solidifies. This leads to the particles becoming deposited in layers to create a coating with specific properties and a characteristic lamellar structure. Thermal sprays are suitable for wide use and allow the surface to be adapted to different operating conditions [1]-[3]. However, the functionality of thermal coatings depends on the correct technology selection and setting of the application parameters and on the technology of further treatment. When performing mechanical machining, it is necessary to take into account, in particular, the properties of the lamellar structure. These structures differ greatly from the same material in cast or mould condition and incorrect machining technology could damage the sprayed coatings. It is also important to consider their adhesion and the importance of the role of the mechanical anchoring to the substrate. Any interference with the surface of a relatively weak coating can significantly contribute to the breach or distortion of the mechanical anchoring. For this reason, it is very important to choose the right machining technology, the cutting tool and the cutting conditions under which the thermal coating will be machined. [1], [2], [8]

## II. METCO 2042: AN ABRADABLE SEALING COATING

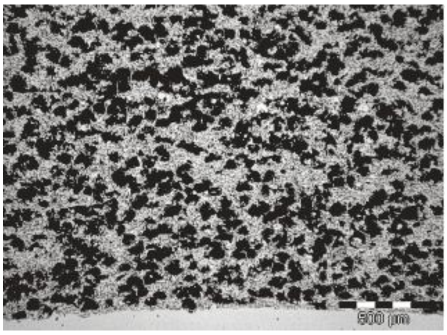

Fig. 1 Microstructure of the Metco 2042 Coating

The most commonly used thermally sprayed coatings in the aerospace industry include thermal barrier coatings (TBCs), anti-wear coatings and abradable coatings. Metco 2042 (CoNiCrAlY – boron nitride with polyester admixture) is a composite powder designed for the production of an abradable sealing coating. The coating is applied to the high-pressure jet engine compressor parts, where it minimizes the wear of the rotating blades, maximizes the efficiency of the gas flow and increases the efficiency of the device. The coated Metco 2042 provides better resistance to oxidation and corrosion compared to other abradable materials. The boron nitride component in the coating provides for good lubrication, improving its abradability and reducing the wear of the blade edge when it is in contact with the coating. The porosity of the coating is due

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to the amount of captured polyester in its structure. After removing the polyester by heat treatment, the porosity of the coating increases even more. To ensure sufficient adhesion of the Metco 2042 abradable coating to the substrate, Metco 480 NS bonding coating was applied between the coating and the substrate by means of thermal spraying. [4]

TABLE I
PROPERTIES OF THE METCO 2042 COATING [4]

| | |
|---|---|
| Chemical composition | 29% Co, 24% Ni, 16% Cr, 6% Al, 0,3% Y, 7% BN, 14% Polyester |
| Macrohardness – HR15Y | 58-65 |
| Coating porosity | 35 - 60 % |
| Coating density | 3.2 ± 0.2 g.cm$^{-3}$ |
| Operating temperature | ≤ 750°C |
| Gap size | 0.05 – 0.5 mm |
| Coating thickness | ≈ 3 mm |
| Technology of application | Plasma coating |

## III. TECHNOLOGY OF MACHINING THERMAL SPRAYED COATINGS

The correct choice of technology of thermal spray machining depends on the functionality of the parts to which thermal coating has been applied. The structure of thermal coatings is lamellar, formed by individual deformed particles (so-called splats), partially melted or unmelted particles, pores and oxidized particles. Thus, a large number of different hard and brittle phases (carbides, oxides, silicides, borides) that affect the machining process are present in the structure. Due to this structure of the thermal spray coating, the cutting is intermittent in interaction with the cutting tool. When machining the coating, the intermittent cut is the cause of adverse impact, leading to the rearrangement of the already existing coating tension, damage, or tearing away of the applied coating layers from the substrate. The cutting tool edge is also subjected to adverse effects during the machining of thermal sprayed coatings. The toughness of the coating, the occurrence of very hard phases and the reinforcement of the deposited particles cause an intense stress on the tool resulting in its rapid wear. By the right choice of tool geometry and cutting conditions, the wear of the tool can be avoided and the desired quality of the surface finish of the thermal coating can be achieved [5], [7].

