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Technology of Thermal Spray Coating Machining

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Abstract**—**This article is focused on the thermal spray coating machining issue. Those are irreplaceable in many areas of nowadays industrial branches such as aerospace industry, mostly thanks to their excellent qualities in production and also in renovation of machinery parts. The principals of thermal spraying and elementary diversification are described in introduction. Plasma coating method of composite materials – cermets – is described more thoroughly. The second part describes thermal spray coating machining and grinding in detail. This part contains suggestion of appropriate grinding tool and assessment of cutting conditions used for grinding a given part. Conclusion describes a problem which occurred while grinding a cermet thermal spray coating with a specially designed grindstone and a way to solve this problem.

Keywords**—**Coating, aerospace, plasma, grinding.

I. Introduction

CONTINUOUSLY increasing requirements for quality, durability and accuracy of components produced for the energy, automotive or aerospace industries also carry higher requirements for manufacturing technologies and materials, from which these components are made. In these specific industries high requirements that are placed onto these components' functional properties cannot be achieved by common machining processes. Often we are forced to use modern technologies that are not quite common, and that we can encounter at specialized workplaces only, to produce these parts. A way to achieve required properties of function planes is application of thermal coating to surface of these parts.

Thermal coating represents a modern technology that creates functionally effective coating (ceramic, metal-ceramic and metal). These flexible, high quality and economical technologies allow optimum adaptation of part properties to operational conditions. Resistance against wear and operational reliability increase is achieved by application of such coating to the parts. Increased durability lowers the necessity to exchange such parts and thus brings financial advantages and better economy of the production process.

Especially important aspect, in the selection of suitable thermal coating technology, is primarily protection of the surface, where focus is placed on traditional ways of application of such thermal coating. However, new applications that focus on functional properties of a given surface start appearing currently. These methods of thermal coating then offer an alternative between using thin coatings and volume materials to engineers [1], [4].

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II. Principle of Thermal Coating

Thermal coating is a particle process, during which coating is created. The material applied this way is in the form of powder (sometimes wire) that is brought a device, where it is melted and accelerated towards a part being coated. When it is applied to the part, such particle spreads areally and solidifies quickly. This creates coating that has characteristically laminated structure and specific properties. However, complete diffuse joining of the sprayed material with substrate is not achieved. Adhesion of sprayed particles usually occurs by mechanical adherence and attachment of sprayed particles, by their cooling and contraction, as well as by physical processes. Connection of the coating and substrate by melting or diffusion may occur (for example in meltable alloys or vacuum sprayed coatings), if immediately during spraying or after it, melting or diffusion thermal coating process occurs. A temperature of the part at the place of coating stays deeply under the temperature of phase-structure changes (approx. 80 – 120°C), which prevents undesirable part deformations. Coated surfaces are usually 50μm to several millimeters thick [1], [5].

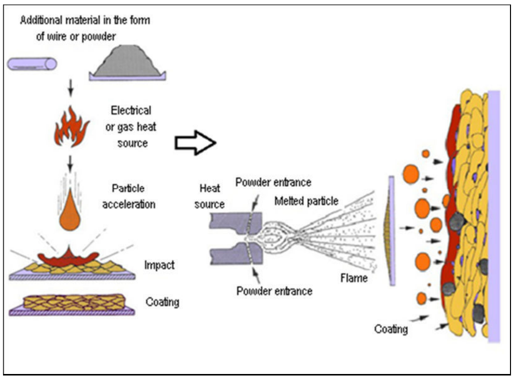

Fig. 1 The scheme of thermal coating [1]

As opposed to other coating technologies, thermal coating is not based on deposition of individual atoms or ions. Whole droplets of melted or partially melted material fall onto surface and stick only to surfaces that lay along their trajectories. In comparison with PVD or CVD deposition methods, thermal coating has a high deposition velocity and wide range of additional materials. The thermal coating technology allows creating coating on practically all types of substrates from such types of ceramics, metals and their alloys that do not disintegrate under their melting points. Structure of thermal coating is more or less heterogeneous and anisotropic with microscopic pores and micro cracks, without regard to the method of coating and used material. A range of different solid phases occur, for example, oxides, carbides, borides, silicides and others [1], [7].

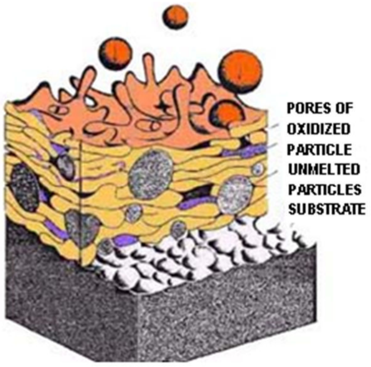

Fig. 2 The scheme of thermal coating structure [1]

To melt additional materials heat energy is necessary for thermal coating. Its source can be a combustion process or electrical energy. Individual types of thermal coating can be differentiated according to equipment design and used energy source.

