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1 Introduction and aims of the project

Surface engineering has experienced a continuous evolution during the twentieth century. New techniques in the field of surface technologies like laser treatment or thermal spraying pretreatment have been developed and introduced in many areas of application, e.g. paper industry, automotive engineering, textile industry as well as metallurgical and steel industry amongst others.

An important field in surface technologies is thermal spraying. Thermal spraying can be defined as the deposition of molten or semi molten particles of ceramic, cermet or metal coating materials on a substrate surface in order to form a dense coating to modify the surface properties (mechanical, electrical, chemical,...) of the substrate material. In this way, the use of ceramic or cermet bulk materials can be avoided in many applications, resulting in cost efficient components and fabrication processes.

Due to the fact that the coating and the substrate material have different physical and chemical properties, a strong bonding mechanism suitable to bear the operation conditions as well as residual stresses is essential. The adherence between substrate and coating is a very important factor for the coating performance under operation. The most important step to achieve adequate bonding is the surface preparation prior to coating deposition (surface pretreatment). For this reason, a characterization and comparison of the surface pretreatment methods available in industrial scale and their influence on the coating characteristics is needed.

The state of the art will be compared and analyzed, and a characterization will be made for the most common techniques. In this research, different pretreatment (grit blasting, mechanical processes and water jet blasting) have been studied and compared.

The most important technique for surface treatment prior to thermal spraying for its wide use is grit blasting. Therefore, a parameter study of this activation method will be carried out.
2 State of the art of thermal spraying

2.1 Principles of thermal spraying

Thermal spraying is defined as a process of particles deposition in which the molten, semi-molten or solid particles are deposited on a substrate and the microstructure of the coating results from the solidification and sintering of the particles [Ref 1].

Thermal spraying involves a variety of apparently simple processes by which a solid material (wire, rod, powder) is rapidly heated and propelled against a substrate, see fig 2.1. The energy source for heating of the spraying material can be an exothermal chemical reaction (combustion), an electrical discharge or laser. For special applications (e.g. cold gas spraying), the energy source can also be a heat exchange.

The feeder material (molten or semimolten particles) is deposited on the substrate for building the coating. The coating may have different functions including protection against wear, erosion, corrosion, and thermal and chemical degradation. The coating may also impart special electrical, magnetic or decorative properties to the substrate.

The deposition of thick coatings is applied in many industrial areas to restore or attain desired workpiece dimensions and specifications [Ref 2].

Fig. 2.1: Schematic description of the thermal spray process
The coating structures formed during thermal spraying are typically heterogeneous and anisotropic, showing different thermophysical, physical and chemical properties in longitudinal and transverse direction. This is due to the coating structure obtained by impact of single particles, which originates a lamellar-like structure. In addition, chemical interaction occurs during coating formation. Metallic particles oxidize on the surface, forming an oxide shell around the splats. The solidified particles are normally deformed into splats, see fig. 2.2, but also unmolten particles can be observed inside the coating structure. Fig. 2.3 shows a typical structure of a thermally sprayed coating. Thermally sprayed coatings are not comparable to sintered bulk materials or materials that have been formed by crystallization from a melt.

A common property of all coatings applied by thermal spraying is their lamellar structure, resulting from the flattening of the molten or semi-molten spray material (droplets). The rapid solidification after impingement on the surface due to heat flow to the substrate (which generally has a much lower temperature because of the higher mass and heat capacity) leads to the formation of so-called splats, see fig. 2.2, that build the coating by mechanical clamping as well as physical and chemical adhesion on the substrate surface and between each other. In combination with unmolten particles, oxides and voids, this lamellar structure is the reason for the anisotropy of the properties of thermally sprayed coatings.
Depending on the desired coating characteristics (layer thickness, porosity, hardness, bonding strength, etc.), the substrate (stainless steel, gray cast iron, light metal alloys, ceramics, glass, etc.) and the application field, a suitable coating technique has to be chosen from the different methods of thermal spraying, see Tab.2.1, (which also gives an overview about some general characteristics of the different thermal spray technologies) [Ref 5].