## IV. EXPERIMENTAL MACHINING OF THE METCO 2042 THERMAL SPRAY COATING

Experimental machining of the Metco 2042 thermal spray coating was designed to minimize the impact and achieve the required quality of the machined surface of the coating. As a result of the cutting process, changes in mechanical properties, structural changes, defects, hardening and residual stresses occur in the surface layers. To determine the hardening intensity of the Metco 2042 thermal coating surface after machining, HR15Y, a method of measuring surface hardness before and after surface machining, was chosen. The influence of selected technology and machining parameters on the quality of the thermal coating surface was assessed on the basis of the measurement of the micro-roughness, namely the roughness parameters Ra and Rz. Due to the high porosity of thermal sprays and the presence of deep pores on the surface, the optical measurement method was used to determine the micro-roughness. For experimental machining of the Metco 2042 thermal coating, a test roller with a coating was designed, see Fig. 2. The structure of the coating and the pore size are in accordance with the standard and correspond to the spraying standard.

Fig. 2 Measured Sample with Applied Coating

In order to process the thermal coating, the longitudinal turning method was chosen, and the cutting tools and the cutting conditions were designed. Indexable sintered carbide cutting insert with geometry designation DCGT11T304F-AL, KX was chosen as the tool for the machining of the coating. It is an uncoated cutting insert with a positive geometry ($\alpha_o$ = 7°), with sharp edge microgeometry and a tip radius of 0.4 mm. This geometry is suitable for the machining of materials which have a tendency to mechanical hardening and especially to adhesion such as non-ferrous metals. An indexable sintered carbide cutting insert with geometry designation RCMT, CP500 was chosen as another tool. For this geometry, two sizes were used, with the designations RCMT0602M0-F1 and RCMT1002M0-F1. These cutting inserts are coated with a thin layer of PVD coating, have a positive geometry ($\alpha_o$ = 7°) and a radius of cutting edge curvature of 20-25 µm. CP500 is a tough fine grain carbide material suitable for finishing machining of steels and stainless steels. [6]

The choice of cutting conditions was based on the standard conditions for machining of thermal coating at Honeywell Aerospace Olomouc s.r.o. The set up parameters can be found in Table III.

TABLE II
GEOMETRY OF SELECTED CUTTING TOOLS

| | **DCGT11T30 4F-AL, KX** | **RCMT0602M0-F1, CP500**<br>**RCMT1002M0-F1, CP500** |
|---|---|---|
| **Cutting tool geometry** |  |  |
| Clearance angle - $\alpha_o$ | A | 7° |
| Tip radius - $r_\varepsilon$ | 0.4 mm | 3; 5 mm |
| Cutting edge radius | 0-5 µm | 20-25 µm |

## V.MEASURING THE HARDNESS OF METCO 2042

To determine the hardening of the surface layer of the coating, the hardness of the surface of the thermal coating was measured before and after machining. The measurement was made in a metallographic laboratory on the LECO LR-

300TDL hardness tester. The Rockwell method HR15Y was used to measure hardness. This method uses a steel hardened ball with a diameter of 12.70 mm as an indentor and is used to measure soft abradable coatings. Surface hardness was measured under the following conditions: [6]

- Minor Load $F_0$ – 3 kg (29.42 N)
- Major Load $F_1$ – 12 kg (117.6 N)
- Total Load F – 15 kg (147.1 N)
- Time – 3 s

TABLE III
SETTING OF CUTTING CONDITIONS

| **Cutting Parameters** | **Cutting Speed** <br> **$v_c$ [m·min$^{-1}$]** | **Feed** <br> **f [mm]** | **Depth of Cut** <br> **$a_p$ [mm]** |
|---|---|---|---|
| Standard | 250 | 0.06 | 0.2 |
| Cutting speed reduction | 150 | 0.06 | 0.2 |
| Cutting speed increase | 350 | 0.06 | 0.2 |
| Feed rate reduction | 250 | 0.03 | 0.2 |
| Feed rate increase | 250 | 0.09 | 0.2 |

