CURRENT TRENDS IN THICK COATINGS DEPOSITION AND APPLICATIONS

HOUDKOVÁ Šárka

Research and Testing Institute, Pilsen, Czech Republic, EU

Abstract

In the paper, the technologies of thermal spraying and laser cladding are briefly described. The traditional methods are reminded and compared with lately developed ones. The technologies are discussed in terms of their application and coatings materials. The advantages of hybrid coatings are presented, indicating the possible future trends of surface modification technologies. The examples of coatings microstructure and measured properties are shown to demonstrate the differences between them and highlight their main features.

Keywords: Thermal spray, laser clad, hybrid deposition processes

1. INTRODUCTION

The technologies of surface modification govern wide range of procedures, addressing various purposes. The most common is the enhancement of wear resistance and corrosion protection, but also other functional properties, such as protection against high temperature, modification of electrical or heat conductivity or compatibility with biological tissues. Essentially, two basic attempts are used to modify the surface properties. First is based on modification of substrate sub-surface layers microstructure, usually by heat treatment or alloying, or by their combination. Technologies of surface hardening, case hardening or nitriding are the typical examples. The second possibility is to add material of different composition and properties on the surface, building a coating. Various types of coatings were developed during time being, making the choice of suitable one for specific application rather difficult. Nevertheless, the coatings can be distinguished according to their purposes, e.g. high temperature protection, or according to the principle of their deposition. In the paper, the attention is paid to the group of so called “thick” coatings, including the thermal sprayed and laser clad coatings. At the end, the advantages of hybrid coatings are presented, indicating the possible future trends of surface modification technologies.

2. THERMAL SPRAY COATINGS

The technology of thermal spraying is well known and widely used in many branches of industry. Its history dates from the beginning of 20th century, when the metal deposition was patented by dr. M. U. Schoop [1]. Up to know, the original technology developed in a wide range of spraying processes. They are usually distinguished according to the source of heat, used for melting of material and it’s accelerating towards the substrate [2]. The flame spraying (FS), electric arc spraying (AS), plasma spraying (PS) and high velocity spraying (HVOF, HVAF) can be classified as the traditional spraying technologies. They are utilized in many branches of industry, providing the common wear and corrosion protection (HVOF, HVAF, PS), high temperature protection (HVOF, HVAF, PS) or more advanced functions such as thermal barrier coatings (PS) or abradable coatings (FS).

In the last decade, several significant innovations appeared in the thermal spraying branch. The development concerns both the spraying equipment and materials.

Cold spray (CS) technology, invented in the Institute of Theoretical and Applied Mechanics in Russia during 1980s by Papyrin [3], spread up not only for deposition of soft metals, but also for advanced materials and applications [4, 5, 6, 7]. The technology of cold spraying is based on the very high velocities of the particles, impacting the surface, while their temperature is kept under the temperature of phase transformation. Such conditions enable to avoid the some of the typical unwonted features of thermal spraying, such as presence of oxides and pores [5, 6, 8].

As in the other material processing technologies, the unique properties of micro- and nano- scale materials are became the point of interest in the field of thermal spraying. Conventional thermal spray technologies, such as HVOF or APS (Atmospheric Plasma Spraying) are not able to deposit the micro or-nanoscaled coatings. To overcome it, the suspension spraying was developed, firstly patented in 1997 by University of Sherbrooke [9]. While the principle of spraying remains the same, the powder is fed into the spraying equipment (both HVOF or PS) dispersed into the liquid. The coatings, deposited by suspension HVOF or suspension PS, exhibits superior properties and enables to broaden the application range. The suspension plasma spraying was up-to know tested for many applications, such as [10]: oxide coatings for TBC, ceramics for medical applications, solid oxide fuels cells, TiO based coating with photocatalytic properties, ceramics wear resistant coatings etc.

3. LASER CLAD COATINGS

Laser cladding belongs to the group of thermal spray processes. It utilizes the energy of laser beam to melt the feedstock powder. On the contrary to other thermal spray processes, it melts simultaneously the substrate material, creating the metallurgical bond between the substrate and the coating (**Figure 1**). The group of materials, that can be laser clad, and also the applications area, is partly similar to HVOF. The comparison between these two technologies was previously done [11, 12]. Both the technologies are namely focused on the deposition of wear a corrosion resistant coatings and coatings for sliding applications. The metal, metal alloys and MMC (Metal Matrix Composites) with different kinds of hard phases are the material suitable for both HVOF and laser clad deposition.