Tab. 2.1: Overview about methods for thermal spraying

<table>
<thead>
<tr>
<th>Process</th>
<th>Heat Source</th>
<th>Maximum Flame Temperature (°C)</th>
<th>Particle Velocity (m/s)</th>
<th>Coating Material</th>
<th>Deposition Rate (kg/h)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flame</td>
<td>combustion</td>
<td>3,100</td>
<td>60-150</td>
<td>metals and polymers</td>
<td>6-8</td>
<td>6-8</td>
</tr>
<tr>
<td>Electric Arc</td>
<td>electric arc</td>
<td>4,000</td>
<td>150-170</td>
<td>metals and alloys</td>
<td>8-200</td>
<td>3-10</td>
</tr>
<tr>
<td>Plasma DC (APS)</td>
<td>electric arc/plasma</td>
<td>20,000</td>
<td>200-400</td>
<td>refracted materials, oxide ceramics</td>
<td>4-8</td>
<td>1-10</td>
</tr>
<tr>
<td>HVOF</td>
<td>combustion</td>
<td>3,200</td>
<td>400-800</td>
<td>metals, ceramics and cermts</td>
<td>2-8</td>
<td>0.2-2</td>
</tr>
<tr>
<td>Detonation</td>
<td>discontinuous combustion</td>
<td>3,200</td>
<td>600</td>
<td>refracted metals, cermet, ceramics</td>
<td>4-8</td>
<td>0.2-2</td>
</tr>
<tr>
<td>Cold Gas</td>
<td>compressed air / heat exchanger</td>
<td>no flame</td>
<td>500-1,500</td>
<td>metals of low melting point</td>
<td>4-10</td>
<td>0.1-1</td>
</tr>
</tbody>
</table>

All thermal spray coatings contain a degree of internal stress. These stresses increase with the coating thickness, which can lead to delamination. Therefore, the coating thicknesses are limited. In some cases, a thinner coating will have a higher bond strength.
2.2 Thermal spraying techniques

Thermal spraying is a well established technology for applying wear and corrosion resistant coatings in many key industrial sectors, including aerospace, automotive, power generation, petrochemical and offshore industry. In recent years, improvements to equipment and material quality have enhanced the technical credibility of thermal spraying processes, leading to a significant growth in new markets, e.g., biomedical, dielectric and electronic coatings. As a consequence, there are many options open to the spray coating supplier in terms of thermal spraying equipment and coating materials.

In order to classify thermal spray technologies, it is possible to consider different criteria, like the kind of material provided (powder, rod or wire). However, the most common classification is with respect to the heat source, see fig. 2.4. In the following, the most important thermal spraying techniques are described [Ref 4].

![Classification of thermal spraying techniques](image)

**Fig. 2.4. Classification of thermal spraying techniques (considering the heat source)**

2.2.1 Heat source: combustion flame

**Flame spraying**

Flame spraying is the oldest of the thermal spraying processes. A wide variety of materials can be deposited as coatings using this process. Flame spraying has distinct advantages, including ease of application and low cost. These benefits make it a widely used process.
In flame spraying processes, a consumable material is heated and propelled onto a substrate to form a coating. Flame spraying uses the heat from the combustion of a fuel gas (usually acetylene or propane) with oxygen to melt the coating material, which can be fed into the spraying gun as a powder, wire or rod. The consumable material gives the name to the two process variants, powder flame spraying and wire flame spraying (see fig. 2.5).

For the powder flame spraying process, powder is fed directly into the flame by a stream of compressed air or inert gas (argon or nitrogen). Alternatively, in some simple systems, powder is brought into the flame using a venturi effect, which is sustained by the fuel gas flow. The carrier gas feeds powder into the centre of a combustion flame where it is heated. A second outer gas nozzle feeds a stream of compressed air around the combustion flame, which accelerates the spray particles towards the substrate and focuses the flame.

