

Development of a shear-tensile testing method to qualify metal spraying technologies

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Abstract. The metal spraying is widely used process to extend the resistance against to wearing, erosion or corrosion. The related standard defines these surface protective methods as special processes because these cannot be qualify by a non-destructive testing method which clearly states the fulfilment of the requirements of a given work. Therefore the quality of the given surface protective method can be determined only during the later use. The main goal of this work is to define a control method which can be used for qualify the given metal spraying method. In our work the used base material as carrier material was P235GH steel and we investigated 6 different metal sprayed layers. To avoid the stress concentrator areas (small cracks) on the surface before the test the surface was grinded and EDM was used to cut out the samples from the manufactured work pieces. To investigate the properties of the sprayed layers tensile tests were used. From the data the strength of the composites and the layers can be calculated. Based on the shear-tensile test we created a calculation method which can be used to qualify the metal spraying methods before its use.

1. The metal spraying

The thermal spraying technologies like metal spraying is widely used for manufacturing or repair/maintenance works in the industry. The main goal of the metal spraying is to create such a layer which is improve the resistance against to wearing, erosion, cavitation, corrosion or the combination of the mentioned damage methods. Therefore the metal spraying technology extend the surface properties and reconstruct the geometrical dimensions of the given part.

The concerning standards (MSZ EN ISO 9000, MSZ EN ISO 14922 [1]) define the surface protective processes as special processes because these cannot be qualifying by a non-destructive testing method during the manufacturing which clearly states the fulfilment of the requirements of a given work. Therefore the quality and the possible mistakes of the given metal spraying method can be determined only during the later use. Because of this it is heavily necessary a method especially during the manufacturing which properly qualify the given work.

There are some researches research about the shear testing of the sprayed coatings and the bonding between the carrier material and the layer which gives the bond stress and the shear strength of the tested material as a result. The results are very promising in every case but the main disadvantage of these methods that they needs a special testing equipment therefore they can not be executed on a classical universal material testing machine [2-4].

A wide range of the thermal spraying method is known and used in the industry which is summarized by the MSZ EN 657:2005 [5] but 5 processes (Powder flame spraying (PFS), Wire flame spraying



(WFS), Arc spraying (AS), Plasma spraying in atmospheric condition (APS), High velocity oxygen fuel (HVOF)) are current. In this study we investigated only two of them which we discuss in detail. In the case of some technology the melting of the wire or powder executed by the same method as the arc welding [6] (in the case of AS) or as the plasma nitriding [7] (in the case of APS).

Powder flame spraying (PFS)

The PFS (Figure 1.) is the most common metal spraying technology worldwide by using oxygen-acetylene or propane heating gas. During the process the sprayed powder is being heated in plastic or melted condition and shot on the surface of the carrier material by the heating gas. Two different technologies are distinguished: warm and cold spraying. In the case of warm spraying the carrier material is preheated to 200-250°C and therefore no primer layer is needed in front of cold spraying where a nickel-base primer layer is used. The velocity of the powder is relative small (40-100 m/s) therefore the manufactured layer can be porous.

Arc spraying (AS)

In the case of AS (Figure 2.) two wires are dosed simultaneously and between them an electrical arc is created to melt the top of them like in the case of arc welding. The used wires can be similar or different materials as well. The melted drops are shot by gas on the surface by the velocity of 100-130 m/s (max. 200 m/s) which is similar to the WFS.

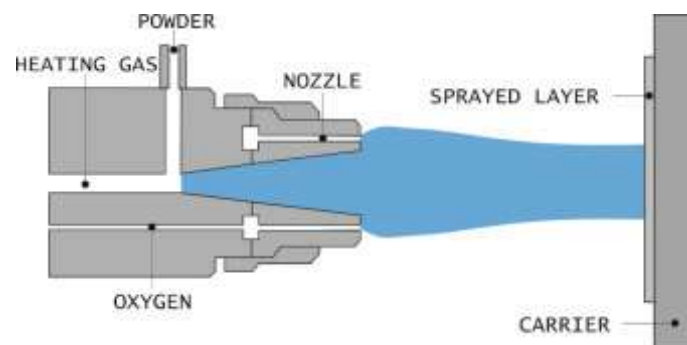


Figure 1. Schematic illustration of the powder flame spraying (PFS)

