Possibilities of using thermally sprayed coatings for surface treatment of rail vehicles components

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Abstract. Thanks to their versatile properties and economical applicability, thermally sprayed coatings are being used in more and more areas of industry. Within the research project, suitable alternatives are being sought for the replacement of surface treatments of selected components of rail vehicles with thermal spraying. The aim is to increase the functionality and service life of selected parts and thus the entire vehicle. Based on the requirements for the functional properties of components, variants for the material and technology of thermal spraying are selected. Technologies considered include HVOF, TWAS, FS, and APS, materials include Fe, Ni, Zn, and Mo based alloys; WC and CrC based cermets. The basic functional properties of these coatings are analyzed and discussed. The further steps of the work to test suitability of these coatings for selected applications and are outlined.

1 Introduction

There are several methods and technologies for coatings formation, as well as an almost unlimited number of materials suitable for the application of surface layers. To correctly choose the suitable coating layer, it is necessary to know the application of the part, the method of loading and types of acting stresses, the working environment and expected lifespan of the part. [1, 2, 3].

Thermal spraying is a general term for forming metallic or non-metallic coatings with the thickness usually greater than 40 μm. The filler material (in the form of powder, wire, or rods) is partially melted using a heat source. It can be electric arc, plasma, or flame. The heated and molten particles are accelerated towards the surface either by process gases or by atomizing nozzles. Due to the high kinetic energy, the particles are anchored on a roughened surface. This creates a bond with the surface of the substrate and the particles form a so-called lamellar structure [1, 2, 3, 4, 5].

The main advantage of thermal spraying technologies is the wide range of materials that can be used to produce desired coatings. Practically any material that does not disintegrate below the melting point can be used. The second major advantage is the ability of most thermal sprays to apply coatings to the substrate without significantly thermally affecting the substrate surface. The third advantage is an ability to repair worn or damaged coatings in most cases without changing the properties or dimensions of the components [2].

The disadvantage of thermal spraying might be then the nature of the application technology. It is practically impossible to apply the coating to small or deep cavities and holes.
This work is a part of the project “Increasing of resistance of rail vehicle components by the means of modern thermal spraying technologies”. The goals of the work are following: 1) to consider the types of loading of selected rail vehicle components, 2) choose suitable candidates for coating materials and technology for applying surface treatment, 3) optimize the thermal spraying application and in detail analyze the functional properties of the coatings and components with the new applied surface treatment.

2 Types of loading of selected parts
Within the research project, the surface treatment of several selected parts of rail vehicles is taken into consideration to be replaced by thermal spraying technologies. The parts are now used without surface treatment or with a surface treatment that can be significantly overcome by replacing by the new type. There are types of parts with similar loading.

The type of parts is located outside the vehicle, with a large surface area. The representative example would be “walkable footplates” which are located on the front of the vehicle. The main load of these parts is mainly external influences such as salt, water, rain, and aerodynamics action. The part will be further affected by stones because the area is walkable. The magnitude of the force will depend on the weight of the person when the weight of the person is calculated to be 200 kg. These parts require protection against external environment and basic protection against abrasion and erosion by stones, weather, and walking. For these parts, the state of the surface after the coating application has to be taken into account, as it is the final surface treatment and the parts would be used in the as-sprayed state.

Another type is parts of the vehicle chassis. These parts are loaded again with external influences as well as with the higher forces resulting from their function in the chassis. An example would be the “handle” which is a part that secures the wheelset when lifting the chassis or the whole vehicle. The force acting on the handle depends on the weight of the wheelset. The surface area requiring protection for these parts is not large, but the applied coating has to withstand significantly higher forces, moreover high resistance against abrasion and friction wear is required.

Another representative of loading would be a combination of pivot with high demand on hardness and abrasion resistance with a combination of its counterpart with a low friction coefficient.

3 Selected thermal spraying technologies and materials
Within the thermal spraying group, there are several technologies with differ in operating temperature, speed of molten particles, amount of additional material, etc. The technologies can be distinguished by the type of heat source. The first group utilizes electric energy – the examples are Twin Wire Arc Spray (TWAS), Atmospheric Plasma Spray (APS) or Vacuum Plasma Spray (VPS) The second group utilizes the combustion of mixed fuel and oxygen – examples are High Velocity Oxygen Fuel (HVOF), Detonation spraying (D-Gun) or Flame Spray (FS) [1, 2, 3].

In this work, the four technologies available at Research and testing institute in Pilsen are considered to be used for treating components of rail vehicles. These technologies are HVOF, TWAS, APS, and FS. The HVOF typical characteristics are high coating density and low porosity, low oxidation rate in a flight of particles and, compressive residual internal stress, while the drawbacks are high noise level and higher costs. Typical applications are coatings with high wear resistance, oxidation, or chemical resistance even at high temperatures. The materials commonly sprayed are superalloys based on Ni, Co, Fe, carbides based on WC or CrC and MCrAlY. The TWAS typical characteristic is high deposition efficiency but high porosity, low cost, mobility, possibility of hand-spray and low noise. Typical applications are corrosion protection sliding surfaces, surface renovation (adding worn-out material), materials commonly used are metal alloys (Fe, Ni, Cu, Al, and Zn based).

The biggest advantage of APS is high temperature enabling the spraying of ceramic materials. Other typical characteristics are high deposition efficiency, high cost and high noise level. Typical
applications are thermal barrier coatings (TBC), wear-resistant ceramic base coatings, corrosion resistance. Typical coating materials are ceramics, carbides based hard-metals, abradable coatings, and alloys based on Ni, Co, and Fe.