Fig. 2.5. Schematic view of the flame spray process

In the wire flame spraying process, the wire feed rate and flame settings must be well balanced in order to ensure continuous melting of the wire to achieve a fine, homogeneous particle distribution in the spray jet. The surrounding compressed air flow atomizes and accelerates the particles towards the substrate.
High velocity oxygen fuel thermal spraying process
The HVOF (High Velocity Oxygen Fuel) thermal spray process is basically the same as the combustion powder spray process with the difference that HVOF has been developed in order to produce extremely high spray velocities. There are a number of HVOF guns which use different methods for achieving high particle velocities. One method is based on a water cooled high pressure combustion chamber in combination with a long expansion nozzle (Laval nozzle), see fig. 2.6. Fuel gases (e.g. acetylene, propylene or hydrogen) or liquid fuel (e.g. kerosene) are mixed with oxygen. The spray powder can be fed axially into the combustion chamber under high pressure or through the side of the Laval nozzle, where the pressure is lower. Another method uses a simpler system of a high pressure combustion nozzle and an air cap. Fuel gas and oxygen are supplied at high pressure, combustion occurs outside the nozzle but within an air cap formed by compressed air. The compressed air accelerates the flame and acts as a coolant for the gun. Powder is supplied at high pressure axially at the centre of the nozzle.

![Fig. 2.6 Schematic illustration of the HVOF process](image)

Coatings which are applied by HVOF spraying are very dense and show mainly compressive stresses, which enables the deposition of thicker coatings than with other processes.

The very high kinetic energy of particles striking the substrate surface does not require the particles to be fully molten to form high quality coatings. The lowest process temperatures additionally enable the deposition of carbide/cermet type coatings.

Detonation thermal spraying
The detonation gun consists of a long water cooled chamber with inlet valves for gases and powder, see fig. 2.7. Oxygen and fuel gases, most commonly acetylene, are fed into the
chamber and powder is added by means of a carrier gas flow. A spark is used in order to ignite the burning gas mixture and the resulting detonation heats and accelerates the powder to supersonic velocity. A gas pulse of nitrogen is used for purging the barrel after each detonation. The high kinetic energy of the powder particles results in the highest coating densities of all thermally sprayed coatings.

![Fig. 2.7. Schematic diagram of the detonation thermal spray process](image)

This technology is used with a narrow range of coating materials and substrates. The material range of the detonation technique involves almost any metallic, ceramic, or cement material which melts without decomposition.

Oxides and carbides commonly are deposited. Because of the high gas velocities and the high-velocity impact of depositing materials such as tungsten carbide and chromium carbide, combustion torches and detonation guns can be used only on metal substrates. The properties of the coatings are much less sensitive to the angle of deposition than for most other thermal spray techniques.

The succession of explosions performing the coating work produces an elevate level of noise which must be controlled by locating the equipment in properly insulated facilities.

### 2.2.2 Heat source: electric discharge

**Arc spraying process**

Arc spraying is the thermal spraying process with the highest productivity. A direct current (DC) electric arc is struck between two continuously consumed wire electrodes which also
form the spray material. Compressed gas (usually air) atomizes the molten spray material into fine droplets and propels them towards the substrate, see fig. 2.8. The impacting molten particles rapidly solidify on the substrate and form the coating. The arc spraying process is easy to operate, and it can be used either manually by means of a hand-guided spray touch, or in an automated manner. It is possible to spray a wide range of metals, alloys and metal matrix composites with this process. In addition, a limited range of cermet coatings (with tungsten carbide or other hard materials) can also be sprayed by the use of cored wires, in which the hard ceramic phase is packed into a metal sheath in the form of a fine powder.

![Fig. 2.8. Schematic diagram of the arc spraying process](image)

Arc sprayed coatings normally have a higher density and mechanical strength than equivalent conventional flame spray coatings. Low running costs, high spray rates and high efficiency are further advantages of the arc spraying process and make it a good tool for the coating of large areas.