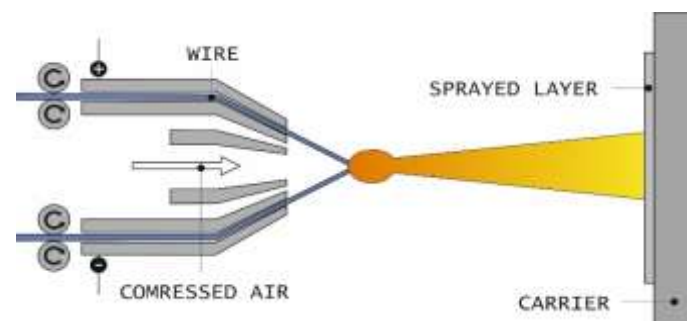


Figure 2. Schematic illustration of the arc spraying (AS)

2. Materials and methods

In our work P235GH micro alloyed steel was used as carrier material (Figure 3.) with the thickness of 5 mm. As metal spraying we used 6 different technology/material combinations (Figure 4.). Table 1. shows the used technologies, materials and the thickness of the sprayed layers.

Table 1. The technologies, the materials and the thickness of the sprayed layers.

Sample	Technology	Primer layer	Layer	Layer thickness (mm)	Comment
A	AS	Kasamas KLD 75	Kasamas KLD 60	0.45-0.55	-
B	AS	Kasamas KLD 75	Kasamas KLD 60	1.45-1.95	-
C	AS	-	Soudokay 848M	1.65-1.75	-
D	PFS	-	Böhler UB5- 2545	1.35-1.45	free deformation
E	PFS	-	Böhler UB5- 2545	1.35-1.45	blocked deformation
F	PFS	UTP EB-1003	Metco 130	1.65-1.75	-

The main difference between the applied coating is the coating material and the thickness of the sprayed layer. In the case of sample A, B and F a primer layer was used which helps the bonding between the carrier material and the coating. In the case of sample C, D and E it was not necessary to use this primer layer. By the samples A-B and D-E the spraying technology and the applied materials were same the only difference is the thickness of the coatings. In the case of sample D and E because of the nature of the applied technology (Powder flame spraying (PFS)) the carrier heated and deformed. By the sample D this deformation was not blocked but in the case of sample E we fixed the carrier to avoid that.

To avoid the stress concentrator areas (small cracks) on the surface before the test the surface was grinded and EDM (Electrical discharge Machining) was used to cut out the samples from the manufactured work pieces (Figure 5.). As testing method a shear-tensile testing was used this was performed on a MTS 810 hydraulic materials testing machine at 1 mm/min speed rate. The elongation of the samples was monitored by Mintron video extensometer. To avoid the damage of the layer during the holding special sample geometry was used (Figure 6.). Before the test the main dimensions of the samples were measured.

To determine the properties of the carrier material a non-sprayed sample was investigated by the mentioned shear-tensile method. The test itself is a tensile test but because the plane of the applied load is out of the plane of the carrier-layer bonding the tensile load will result shear load in the boundary layer as well. Table 2. shows the measured and calculated values of the carrier material.



Figure 3. Plate from the carrier material

Figure 4. Metal spraying on the carrier surface

Figure 5. Grinded and EDM cut sample.

Figure 6. Prepared sample for the shear-tensile test with the holding accessories.

Table 2. The properties of the P235GH carrier material.

Upper yield stress (MPa)	$R_{p0.2}$ (MPa)	Tensile strength (MPa)	Elongation, A (%)	Contraction, Z (%)	Young's modulus, E (GPa)
294	291	407	39	60	2,18x10 ⁵

The first cracks in the sprayed layers appear at the first maximum peak of the tensile diagram which is the border between the elastic-plastic behaviour. At this point the measured force consist of two parts: the force of the carrier material and the force of the sprayed layer (Figure 7-8.).

