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EDM AND TURNING MACHINING SURFACE PREPARATION
INFLUENCE ON THE ADHESION OF ALUMINUM THERMALLY
SPRAYED COATINGS

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Abstract. *Thermal Spray is a process in which particles of molten (or semi-molten) metal are projected against the surface of a substrate, with the goal of enhancing its mechanical properties and its resistance against corrosion, also decreasing the wear rates on a surface. This work analyses the relation between the roughness of a surface before being subject to a thermal spraying process, and the adhesion of the coating obtained, giving us a better understanding on what happens between the surface and the coating, when subject to higher loads. We analysed the roughness on surfaces prepared by the EDM and Turning Machine methods. It was observed that if we increase the roughness of the substrate's surface before spraying, we obtain a greater resistance against external tensions. The EDM method of preparation has shown to be more effective than the Turning Machined surfaces when requested to increase the surface's roughness capabilities for coating adhesion.*

Keywords: *thermal spray, aluminium, EDM, machining, tensile adhesion*

1. INTRODUCTION

The thermal spraying process is formed by a group of techniques that allow depositing coatings in the form of layers of metallic, nonmetallic materials or mixtures of those, on a previously prepared surface, with the purpose of altering its surface characteristics (VOORT,2004). The overall coating application is primarily intended to take advantage of the specific properties of the deposited material and thereby increase the corrosion resistance and decrease the wear rates and erosion in structural parts and components subjected to aggressive environments (LIMA and TREVISAN, 2002).

1.1. Electric Arc Thermal Spraying.

The arc-spraying process uses wire shaped metal, as a feeding source. This thermal spray process differs from the others because there is no external heat source such as flame or plasma (VOORT,2004). In the ASP thermal spraying process, two wires are continuously fed into the gun, which maintains an electric potential difference, and when they approach, they open an electric arc with sufficient energy to melt the materials of the wires, that are then propelled by an atomizing gas, inert or not, against a substrate (CRAWMER,2004). The atomizing gas is the responsible for the separation of the molten metal and the formation of droplets. These droplets will form the characteristic splats when they hit the sprayed surfaces (PUKASIEWICZ,2008). Fig. 1 shows what happens in the pistol of the ASP deposition process.

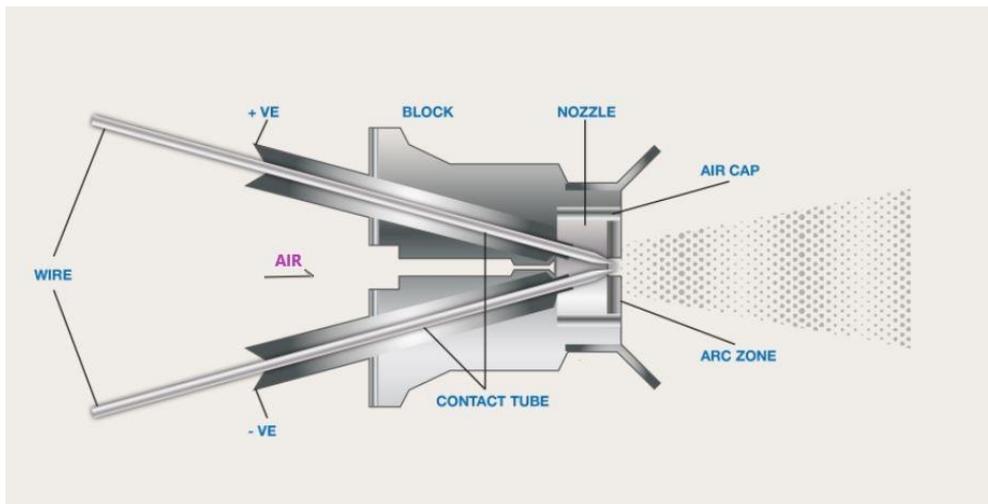


Figure 1. APS torch schematic drawing.

The process of thermal spraying by electric arc stands out in relation to other processes because it presents a higher rate of deposition; it is easy to operate, manually or even automatically; its consumable wires are found at low costs; and has better adherence levels than the Flame Spray process, for example (WANG et al, 1999). The coatings obtained with APS have a relatively high porosity, when compared to other forms of thermal spray (HVOF, high velocity oxy-fuel process) and therefore have lower density values, but they also present a good tensile bonding strength, depending on the materials used in the process (up to 70MPa for NiAl alloys, for example). The heat transferred to the substrate by the ASP process is lower than in the flame processes, because the heat of the electric arc is mostly directed to the consumable metal only and not to the substrate, as in the FS, HVOF and APS processes (CRAWMER,2004).