Fig. 3 Scheme of the Sample Machining

Fig. 4 Used Hardness Tester LECO LR-300TDL

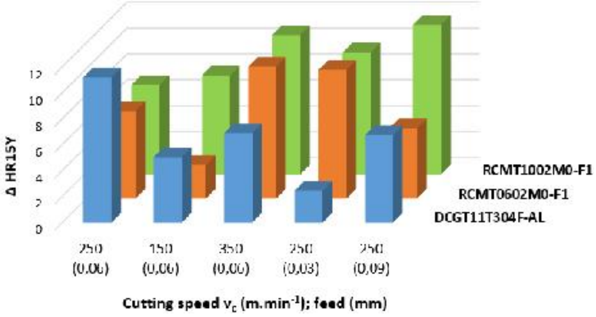

Fig. 5 Dependence of Tool Geometry and Cutting Conditions on Δ HR15Y

The intensity of the surface hardening of the thermal coating was determined from:

$$\varphi = \frac{\Delta H\ \ 1\ \ Y}{\Delta H\ \ 1\ \ Y_{\text{Б}}} * 100\ (\%) \qquad (1)$$

## VI. MEASURING THE ROUGHNESS PARAMETERS OF METCO 2042 COATING

To determine the impact of the chosen machining technology, cutting geometry and cutting conditions on the quality of the surface of the thermal spray coating, the roughness parameters Ra and Rz were measured. Due to the unevenness on the surface of the coating and the considerable porosity, a non-contact optical method was used to determine the surface micro-roughness. Measurement was performed on the Alicona Infinite Focus G5 optical microscope, see Fig. 6. The micro-roughness values were obtained by changing the focus during the vertical scanning of the surface of the thermal spray coating.

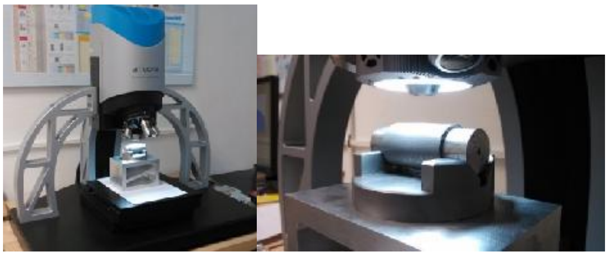

Fig. 6 Optical Microscope Alicona Infinite Focus G5

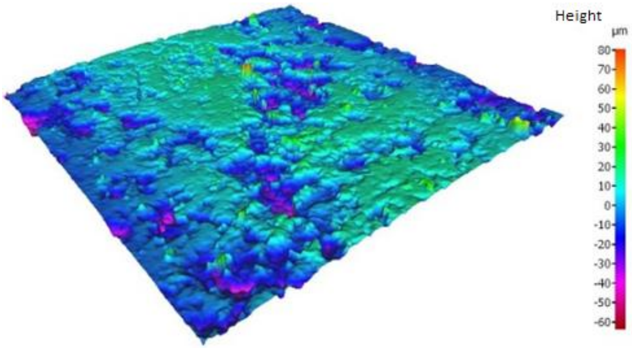

Fig. 7 3D Surface of the Machined Coating

## VII. CONCLUSION

Thermal spray coatings represent a modern surface treatment technology that produces functionally effective coatings used in many industries. Applying thermal spray coatings can optimally adapt the surface properties of components to operating conditions. Depending on the type of thermal spray coating, there is increase of surface resistance to stress, durability of the components and, in some cases, increase of efficiency of machinery (abradable thermal spray coatings in aircraft engines and turbines).

As mentioned in the introduction, the structure of the thermal spray coatings is lamellar, consisting of individual deformed particles, so-called “splats”, partially melted or unmelted particles. In addition to the conventional structural components, the spray coating structure contains a considerable number of pores, soft and in some places even hard phases. This structure is the cause of intermittent cut when machining in interaction with the cutting tool. This gives rise to impact stresses which, together with mechanical changes in the surface, can cause its deformation and thin layers of spray coating becoming torn away from the substrate. In order to prevent intense mechanical changes in the surface of the spray coating, machining technology, cutting tool geometry and cutting conditions were designed for experimental operation.

