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Experiential learning - creation and testing of sprayed coatings

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ABSTRACT: Engineering graduates' generic high degree skills can be developed only by experiential learning. The main opportunity for acquiring these skills is the course work or final thesis. Coating the parts made by arc spray causes serious problems. The thermal arc sprayed coatings should have high tribological properties, hardness, Jung's module, corrosion resistance and wear behaviour. Sprayed coating properties depend on wire materials and technological parameters. Analysis of coating properties data reveals to student the influence of technological parameters and the sort of spray materials on the properties of the coatings. It is possible for students to estimate the relationship between the spray parameters and coating properties, coating resistance to abrasion, corrosion, contamination by oxide inclusions, etc. This article focuses on work carried out by students during their Master degree studies. This experiential learning project has proved to be successful in its aims associated with practical skills and the use of modern technological equipment, and to be an effective motivator for research-based projects.

INTRODUCTION

The thermal spraying processes have a wide ranging utilisation in both manufacturing and maintenance. Arc spraying (AS) is a process in which finely divided metallic surfacing materials are deposited in a molten condition on a prepared substrate to form a spray deposit. The thermal spraying gun generates the necessary heat by using an electric arc. With the wire arc process, two consumable wire electrodes connected to a high-current direct-current power source are fed into the gun and meet, establishing the arc between them that melts the tips of the wires [1]. As the wire material is molten, the small droplets are accelerated by compressed air. The confined streams of particles are conveyed to the substrate. Temperature within the arc rise to 6,500 ^{0}C. However, thermal spraying is not appropriate for coating surfaces that are not accessible to the spray jet. The particles strike the surface, flatten and adhere to the irregularities of the prepared surface. As the sprayed particles impinge upon the substrate, they cool and build up, particle by particle, into a lamellar structure, thus a coating is formed [2].

The properties of the applied coating are dependent on the feedstock material, the thermal spray process and application parameters, and post treatment of the applied coating. Thermal spray metallic coatings have a lamellar microstructure consisting of splats, and they also contain an oxide inclusion between the splats. The wear behaviour of thermal arc sprayed materials is essentially influenced by spray processing variables and process operating parameters, which impact the coating microstructure and chemical composition.

PRACTICAL TRAINING METHODS

Arc spray equipment and spray feedstock: the students receive different chemical composition feedstock wires types (Table 1) of a diameter 1.6 mm. The coatings can be sprayed by a range of equipment. The Castolin Eutectic arc spray gun and Kemppi ProEvolution 5200 power source with synergic parameters are used in the laboratory, providing a good spraying correlation and arc stability. The different spraying current (320 A; 350 A; 380 A) and voltage (30-38 V) are proposed.

Table 1: Chemical composition of the wires used as spray feedstock.

Feedstock wire	Chemical composition (mass content %) Fe balance					
	C	Mn	Si	Cr	Mo	Ni
A	0.5	1.1	0.3	0.3	4.8	1.5
B	1.3	0.8	1.4	6.5	-	-
C	0.5	1.5	0.6	6.0	0.5	-
D	2.0	0.8	0.26	22.61	-	-

Coatings are sprayed on to degreased and grit blasted mild steel substrates (S235JR) to a thickness of 600-1,000 μm. Hardness measurements are carried out with a standard Vickers hardness tester. Quantitative wear characterisation has been done by gravimetric mass loss of the tested specimen during wear testing using a rubber wheel test. Qualitative characterisation of worn surfaces and worn edges has been carried out by evaluating of macroscopic and cross-section images and by SEM investigations.

Wear examinations: the dry sand/rubber wear examination machine is built in accordance with ASTM G65 standard. The rubber wheel is in contact with a specimen under an applied load. A flow of silica sand particles is directed to the gap between a rotating rubber wheel with a chlorobutyl rubber tire or rim of the specimen with coating. The sand particles scratch the surface of the specimen under the applied load at a sliding speed of ωR, where ω is the angular speed of the rubber wheel and R is its radius.

Specimens are weighed before and after the test and the wear mass loss is recorded. The learners should prepare 12 different sprayed coatings with different hardness values. Wear loss of a specimen is evaluated by measuring the sliding distance of 4,309 m and using constant force of 130 N (recommended by ASTM G65 standard). Using a fixed load and sliding speed to rank industrial materials may be better for evaluating different mass loss of coatings.