1.2. Electrical Discharge Machining – EDM

This machining process uses a high frequency pulse current (ac or dc) to remove material from a workpiece, removing chips from its surface not by cutting it, but rather, eroding some pieces of it. In general, the workpiece is charged electrically with an opposing charge signal to the electrode, the most common set up, being the workpiece negatively charged, to protect the electrode from deterioration. Both pieces are positioned close together, and as they near each other, an intense electromagnetic flux is formed, eventually breaking the dielectric fluid's insulating properties, therefore, there is no contact between the electrode and the substrate. The power supply produces a high frequency series of electrical arc discharges between the electrode and the workpiece, this power supply provides the required strength (in amperes) and presets the gap voltage. The main controllable variables for this process are then, the on-time, and the off-time; these variables control the amount of time in which the electrical discharge is going to occur, and the amount of time in which the system will remain in resting period, respectively. Data such as the current of the system, the gap voltage and its frequency, are dependent of these on and off settings, the current being also relate to the dimensions, the material of the electrode in use and the number of diodes (Ts) in use during the process (BROWN,1998).

When regarding to surface finishing, we must consider that, unlike other machining methods, in EDM there's no contact between the parts, so discussing any chip formation is complicated. On the other hand, EDM does not present a pattern on its surface finishing, meaning that reading roughness values will not depend on machining directions. The two most important parameters when regarding to surface finishing are the "on-time" and peak current. Studies have shown that for rougher surfaces, higher values of either "on-time" periods or peak current are recommended. (GUITRAU,1997).

1.3 Turning Machining Process

Lathe turning machine is the most straightforward machining method in use throughout the world. Turning is a combination of a rotational movement (the workpiece) and a feed movement of the turning tool, it is often described as the removal of material from a surface (its diameter, or its face, in facing processes) with a single point tool. The shape of the tool has a significant effect on a surface's finishing. For this experiment, we used a machine set up appropriated for facing process on our samples, leaving marks concentrically along the surface.

1.4. Surface preparation

The preparation of the substrate's surface for the application of thermal spray coatings is a fundamental step of the process where it is necessary to achieve optimum levels of cleanliness and roughness. The cleaning of the surface is aimed to remove contaminants that may impair the adhesion of already deteriorated coatings or other surfaces, so cleaning must be done with appropriate techniques, procedures and materials (PUKASIEWICZ, 2008; LMA, 2001).

At times, it is necessary to use solvents based on hydrocarbons, chlorides and alcohols, among others, but health risks and compatibility between the solvent and the substrate must always be observed. The use of water vapor under pressure can be effective in many cases. The use of ultrasound also favors cleaning (LIMA, 2001).

In addition to cleaning, the surface must have a suitable roughness for the desired adhesion to occur (LIMA and TREVISAN, 2007). The adhesion is dependent on the number of anchor points and the specific interfacial area. It is considered as an adequate roughness the one that allows an increase in the anchorage and in area of contact between substrate and coating. The anchorage area is a result of the roughness of the coatings and the contact of the sprayed splats with such irregularities. When the splats start solidifying around the points they become attached to the substrate by liquid shrinkage, resulting in enough strength for the adhesion. (PAWLOWSKI,2008).

Abrasive blasting is the main method used in the preparation of the coating surface, but for larger layer thicknesses, subjected to high stresses and / or requiring greater strength, coarse machining or gouging is often used. For thick coatings, the combined use of coarse machining followed by abrasive blasting is employed for maximum adherence of the deposited layer (LIMA and TREVISAN, 2007).

The objective of this work is to observe the viability of use of machining by EDM (Electro Discharging Machining) and Turning Machining to prepare surfaces for ASP Aluminum deposition. By varying some of the most influential parameters in these machine methods, we will be able to determine which one provides the best surface for thermal spraying. As mentioned above, many methods can be used for increasing roughness on a surface and make thermal spray a possible solution for said surfaces. EDM and turning are two possible solutions for obtaining a greater anchorage area in the splats deposition (PAWLOWSKI,2008). This work will, therefore, analyze both roughness measurements, and then compare the results with adhesion tests, combined with microstructure analyzes, utilizing Scanning Electron Microscope data, as well as optical microscopy, to better understand the underlying mechanisms behind the anchorage phenomenon and its relation to the processes adopted in this work.

2. EXPERIMENTAL PROCEDURE

2.1 Surface Preparation

Each sample was prepared with the objective of increasing their surface roughness, and as mentioned in the section above, the techniques chosen for this preparation were EDM and turning machine. Literature has shown us that both machining procedures are able to obtain good roughness values for the surfaces that undergo such work. Therefore, in the completion of these studies, we have decided to analyze the varying roughness measurements within each preparation method, changing the machines set ups to obtain different levels of thermal spray anchorage results. We have chosen to classify our samples as "smooth", for parameters with lowest roughness, "medium" for the middle values and "rough" for the greatest roughness values obtained with given parameters.