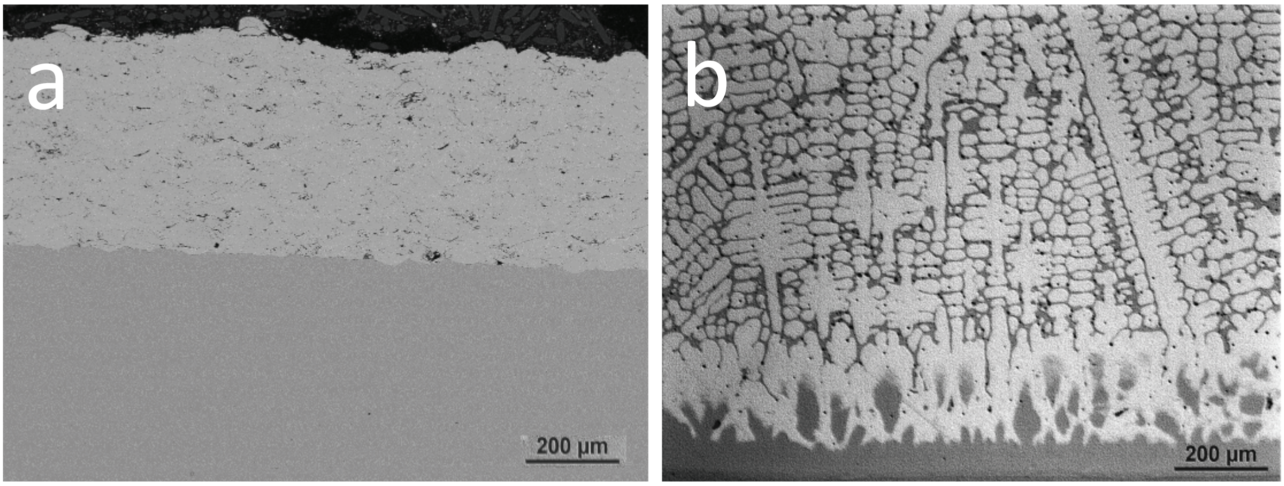

Figure 1 Boundary between Stellite 6 coating and steel substrate a) HVOF sprayed; b) laser clad

In some applications, both HVOF and laser clad technologies can be used to meet successfully the requirements. In that case, the economical aspects are decisive. In the **Table 1**, the comparisons of economical aspects that are taken into consideration while the deposition technology is chosen are summarized. Up to know, the HVOF spraying is more beneficial if large areas have to be covered, while laser cladding can offer better solution in the case of geometrically complicated parts is supposed to be coated.

Table 1 Economical aspects of HVOF and laser cladding technology

Procedures	Thermal Spray	Laser clad
Surface preparation	Masking, grid blasting	Cleaning
Material consumption	50% efficiency	95% efficiency
Power and working gas consumption	Working and carrying gases	Working and carrying gases
Deposition time	lower	4-5 x higher
Finishing	Grinding	Grinding

4. HYBRID AND COMPOSITE COATINGS

After many years of intensive research and development, the possibilities of current surface treatment technologies are coming across their limits. Nevertheless, the requirements of increasingly advanced components on the surface function properties are still more demanding. The now-a-days surface engineers react to such challenge by combination of different, previously self-contained technologies.

Two attempts can be adopted in combining the surface treatment technologies:

i) The processes take parts at the same time - “hybrid coatings”
ii) The surface treatment follows each other - “composite technologies”

The laser assisted cold spraying (LACS) belongs to the already established hybrid technologies. The main advantage of cold spray technology consists in almost zero oxidation during deposition thanks to the low temperature of flying particles. On the other hand, the same low temperature is responsible for low ductility of certain metal alloys, which led to a low spray-ability. To enlarge the group of materials, which can be deposited by cold spray, the laser power is used to i) preheat the substrate, soften it and remove the oxide layer from its surface and ii) heat up the particles at the moment of impact to make them more ductile [13]. By LACS, the non-conventional materials can be deposited - in [14], the hydroxyapatite is deposited for biomedical applications.

The in-situ laser remelting during spraying can significantly increase the cohesion of coating and consequently its functional properties. The details can be found in the work of IRTES-LERMPS (France) group, For example, in-situ laser remelting during APS spraying of NiCrBSi coating is described in [15].

The deposition of thermal barrier coating (TBC) is one of the most challenging topic of surface engineering. Traditionally, the TBC are prepared by plasma spraying technologies. Recently, hybrid technologies providing the TBC with potentially better functional properties are became a topic of interest. To fill the gap between the plasma sprayed TBC coating, which are relatively thick, and conventional vapor phase processes, such as electron beam physical vapor deposition (EB-PCD) with the disadvantage of low deposition rates, the hybrid technology Plasma Spray - Physical Vapor Deposition (PS-PVD) was introduced [16, 17]. It enables to produce the columnar-structured strain-tolerant TBC with columnar structure.