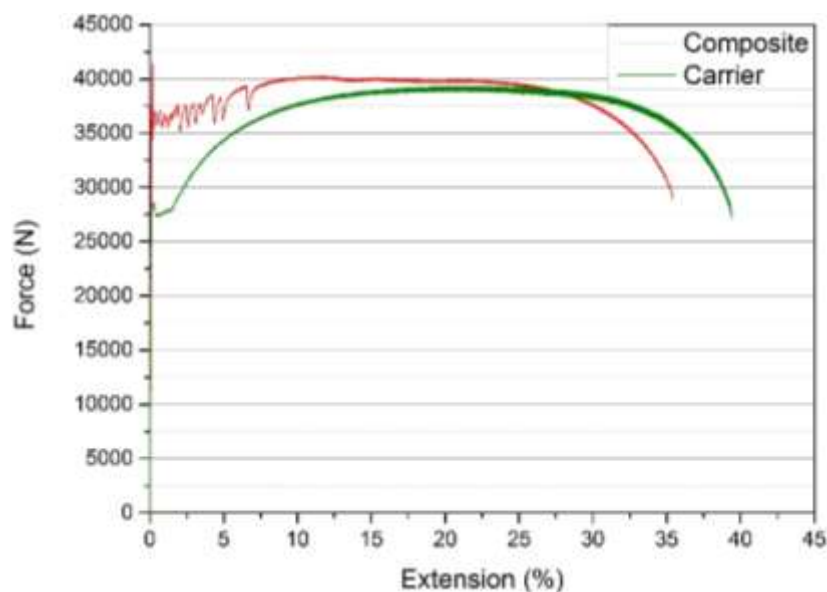


Figure 7. The force-elongation diagram of the carrier material and the carrier-sprayed layer composite by the shear-tensile test.

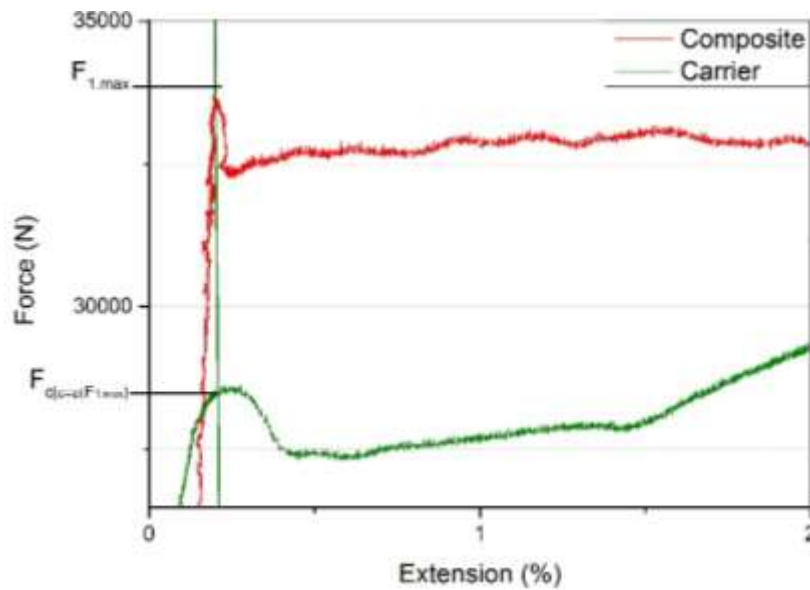


Figure 8. The beginning of the force-elongation diagram with the values for the calculations.

Due the pre-tests the mechanical properties of the carrier material are known therefore the strength of the sprayed layer can be calculated:

$$\sigma_{layer} = \frac{F_{1,max} - F_{c|\varepsilon=\varepsilon(F_{1,max})}}{S_{0,layer}}$$

where $F_{1,max}$ is the first maximal peak where the first cracks appear on the layer, $F_{c|\varepsilon=\varepsilon(F_{1,max})}$, is the force of the non-sprayed carrier material at the same elongation which was at $F_{1,max}$, $S_{0,layer}$ is the cross section of the sprayed layer.

For the comparison of the samples, the average stress in the carrier-sprayed layer composites can be determined at the first cracking in the sprayed layer using the following formula:

$$\sigma_{composite} = \frac{F_{1,max}}{S_{0,composite}}$$

where $F_{1,max}$ is the first maximal peak where the first cracks appear on the layer and $S_{0,composite}$ is the cross section of the composite.

3. Results

The mentioned testing method was performed on the samples which results shows a sizeable difference between the variant spraying materials and technologies.

Sample A (AS, Kasamas KLD 75+Kasamas KLD 60, thin layer)

The sprayed layer showed rigid behaviour, the cracks was appeared in the whole volume of the layer. After the first cracks the layer did not added strength to the composite. Before the contraction some larger piece of the sprayed layer removed from the carrier surface which means bad connection between the carrier and the sprayed layer. At the contraction the layer fully removed (Figure 9.).

Sample B (AS, Kasamas KLD 75+Kasamas KLD 60, thick layer)

In the case of sample B the sprayed layer started to peel from the carrier at the plastic zone therefore it was fully removed at the end of the shear-tensile test. It can be concluded that the applied materials and spraying parameters do not meet the requirements (Figure 10.).