The FS typical characteristics are high deposition efficiency, low adhesion, high porosity, low cost, low noise, and the possibility to hand-spray. Typical applications are wear and corrosion protection, surface renovation. Typical coating materials are Fe and Ni-based alloys, abradable coatings, self-fluxing alloys.

The selected materials considered for surface treatment are listed in Table 1. For a high demanding application for wear and corrosion resistance, the WC-CoCr and Cr$_3$C$_2$-NiCr sprayed by HVOF or flame sprayed NiCrBSi are selected. For corrosion and sufficient wear protection of large parts, Fe based stainless steel, Fe based alloy, or ZnAl sprayed by TWAS are chosen. For applications demanding good sliding properties along with sufficient wear resistance, Mo sprayed by TWAS and APS are selected.

| Coating material | Form   | Technology | Commercial designation |
|------------------|--------|------------|------------------------|
| Mo               | Powder | APS        | Amdry 313X             |
| NiCrBSi          | Powder | FS         | FST 771.33             |
| WC-10Co4Cr       | Powder | HVOF       | Woka 3652              |
| Cr$_3$C$_2$-25NiCr | Powder | HVOF   | Amperit 588.074        |
| Mo               | Wire   | TWAS       | W400.1                 |
| Fe13Cr           | Wire   | TWAS       | W504.1                 |
| Zn15Al           | Wire   | TWAS       | Zinacor                |
| Fe-based alloy   | Wire   | TWAS       | Metco 8294             |

4 Coating microstructure and properties

The microstructure of HVOF sprayed WC-CoCr and Cr$_3$C$_2$-NiCr coatings are depicted in Figure 1. Both coatings represent typical microstructure for HVOF coating, high density with minimal porosity, vaguely distinguished individual splats, absence of cracks. These carbide-based coatings have the highest hardness and wear resistance of presented coatings. The surface hardness HRC is 59 ± 2, the microhardness on cross-section HV0.3 is 1170 ± 15 for WC-CoCr. The Cr$_3$C$_2$-NiCr has surface hardness HRC is 54 ± 4, the microhardness on cross-section HV0.3 is 948 ± 69.

![Figure 1. WC-CoCr (left) and Cr$_3$C$_2$-NiCr (right)](image)

The microstructure of NiCrBSi coating sprayed by FS is depicted in Figure 2. It shows typical features of the microstructure of FS sprayed coatings, i.e. higher porosity and easily distinguishable
individual splats, and the occasional occurrence of un-melted particles. The surface hardness HR15N is 78 ± 2, the microhardness on cross-section HV0.3 is 810 ± 57.

![Figure 2. NiCrBSi FS sprayed](image)

Zn15Al has very good corrosion resistance in the atmosphere and immersion in either fresh or saltwater. This coating offers better corrosion resistance than either pure zinc or aluminum, by combining advantages of both materials. ZnAl coating sprayed by TWAS, presented in Figure 3, has a very fine microstructure with almost zero porosity and without the occurrence of cracks or other defects. Differentiation of individual splats is possible only at higher magnification. The surface hardness HR15Y 85 ± 2. To comparison, the TWAS sprayed stainless steel Fe13Cr has a structure more typical for TWAS coatings, easily distinguished splats, and higher porosity. The surface hardness HR15N is 79 ± 1.

![Figure 3. TWAS sprayed Zinacor (left) and Fe13Cr (right)](image)

Molybdenum coatings are widely used as surface treatment due to their high wear and scuffing resistance and excellent sliding properties. Molybdenum coating deposited by the TWAS method (depicted in Figure 5) is without noticeable defects in the form of cracks. There is significant porosity on the boundary of individual splats. For comparison, the Mo coating sprayed by APS is depicted in Figure 5. There is also significant porosity, nevertheless, the bottom layer of the coating is more densified, the splats are smaller. The surface hardness HR15N of Mo coating sprayed by TWAS or APS is in the same range, is 67 ± 3.
Conclusion

The paper presents possible alternatives to the surface treatment of components for rail vehicles. The demands and expected types of loading and stresses acting on the selected parts are shortly discussed. Then, the four thermal spraying methods which are considered for these applications are presented, the technologies are HVOF, TWAS, APS, and FS. Based on the requirements of individual parts, the suitable coating materials were chosen, the materials include WC and CrC based carbide coatings for hard abrasive resistance coatings, Fe and Zn based alloys, and Mo for low friction applications. The microstructure of these selected coating sprayed above mentioned technologies was presented, along with surface hardness microhardness on cross-section, which represents some basic functional properties of the coatings. Based on preliminary results, the potentially suitable coatings for selected components were chosen. For each component, at least two coatings variants will be applied. The treatment of selected components is underway. For the components located outside the vehicle, with a large surface, the Fe and Zn based coatings are chosen. They provide sufficient protection and the spraying by TWAS is easily adjustable to spray these components. For the components requiring high wear and corrosion resistance, the HVOF sprayed cermet coatings or Flame sprayed NiCrBSi coating is considered. For applications demanding good sliding properties along with sufficient wear resistance, Mo coatings are selected. The sprayed components along with components treated with current methods will be tested for corrosion resistance in salt fog. Further, the abrasion and erosion resistance of the applied coatings will be tested. The most suitable surface treatment for selected parts will be considered for series production.

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