In order to generate advanced multilayer thermal and environmental protection systems, a new deposition process is needed to bridge the gap between conventional plasma spray, which produces relatively thick coatings on the order of 125-250 microns, and conventional vapor phase processes such as electon beam physical vapor deposition (EB-PVD) which are limited by relatively slow deposition rates, high investment costs, and coating material vapor pressure requirements. The use of Plasma Spray - Physical Vapor Deposition (PS-PVD) processing fills this gap and allows thin (< 10 μm) single layers to be deposited and multilayer coatings of less than 100 μm to be generated with the flexibility to tailor microstructures by changing processing conditions.

Combined technologies cover a wide range of surface treatment processes. The most widespread is the combination of laser treatment with previously deposited coating. Such technology is sometimes called Two-step laser deposition (2SLD) or Two-step laser cladding. The coating can be deposited by various technologies of thermal spraying - HVOF, PS, FS, Cold spraying, etc. The microstructure of thermal spraying always contain certain amount of pores, cracks, intersplat boundaries or other features, which can be considered as a disadvantage in some types of applications. The laser remelting process increases the homogeneity of the coating and improves its cohesive strength. The depth of remelting is dependable on the laser process parameters, namely laser power, laser beam scanning velocity [18]. The enables to create a coating with remelted layer with previously determined thickness. The advantage of such attempt compare to laser clad is the lower heat input to the substrate material, lower deformation due to the solidification shrinkage or elimination of degradation of coating material by dilution. Sometimes, the partial remelting of PS sprayed ceramic coatings enables to preserve the coating flexibility during deformation of coated parts, which is one of the benefits of lamellar splat structure of thermally sprayed coatings.

Some coating materials can improve their behavior due to the thermal post treatment, particularly laser remelting. The improvement of influence of laser remelting process on the HVOF sprayed NiCrBSi coating microstructure and tribological properties were described in [19]. It can be seen from the **Figure 2**, that not only porosity and splat boundaries were eliminated, but also precipitation of hard phases was promoted.

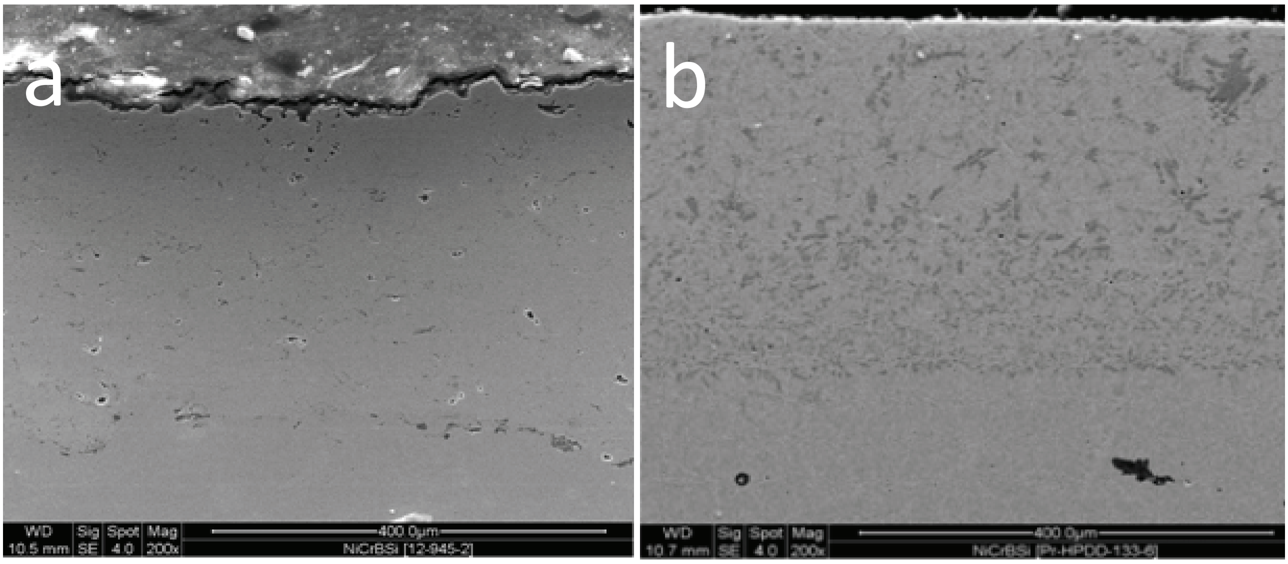

Figure 2 The cross section of NiCrBSi coating a) HVOF as-sprayed; b) HVOF + laser remelted

The microstructural changes, responsible for changes of tribological behavior, was also obserned for HVOF spread Co-based Stellite coating, remelted by HPDD laser [20]. The laser post-treatment changed the ratio between phase content in the Co-based solid solution, as well as the grain size. The microstructural changes enables the Co-based coating to undergo the stress-induced martensitic transformation during sliding wear, which results in and significant increase of coating wear resistance (**Figure 3**).