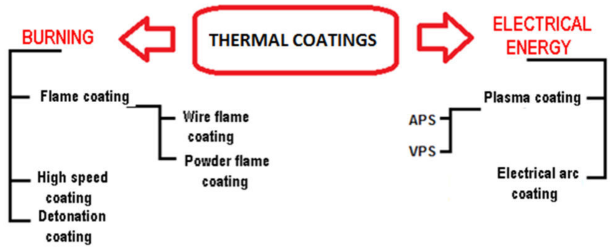

Fig. 3 Basic division of thermal coating types according to energy source

III. Plasma Coating Technology

In the experimental part we created coating that was applied by plasma spraying to the part surface. Plasma coating is characterized as a technological process, where an electric arc burns between water cooled tungsten cathode and a cylindrical copper anode that is a plasma burner nozzle at the same time. The electric arc burns in plasma gas (argon or another inert gas). The plasma gas is axially brought into a burner, from which high temperature plasma (up to 20 000 K) and enthalpy comes out on the other end. Applied material is brought into the burner by carrier gas. In atmospheric application of APS coating high plasma temperature can cause oxidation, phase composition change or burn-out of some components of applied material during coating. In order to achieve extremely high density, adherence and purity of coating it is possible to apply the coating in vacuum or VPS in the chamber under very low pressure (usually 0.005-0.02 MPa). The main difference in plasma method coating techniques lies in chemical activity of the environment, to which the applied material is exposed [1], [5].

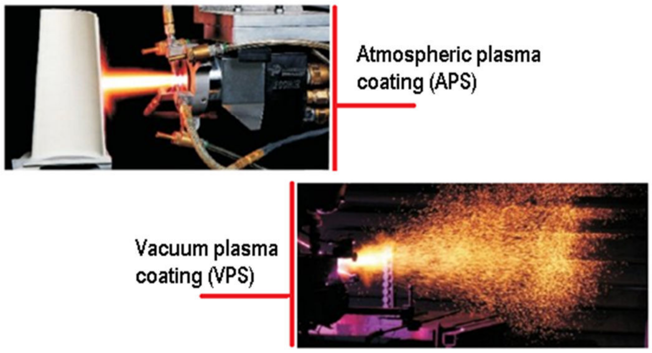

Fig. 4 Plasma coatings [8]

IV. Coating Materials

When performing thermal coatings requirements placed on coating functions, for example wear, corrosion and temperature resistance, are ensured by using a suitable type of additional material. The plasma coating method allows using of practically any material that is stable up to the melting temperature for coating. This technology is suitable to spray metals, most ceramics and cermets. Most devices use additional materials in the form of powder or wire.

Cermet coating is made from powder composed of two different materials. It is composite material that is composed from metal and ceramic matrices. Connection of these materials creates cermet with optimum properties, high temperature resistivity, hardness and toughness. The metal matrix is composed of metals like nickel, molybdenum, cobalt, chrome and their alloys. Ceramics are most often represented by tungsten, chrome or titanium carbides that provide wear resistivity [2], [6].

V. Plasma Coating Experimental Testing Design

Functionality of parts with thermal coating is influenced by proper selection of technological procedure of additional modifications or finish after coating. During finishing or modification of thermal coating it is primarily necessary to take laminar structure properties into account. This structure significantly differs from the structure of the same material in the cast or molded form. Common ways of finishing, suitable for cast or molded materials, would probably damage thermal coating.

Hard thermal coatings based on cermet are materials very hard to machine. They excel by their high wear resistance under high temperatures and create wear resistant, hard and strong surfaces that are corrosion resistant even under high temperatures. These surfaces usually do not require any additional modifications. If finish is required, it is primarily due to ensuring of higher quality surface. Created coatings are relatively thin; therefore it is important to propose a suitable finishing method that would ensure functionality of a given part [5].

VI. Thermal Coating Characteristics

The powder designated as Metco 81 VF-NS was selected for coating. It is a mixture of small chromium carbide particles and nickel and chrome powder. Its chemical composition is 75% Cr_3C_2, 20% Ni and 5% Cr. The melting temperature is about 1400°C. The coating is characterized by high wear resistance, strength and corrosion resistance under the operational temperatures of 540-815°C. It meets requirements for the finished part by combination of these properties. Metco 81 VF-NS creates thin, dense, hard and smooth anti-oxidation surface. This coating is so good that it is not necessary to further finish it in any way in most cases. Metco 81 VF-NS is applied to the part surface by the Meteo Plasma Flame Spray Systems plasma coating method [3].