Table 1 shows the varying parameters that were chosen for the EDM process. "Ton" stands for Time ON, whereas "Toff", Time OFF. "Ts" is the number of active diodes. In theory, by increasing the Ton numbers, we should obtain a rougher surface, because the frequency values would be lower (GUITRAU,1997), so we decided on increasing the on time and the number of active diodes of the process, as shown below.

Table 1. EDM process parameters

<i>Parameters</i>	<i>Values</i>		
	Smooth deposition	Medium deposition	Rough deposition
Ton (µs)	500	500	750
DT	97%	95%	97%
Ts	5	10	11.5

For the Turning machining parameters, we also took 3 different roughing steps, in a similar manner to the EDM process. This time, we chose to vary the feed rate, maintaining the same tool, and the same rotation. Because we used AISI1020 steel subtract samples, and a coated, cemented carbide tool from Sandvik® with 0.4 mm radius for a relatively short period of time, we did not change the tool, for its wear was considered insignificant for the purposes of this work.

The following table, shows the parameters chosen in the process. Notice that, for each roughness variation, only the feed rate was modified.

Table 2. Turning machine process parameters

<i>Parameters</i>	<i>Values</i>		
	Smooth deposition	Medium deposition	Rough deposition
Tool Radius (mm)	0.4		
Rotation (rpm)	1240		
Feed rate (mm)	0.053	0.449	1.013
Depth (mm)	0.3		

After preparing the surfaces of the samples, we started the coating process. For every sample and its variations (roughness variations) we used the same spraying parameters. Roughness measurement was made in an Optical Profilometer Taylor Hobson CCI Lite, using a 50 x lens.

Depositions were made with an electric arc TBA equipment model 300E, with "fine" air cap. Parameters values used for sample preparation are in table 3.

Table 3. Arc Spray deposition parameters

<i>Parameters</i>	<i>Values</i>
Arc Tension (V)	37
Arc Current (A)	72
Air Pressure (KPa)	410
Atomizing Gas	Air
Deposition Distance (mm)	120

The final step of this research, was analyzing the results. We took one of each sample and performed tensile adhesion tests, according to ASTM C633 standard, obtaining the tensile values shown in table 4 of the next section of this work. The samples were also analyzed with an optical profilometer Taylor Hobson CCI Lite, allowing us to make a comparison in the roughness evolution of our samples, before and after undergoing the machining processes.

3. RESULTS AND DISCUSSION

Figure 2 shows the typical surface profile of the turning machined surface, and Figure 3 shows the EDM sample. Table 4 shows the roughness values obtained after the tests. Comparing the EDM results with the machined ones, it is noticeable that the adhesion values reveal better performance with the EDM samples, and smaller variations on the standard deviation of the experiments.

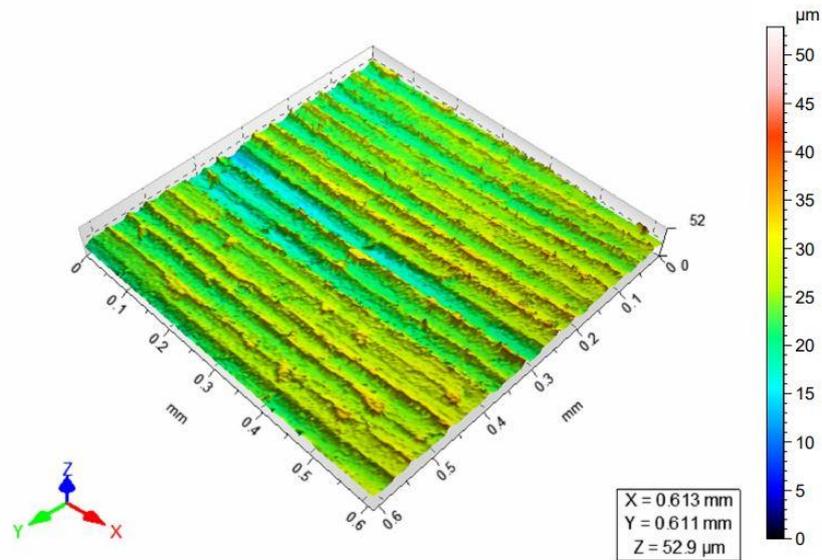


Figure 2. Profilometer 3D view from the surface's roughness of turning machined sample (smooth process) before coating process.