Microstructure examinations: cross sectional analysis can be performed by using optical microscopy and back scattered scanning electron microscopy (SEM). An image analysis program helps to measure the porosity and volume of oxides in the coatings, because porosity influence considerably the mechanical and thermos-physical characteristics of deposits.

EXPERIMENTAL RESULTS AND DISCUSSION

Hardness test and coating characteristics: the average thickness of coatings is between 695 μm and 1,000 μm. Light optical microscopy shows the typical porosity and oxidation of the thermal sprayed coatings. The oxide content can be traced back to both the inflight oxidation of the molten metal particles and the surface oxidation of the deposited coating layers.

Despite the theory that hardness levels can also increase with increasing oxide content, the results reveal that the role of oxides is ambiguous. On the one hand, their higher hardness will increase the overall hardness of a coating, on the other hand, their presence as stringers may reduce splat/splat bonding and, hence, lower the measured hardness due to lowered impression resistances [4].

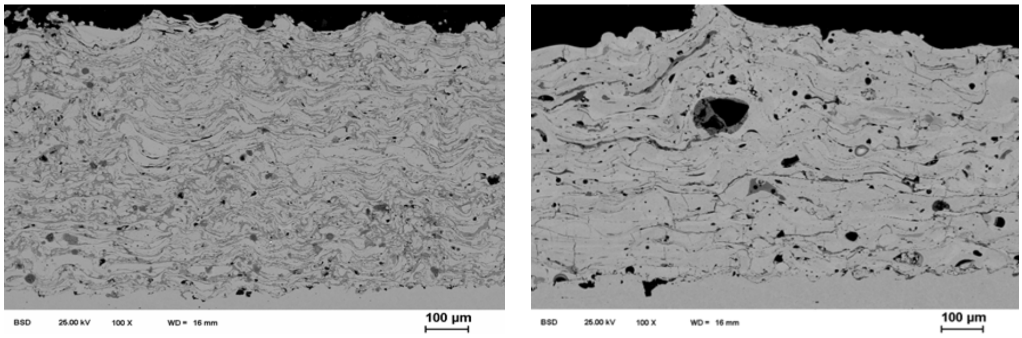
Table 2 shows the average of coatings hardness and other properties. Using the HV0.1 results refer to the splat hardness, whereas the HV0.3 values are integral values of splats lamellas and in homogeneities. The coatings' general hardness levels strongly depend on the coatings' chemical compositions (see Table 1) and are decreased by about 15 % in the coating type C in comparison to the coating type B and 30 % in the coating type D in comparison to the coating type A.

Table 2. Spray coatings properties.

Coating type	Experiment	Hardness $HV_{0.1}$	Hardness $HV_{0.3}$	Porosity, %	Non-metallic inclusions, %	Rubber wheel mass loss, %
A	1	724	556	3.5	10.9	167
	2	806	604	1.9	5.6	145
	3	836	591	2.3	7.0	199
B	1	582	462	3.1	15.2	178
	2	643	480	1.5	7.9	174
	3	666	501	3.1	11.9	186
C	1	714	494	3.0	10.1	205
	2	749	505	2.7	9.1	190
	3	777	508	4.5	10.5	188
D	1	1362	1184	2.7	4.8	161
	2	1413	1192	1.2	3.7	155
	3	1479	1234	3.1	3.4	164

The hardness of sprayed coatings are given in Table 2. The differences in hardness of the same coatings and different applied load can be explained; measurements using 100 g determine the properties of one lamella; however, measurements with 300 g load gives results of few lamellas and inclusions of pores or oxides. SEM pictures analysis of the coatings are shown in Figure 1.