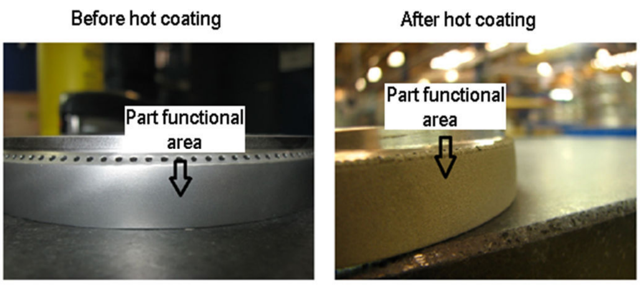

Fig. 5 Part with thermal coating

The part intended to be thermal coated is made from the Haynes 230 material. It is metal heat resistant alloy used primarily in the aircraft industry. Thermal coating with the thickness of 0.4 to 0.5mm is applied to the outer round surface (see Fig. 5). It is not easy to achieve exact thickness of the plasma thermal coating that is why two values are specified. After finishing of the components remains on the coating layer of a thickness of 0.3 mm on the part. The reason for coating is proper function of the part in operation, when the coated part touches the counterpart that performs rotational movement. Coating prevents damage of the part substructure due to friction that is between the parts.

Commonly this coating is not modified in any way. Usually it is used to protect base material against corrosion, high temperatures and other stress. However, if it is necessary to maintain surface quality, the coating needs to be suitably finished. Since here the focus is on the quality of surface with certain coarseness, it needs to be processed mechanically - by chip machining.

VII. The Proposed Machining Technology of Thermal Coating - Grinding

High demands are usually placed on function plane quality of parts made of hard-to-machine materials, both from the point of view of geometrical accuracy, and quality (coarseness) of the surface. That is why a new technology of machining of thermal coatings needed to be designed that would meet requirements placed on shape, dimensions and quality of machined surface, and that would ensure effective and economical production of the part at the same time.

Grinding technology appears the most suitable for finishing of super hard coatings. It is recommended both by coating manufacturers and technologists, who encounter these questions in practice. For hard-to-do machining of thermal coatings this technology is preferred ahead of chip machining methods, primarily due to less stress placed onto the coating in comparison with, let us say, machining. Grinding is advantageous, economical way of machining by multiple-blade tool with geometrically undefined cutting edges presented by abrasive with grains joined by binding material. This type of grinding can achieve very high quality surface and high geometrical accuracy of shape and dimensions. It can take away smaller amount of material that is why it is used primarily for finishing work.

A. Selection of Machining Equipment and Tools

Pre-requisition of grinding was a guarantee of part finishing without consequent necessary repairs of finished surface. However, it was necessary to select optimum cutting conditions, including suitable machining equipment and a tool. The proper selection lied primarily in objective evaluation of the effect of individual conditions that will influence effective meeting of production quality, productivity and economy requirements. Grinding of thermal coatings can be done on powerful rigid machining machines with suitable tools. Thus for grinding of cermet coating the Springfield 25E – CROWN CNC grinder with a diamond grinding disk that is used to grind hard materials, like cermets, was selected. During its design we needed to follow mechanical and physical characteristics that are specified by the manufacturer for the Metco 81 VF-NS coating. This primarily means the correct type of grinding material, size of grinding grains, hardness of the wheel, its structure and the binder that binds the grinding particles. Also the shape of grinding wheel was important, since the area of the coated part (see Fig. 5) is rounded with the 62mm radius. A plane rounded this way could not be ground by any of commonly available grinding wheel shapes. Therefore it was necessary to special make a wheel that would correspond to required conditions and parameters.

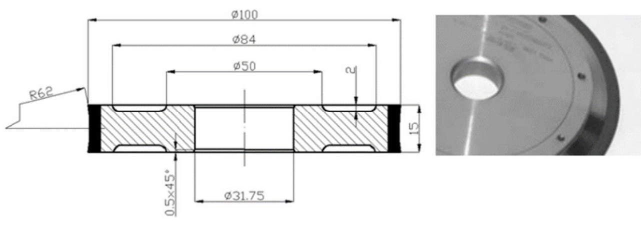

Fig. 6 The grinding wheel 1FF1V 100 – 15 – R62 – 31.75 D126 Ni [9]

The WINTER Company that specializes in grinding wheel production was selected as the wheel manufacturer. Its task was to supply such grinding wheel that would ensure effective production of the part with special focus on the quality of thermal coated surface. The wheel consists of a rotational steel body that has a diamond grinding layer galvanized to it. The requirement was that the grinding plane would have the shape negative to the ground part surface, and that the ground surface would meet the coarseness parameter Ra 0.8 µm. The selected grain size of grinding wheel followed this requirement. Three grinding wheels with different grain sizes were offered according to the FEPA standard and used finishing method. The WINTER company supplied the PKD wheel designated 1FF1V 100 – 15 – R62 – 31.75 D126 Ni and the D 126 grain size with the average grain size of 118µm [9], [10].