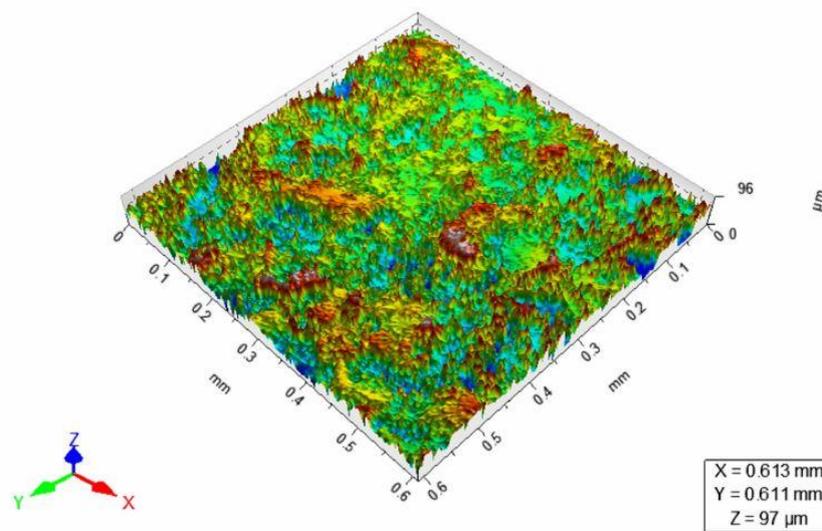


Figure 3. Profilometer 3D view from the surface's roughness of EDM machined sample (smooth process) after coating process.

By analyzing the profile parameters obtained we can start drawing some conclusions on what happened to the surfaces after the machining processes. Table 4, shows the profile data obtained with the optical profilometer.

Table 4. Sample's profile roughness

		Ra (μm)	Rq (μm)	Rz (μm)	Rsk
Turning Machine	Smooth	0.14	0.17	0.773	0.00589
	Medium	0.52	0.65	2.91	0.000717
	Rough	9.02	13.40	110.00	0.311
EDM	Smooth	0.714	0.898	4.08	-0.0689
	Medium	1.12	1.40	6.07	-0.135
	Rough	21.00	26.80	149	-0.539

It is notable how the Rsk values remained close to zero, meaning they have a near Gaussian distribution, which is a characteristic of machining processes (MAINSAH; GREENWOOD; CHETWYND, 2001).

Even more fundamental to our analysis, are the areal field parameters shown on table 5. These results represent the aspect of the surfaces calculated in relation to a given area.

Table 5. Sample's surface roughness parameters.

		Sa (µm)	Sq (µm)	Sz (µm)	Sku
Turning Machine	Smooth	2.84	4.06	104.00	10.00
	Medium	9.30	13.60	120.00	6.90
	Rough	11.20	16.70	361.00	9.85
EDM	Smooth	12.40	16.50	107.00	4.07
	Medium	19.20	25.70	192.00	4.15
	Rough	23.20	29.70	186.00	3.42

The Kurtosis value, Sku, represents the sharpness of a surface height distribution. Gaussian distributions have a kurtosis value of 3, any values greater or smaller than that represent the heterogeneity of the peaks and valleys distributions. Upon analysing table 5 the EDM samples presented a steadier surface variation, meaning that those samples were more homogeneous when regarding to the distribution of roughness, suggesting that, for these samples, the active anchorage area, might be more efficient, resulting in a more resistant coating, when considering adhesiveness.

Table 6 shows the tensile adhesion tests according to ASTM C633. It represents the obtained values for the adhesion test. As mentioned above, greater active anchorage areas should represent a more resistant coating. This assumption is confirmed after checking table 6.

Table 6. Tensile adhesion test results

		σ (MPa)	Std. deviation
Turning Machine	Smooth	3.04	1.03
	Medium	3.03	1.04
	Rough	7.15	2.23
EDM	Smooth	7.06	2.24
	Medium	7.04	0.77
	Rough	7.98	2.72

The EDM samples have shown to obtain a more adhesive surface, as displayed on Table 6, having every result on the adhesion test surpassing the values shown for the samples prepared with turning machines. It is interesting that the "smooth" EDM sample obtained higher adhesive value than the "medium" samples. This may be explained as an experimental variation. The standard deviation for the "medium" samples was very low, while all the other samples have had greater variations, perhaps upon increasing the number of tests on similar samples, we might obtain a smaller statistical variation.

4. CONCLUSIONS

We can understand from the results acquired that the adhesion of the coatings are increased for both, the EDM and turning machine methods, though such values were greater for the EDM samples. The tensile adhesion results are seen to increase, as the roughness of the surfaces are higher, confirming what the literature suggested as an increase in the active anchorage area, working as a mechanism of adhesion. The fact that the roughness distribution on the EDM processes resulted in more even "peak-valley" relation, throughout the surface (as shown in table 5), are possibly the reason why the tensile strengths value were higher on these samples. It is possible to conclude that, these higher values are related to how the EDM process occurs, with material being removed uniformly in a spherical way. Even though the turning machined samples also presented good roughness values, their surfaces had a more uneven distribution of these numbers, which may lead to an understanding that, in these samples, there might be areas where these roughness do not possess anchor points, and while also allowing the splats to solidify against its peaks and/or valleys forming the anchorage phenomenon, they are not as good or as stable as in the EDM process, due to a better relation between the presence of heights and depths and their distribution on the surface.

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