For all processed feedstock materials, the most homogeneous coating microstructures at elevated hardness levels are reached using a spray current of 350 to 380 A. The analysis of microstructure showed that increasing the spraying current formed a smaller lamellar. Vertical cracks in the coatings (coating type C) lamellar, which has the highest hardness were observed. It means that large internal stresses exist in these coatings.



a b

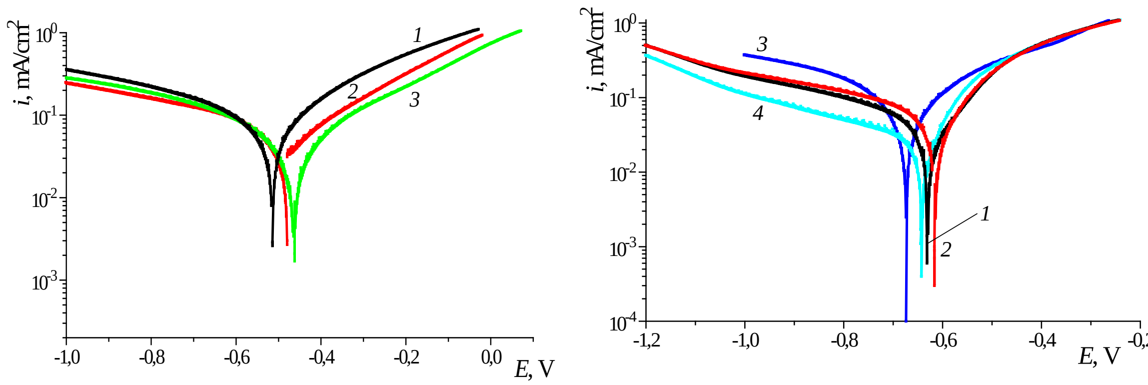
Figure 1: SEM photographs of cross sections of the thermal spray coatings: a) thermal spray coating (current 320 A, coating type C), b) thermal spray coatings with visible non-metallic inclusions and gas bulbs.

Wear loss: mass loss of the different coatings is measured with the same load 130 N and the same sliding speed, but at three different testing times (30 sec., 270 sec., 600 sec.). The wear loss of the tested coatings results are presented in Table 2. It shows the cumulative mass loss per time.

The test results demonstrated that wear losses of all materials in the test decreased and later increased using the same loads. The least weight loss for a coating was recorded in the second spraying experiment in all coatings. This is understandable, because in these spraying modes coatings have the minimum level of pores and oxides. Of course, another important mechanical property is the hardness of coatings, which can result in greater surface damage. The smallest wear losses had the coating type D (wear 155-164 mg.). The wear loss of coatings deposited from the coating type C was one of the biggest (188-205 mg). This kind of coating had a high level of porosity. Coatings deposited from the wire type A and type B had a mass loss of 145-199 mg and 174-186 mg, respectively.

The largest mass loss was found at the third spraying experiment in all coatings. This may mean that residual cracks form in the coatings with the highest hardness. It is possible to conclude that internal stress in the coatings cause the internal cracks and reduce the surface cohesion, thus, creating the huge mass loss during the dry friction, although the coatings are very hard.

Corrosion resistance: potentiodynamic polarisation is a technique where the potential of the electrode is varied at a selected rate by application of a current through the electrolyte. This method allows for the study of materials behaviour in a particular medium and corrosion mechanism, evaluating of pitting susceptibility and determining of potential of passivation and corrosion. The potentiodynamic polarisation curves are shown in Figure 2.



a) b)

Figure 2: Potentiodynamic polarisation curves: a) flux-cored wire A; b) flux-cored wire D.

These experiential learning projects have proved to be successful in the aims associated with practical skills and the use of modern technological equipment, and proved to be an effective motivator for research-based projects [5].

CONCLUSIONS

During the practical training and research elaborated here, students will be able to do a number of things:

- Investigate the hardness of coatings, showing that hardness of splats depends on the arc spraying regime parameters. Increasing the spray current produces smaller spraying particles. The smallest particles' crystallisation process is much faster and the hardness of lamellas is bigger.

- The analysis of results can show that coatings with different hardness have similar results of wear mass loss. It can be concluded that the hardness of coatings is not the main factor determining the mass loss. It is necessary to evaluate the amount of pores and oxides in the coating.
- Recorded polarisation curves allow for the determination the influence of alloying elements on coating corrosion resistance.
- Experiment-based study courses prove to be an excellent opportunity for those students with a strong interest in practical approach to engineering science and practice.
- The work presented here has shown, first of all that, when using a simple laboratory, it is possible to simulate the comparative friction efficiency of various alternative coatings.

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