Sample C (AS, Soudokay 848M)

The sprayed layer showed rigid behaviour, the cracks was appeared in the whole volume of the layer. After the first cracks the layer did not added strength to the composite. Before the contraction some larger piece of the sprayed layer removed from the carrier surface which means bad connection between the carrier and the sprayed layer. At the contraction the layer fully removed (Figure 11.).

Sample D and E (PFS, Böhler UB5- 2545)

The sprayed layer resulted significant increasing in the measured force in the elastic and the plastic zone as well. When the first crack was appeared a remarkable drop was seen on the tensile diagram. The connection between the sprayed layer and the carrier material is appropriate which is certified by the secondary cracks in the layer which was perpendicular to the direction of the tensile (Figure 12-13).

Sample F (PFS, UTP EB-1003+ Metco 130)

The sprayed layer showed rigid behaviour, the cracks was appeared in the whole volume of the layer. During the test the layer was removed from the carrier. The sprayed layer was very porous (Figure 14.).



Figure 9. Sample A after the shear-tensile test.



Figure 10. Sample B after the shear-tensile test.



Figure 11. Sample C after the shear-tensile test.



Figure 12. Sample D after the shear-tensile test.



Figure 13. Sample E after the shear-tensile test.



Figure 14. Sample F after the shear-tensile test.

4. Summary

The main advantage of the studied shear-tensile test method is it can be performed on a universal testing machine therefore it does not need any special testing equipment. Based on our results it can be concluded the presented testing-calculation method is appropriate to investigate and qualify the different metal spraying technologies right after the manufacturing process. With the discussed calculation method the different sprayed layer materials can be measured indirectly.

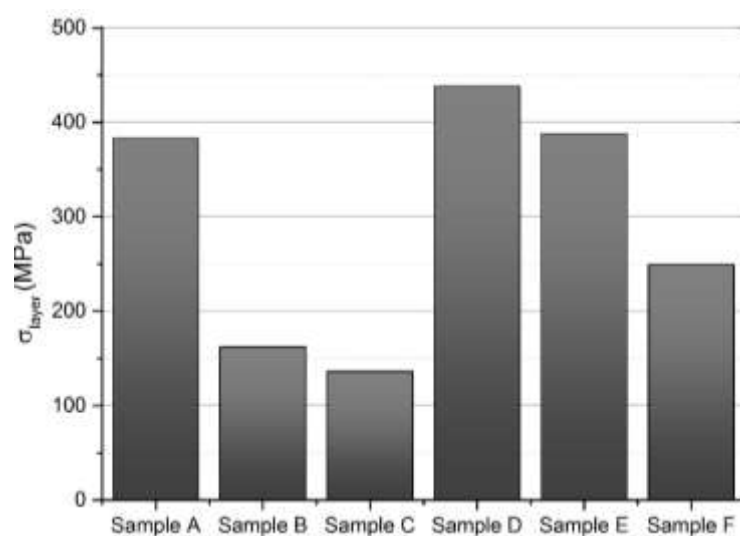


Figure 15. The calculated stresses in the sprayed layers.

In the case of the investigated spraying technologies with different powder or wire material can be seen that the PFS technology resulted more strength and more adhesive layers (Figure 15-16.).

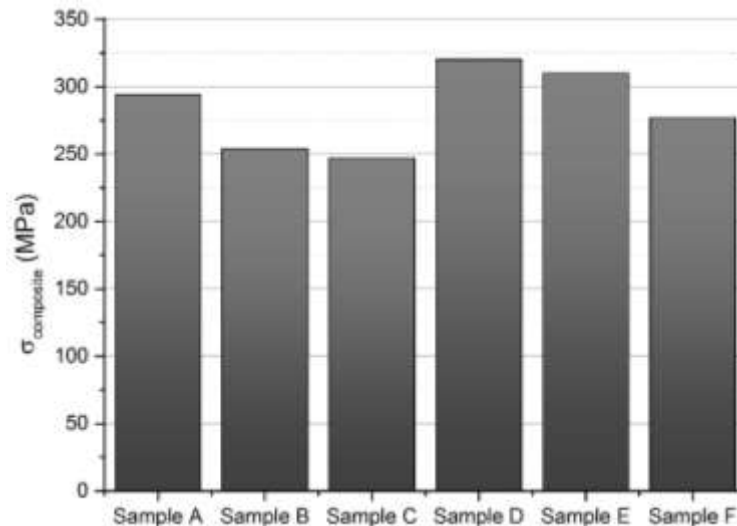


Figure 16. The calculated stresses in the carrier-sprayed layer composites.

References

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