The significant wear resistance improvement was also recorded for surface treatment, consisting of cold spraying of autenitic steel, combined with laser remelting and followed by plasma nitriding. The sliding wear resistance of such surface treatments increased the sliding wear resistance more than twice [21].

Another promising example of combined processes is to use surface laser texturing (SLT) process to create the pattern with defined geometry on the surface of coated part. The patterns can replace traditional grid blasting surface preparation and increase the thermal/cold sprayed coatings adhesion [22].

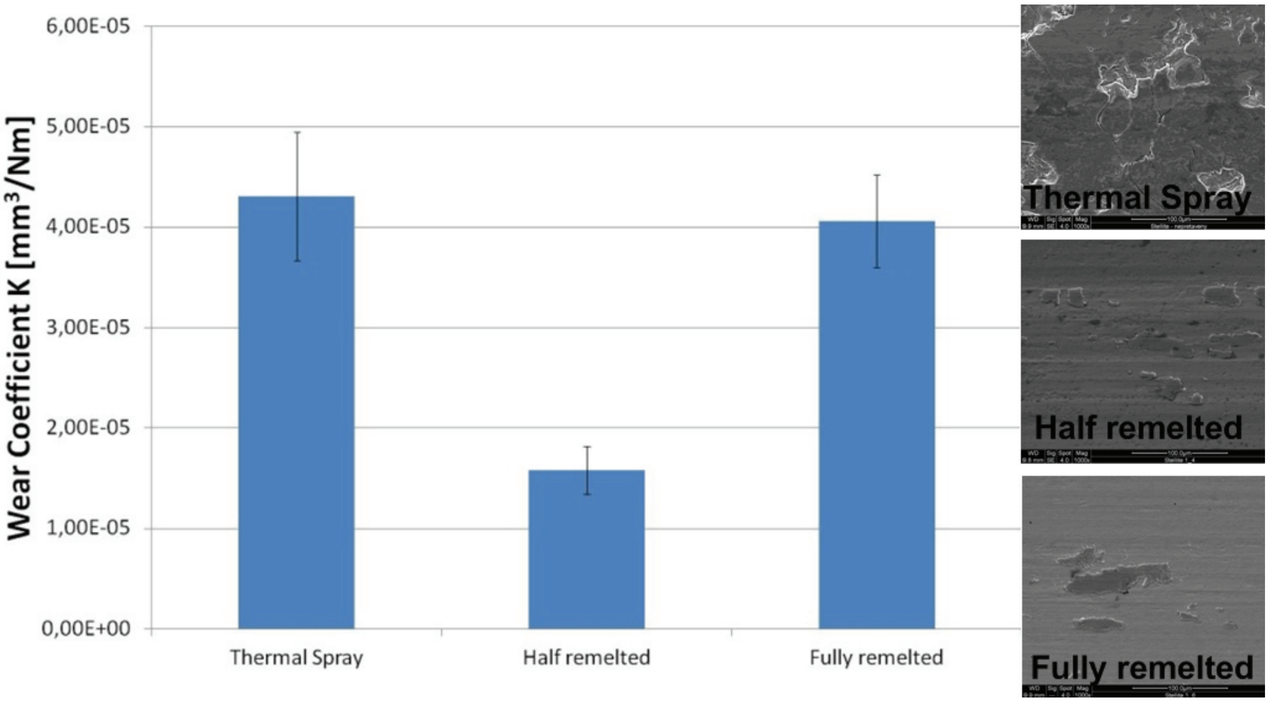

Figure 3 The improvement of sliding wear behavior of Co-based HVOF sprayed coating by laser remelting with controlled laser parameters

5. CONCLUSION

In the paper, the overview of current trends in thick coatings development is shown, focused namely on thermal spray and laser clad coatings. In last decade, the increasing requirements of advanced application forced the surface engineers to increase the functional properties of coatings to their limits. The further improvement can be achieved by combination of existing technologies, introducing hybrid and combined processes, developing the tailored surface structures for specific application.

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