TABLE I
GRAIN SIZES ACCORDING TO THE FEPA (ISO 6101) STANDARD [10]

Ra [µm]	Use	FEPA Grain size
0.8	Power grinding and roughing operations	D126
		D107
		D91

B. Setting of Cutting Conditions

The affectivity of diamond wheels to large extent depends on their correct selection and way of use. Diamond wheels can be used with cooling or without it; however, they function better when processing liquid is used. Water prevents overheating of surface and also base material, significantly lowers the amount of harmful dust, helps to remove chips from the cutting location and extends service life of the grinding wheel.

During selection of suitable cutting conditions we followed recommendations of the manufacturers of thermal coating powders and materials. Cutting speed while grinding is usually several times faster than for machining and has significant influence on resulting quality of the machined material surface. The speed of movement of grinding wheel into the cut must be compensated by increase of cutting speed. When selecting revolutions, we followed diamond wheel recommended parameters. Approximate values needed to be chosen that followed values prescribed for thermal coating. Even though it was not easy to determine these cutting conditions, since the used grinding wheel had specific shape and dimensions. From this followed that the most effective cutting conditions for grinding of cermet thermal coating were to be set experimentally during the grinding process. All cutting conditions, i.e. wheel revolutions, ground part revolutions and movement speed, were gradually based on testing and practical experience.

TABLE II
THE PROPOSED CUTTING CONDITIONS

$\mathbf{v_k}$	2200 m.min^{-1}
$\mathbf{v_s}$	16 m.min^{-1}
$\mathbf{f_d}$	0.076 mm
$\mathbf{d_k}$	100 mm
$\mathbf{d_s}$	124 mm
$\mathbf{n_k}$	7000 min^{-1}
$\mathbf{n_s}$	40 min^{-1}

C. Progress and Evaluation of Grinding

Grinding of the part was outer diameter grinding, therefore the main movement was towards axis of the machined part. This means that the recess grinding method was selected, in which the grinding wheel cuts a 0.1 – 0.2mm of coating layer from the part surface. In the recess method the whole length of the part is ground by a wheel, whose width is a little wider than the part. 10 pieces were ground this way, and then their surface roughness, whose values should have corresponded to the entered value of Ra 0.8µm, was measured. Each part's roughness was measured 3 times by the Hommel Tester T 500 roughness meter and the averages were calculated.

TABLE III
THE MEASURED AVERAGE VALUES OF THE RA ROUGHNESS PARAMETER

Part no.	11	12	13	14	15	16	17	18	19	20
Ra [µm]	0.78	0.79	0.80	0.80	0.72	0.75	0.77	0.79	0.79	0.80

VIII. CONCLUSIONS AND THE DIRECTION OF FUTURE RESEARCH

Thermal coating plays important role in a number of industrial branches. Thermal coating technologies are irreplaceable and play a key role in both original production, and in renovations. Their practical impact on the quality of products lies mainly in technical and economical improvement of use characteristics.

Characteristics and use of thermal coatings applied to part surfaces are in part influenced by the correct selection of technological finish procedure. In order to meet required quality the applied thermal coat needed to be ground. The main problem lied in insufficient theoretical knowledge of machining of a given coating. Hard cermet coatings create a group of materials, for which suitable cutting conditions, under which machining can be most effective, are not quite known. Manufacturers of these modern materials recommend certain parameters; however, these parameters can be different under actual operating conditions. The values of acceptable cutting conditions can be determined only while machining these materials. However, even with correctly proposed cutting conditions there were problems with surface micro geometry. The machined surface continually showed unacceptable roughness of the part functional planes. A solution of this problem was to design a new grinding wheel with finer structure. This resulted in achievement of required surface roughness by thermal coat grinding.

During closer investigation of this problem it was found that grain size of the first wheel that should, according to the standard, guarantee the Ra 0.8µm surface roughness, was sufficient. The WINTER Company supplied a wheel that was able to guarantee required roughness, however, while grinding with longitudinal movement. That is why, during selection of cutting conditions, it is important to select also proper direction of grinding movement that, according to measured values, also affects final quality of the machined surface.

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Current list of R&D results at: http://innet.vsb.cz/profily/cs/nov92/vedeckovyzkumnevystupy.