TABLE IV
MEASURED HR15Y HARDNESS DATA

| Cutting Speed | Feed | Depth of Cut | Cutting Geometry | Tip Radius | Strength. ϕ |
|---|---|---|---|---|---|
| Sample no. | HR15Y $_{\text{(BEFORE)}}$ | HR15Y $_{\text{(AFTER)}}$ | Δ HR15Y | $\bar{\Delta}$ HR15Y | |
| 250 m·min$^{-1}$ | 0.06 mm | 0.2 mm | DCGT11T304F-AL | 0.4 mm | 17.3% |
| 1. | 61.14 | 75.6 | 11.46 | 11.21 | |
| 2. | 67.84 | 78.8 | 10.96 | | |
| 150 m·min$^{-1}$ | 0.06 mm | 0.2 mm | DCGT11T304F-AL | 0.4 mm | 7.6% |
| 3. | 67.54 | 75.40 | 7.86 | 5.05 | |
| 4. | 64.50 | 66.74 | 2.24 | | |
| 350 m·min$^{-1}$ | 0.06 mm | 0.2 mm | DCGT11T304F-AL | 0.4 mm | 10.6% |
| 5. | 64.18 | 69.66 | 5.48 | 6.90 | |
| 6. | 65.42 | 73.74 | 8.32 | | |
| 250 m·min$^{-1}$ | 0.03 mm | 0.2 mm | DCGT11T304F-AL | 0.4 mm | 3.6% |
| 7. | 64.48 | 64.96 | 0.48 | 2.43 | |
| 8. | 68.98 | 73.36 | 4.38 | | |
| 250 m·min$^{-1}$ | 0.09 mm | 0.2 mm | DCGT11T304F-AL | 0.4 mm | 10% |
| 9. | 63.00 | 72.30 | 9.30 | 6.73 | |
| 10. | 70.44 | 74.60 | 4.16 | | |
| 250 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT0602M0-F1 | 3 mm | 10.6% |
| 11. | 62.04 | 64.1 | 2.04 | 6.75 | |
| 12. | 64.82 | 76.26 | 11.44 | | |
| 150 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT0602M0-F1 | 3 mm | 3.8% |
| 13. | 64.86 | 69.26 | 4.4 | 2.58 | |
| 14. | 70.74 | 71.5 | 0.76 | | |
| 350 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT0602M0-F1 | 3 mm | 15.2% |
| 15. | 63.82 | 75.80 | 11.98 | 10.17 | |
| 16. | 69.46 | 77.82 | 8.36 | | |
| 250 m·min$^{-1}$ | 0.03 mm | 0.2 mm | RCMT0602M0-F1 | 3 mm | 14.9% |
| 17. | 70.18 | 78.06 | 7.88 | 9.92 | |
| 18. | 62.18 | 74.14 | 11.96 | | |
| 250 m·min$^{-1}$ | 0.09 mm | 0.2 mm | RCMT0602M0-F1 | 3 mm | 7.9% |
| 19. | 67.78 | 75.40 | 7.62 | 5.41 | |
| 20. | 68.46 | 71.66 | 3.20 | | |
| 250 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT1002M0-F1 | 5 mm | 10.1% |
| 21. | 70.66 | 75.14 | 4.48 | 6.91 | |
| 22. | 66.28 | 75.62 | 9.34 | | |
| 150 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT1002M0-F1 | 5 mm | 11.2% |
| 23. | 70.06 | 77.36 | 7.30 | 7.63 | |
| 24. | 65.32 | 73.28 | 7.96 | | |
| 350 m·min$^{-1}$ | 0.06 mm | 0.2 mm | RCMT1002M0-F1 | 5 mm | 16.6% |
| 25. | 69.28 | 77.32 | 8.04 | 10.76 | |
| 26. | 60.36 | 73.84 | 13.48 | | |
| 250 m·min$^{-1}$ | 0.03 mm | 0.2 mm | RCMT1002M0-F1 | 5 mm | 13.9% |
| 27. | 64.48 | 78.40 | 13.92 | 9.41 | |
| 28. | 70.98 | 75.88 | 4.90 | | |
| 250 m·min$^{-1}$ | 0.09 mm | 0.2 mm | RCMT1002M0-F1 | 5 mm | 17.6% |
| 29. | 63.90 | 77.24 | 13.34 | 11.55 | |
| 30. | 67.02 | 76.78 | 9.76 | | |

TABLE V
MEASURED VALUES OF ROUGHNESS PARAMETERS

| | Sample no. | Ra (µm) | Rz (µm) | Sample no. | Ra (µm) | Rz (µm) |
|---|---|---|---|---|---|---|
| | **1.** | 7.54 | 58.48 | **16.** | 6.47 | 67.23 |
| | **2.** | 8.85 | 62.23 | **17.** | 7.58 | 64.96 |
| | **3.** | 10.29 | 73.96 | **18.** | 7.32 | 80.21 |
| | **4.** | 9.53 | 70.24 | **19.** | 6.69 | 51.75 |
| **Filter: Lc = 2.5 mm** | **5.** | 4.97 | 42.09 | **20.** | 5.87 | 55.32 |
| | **6.** | 5.53 | 48.23 | **21.** | 4.99 | 44.36 |
| | **7.** | 5.22 | 40.82 | **22.** | 5.37 | 52.12 |
| **Measured Length: ln = 12.5 mm** | **8.** | 6.35 | 49.41 | **23.** | 6.24 | 49.68 |
| | **9.** | 6.67 | 46.65 | **24.** | 5.98 | 51.39 |
| | **10.** | 7.11 | 55.34 | **25.** | 4.58 | 52.70 |
| | **11.** | 6.30 | 66.05 | **26.** | 4.27 | 49.11 |
| | **12.** | 5.92 | 58.71 | **27.** | 4.36 | 44.75 |
| | **13.** | 5.67 | 55.45 | **28.** | 5.13 | 48.79 |
| | **14.** | 6.84 | 57.35 | **29.** | 8.23 | 56.91 |
| | **15.** | 7.02 | 51.01 | **30.** | 7.47 | 53.48 |

For longitudinal turning of the spray coating, cutting tools and geometry were chosen to meet all the requirements for efficient machining of materials such as thermal spray coatings. In both cases, sintered carbide tools with fine grain structure and positive geometry were chosen. Different size of tool tip radius rε and its design (uncoated tip with cutting edge radius of 0-5 µm vs. coated tip with a cutting edge radius of 20–25 µm) should lead to the desired results in determining the hardening and quality of the surface of the thermal spray coating.

The values of surface hardness measured by Rockwell HR15Y method before and after the machining process clearly show that there has been a partial impact on the surface and that its hardness has changed. This change may have been due to a number of mechanical changes in the surface when machining the spray coating, but it must also be taken into account that the hardness of the spray coating increases with decreasing thickness. From the experimental measurement of the hardness of the coating surface, no direct dependence can be drawn between the chosen geometry of the tool and the cutting conditions designed. However, it is necessary to choose a cutting tool, geometry and cutting conditions so that the load during the machining of the hardened surface layer does not exceed the value of the coating’s mechanical anchoring to the substrate.

Depending on the selected machining parameters, the quality of the machined surface of the thermal spray coating was also evaluated. The roughness parameters Ra and Rz were measured to determine surface roughness. The measured values of surface roughness of the spray coating surface correspond to the requirements of the aviation standard. However, when machining parameters changed, no significant improvement or deterioration of surface roughness was noted. This may be due to the fact that the Ra and Rz roughness parameters are not suitable for assessing the surface quality of materials such as thermal spray coatings due to their considerable porosity. A much more telling value of the micro-roughness found on the surface of thermal spray coatings is expressed by the material share, the so-called Abbot curve.

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