Disadvantages of the arc spraying process are the limitation in the choice of the spraying material to electrically conductive wires, and the need of a separate heat source if substrate preheating is required.

The main applications of arc spraying are anti-corrosion coatings of zinc and aluminium and the repair of large volume wear on machine components.
Plasma spraying process

In the plasma spraying process, material in the form of powder is injected into a high temperature plasma flame, where it is rapidly heated and accelerated. The hot material impacts on the substrate surface and rapidly cools building a coating.

The plasma gun consists of a ring-shaped nozzle-anode of copper and a concentrical tungsten cathode, see fig. 2.9 (both electrodes are water cooled). Plasma gas (argon, nitrogen, hydrogen, helium) flows around the cathode and through the anode. The plasma is initiated by a high voltage electrical discharge which causes localized ionization and the formation of a conductive path for a DC electric arc that forms between cathode and anode.

The heat from the electric arc causes the gas to reach extreme temperatures, dissociate and ionize to form a plasma. The plasma exits the anode nozzle as a free or neutral plasma flame (plasma which does not carry electric current) which is quite different to the plasma transferred arch coating process, where the arc extends to the surface of the substrate. When the plasma is stabilized ready for spraying, the electric arc extends down the nozzle (instead of shorting out to the nearest edge of the anode). This stretching of the arc is caused by a thermal pinch effect. The cold gas which streams around the surface of the electrodes (being electrically non-conductive) constricts the plasma arc, raising its temperature and velocity.

Fig. 2.9. Schematic diagram of the plasma spraying process
Powder is fed into the plasma flame most commonly via an external powder injection system, mounted near the anode nozzle exit. The powder is rapidly heated and accelerated in the plasma jet. Spray distances can be in the order of 25 to 150 mm.

Plasma spraying offers the advantage that materials with high melting points can be processed, such as refractory metals (e.g. tungsten) and ceramics (e.g. zirconia), which can not be thermally sprayed with combustion processes. Disadvantages of the plasma spraying process are the relatively high costs and the complexity of the process.

2.2.3 Heat source: laser

Laser spraying
Generally, there are three methods of laser surface treatment with solid additives. One possibility is a two-step process, which involves the remelting of a previously deposited layer on the substrate surface. The deposition of this layer can be achieved by paste printing or spraying. The two other methods are single-step processes. Thereby, the layer will be produced either by laser cladding with a powder or a powder mixture, or alternatively, by laser melt particle-injection. The difference between these two methods lies in the degree of substrate melting, which is higher for the laser melt injection process. A laser spraying process is shown in fig. 2.10.

![Fig. 2.10. Schematic diagram of a laser spraying process](image)

CO₂ lasers are the most common high power lasers and are available in different power levels. The high wavelength of CO₂ (10.6 µm) results in a relative low degree of absorption of the laser beam by metals.
There are lasers that operate at a lower wavelength which improves the absorption characteristics. However, these lasers operate at significantly lower electrical/optical efficiency which makes the equipment more heavy and the cost of operation higher.

High power diode lasers (HPDL) were introduced recently (940 nm). They represent the newest generation of high power lasers for material processing like:

- welding
- coating and surface treatment
- polymer welding
- brazing and soldering

Due to the very high electrical/optical efficiency, HPDL equipment is remarkably smaller in size than other lasers with a similar power level. The poor beam quality is not a key factor when using HPDL laser for coating and surface hardening.

### 2.2.4 Others: Cold gas dynamic spraying process

The process basically uses the energy stored in high pressure compressed gas to propel fine powder particles at very high velocities (500 - 1500 m/s). Compressed gas (usually helium) is fed to the gun via a heating unit where the gas exits through a specially designed nozzle at very high velocity and temperature, see fig. 2.11. A high pressure powder feeder is used in order to introduce powder material into the high velocity gas jet. The powder particles are accelerated and moderately heated to a certain velocity and temperature where on impact with a substrate they deform and bond to build a coating.
The particles remain in solid state and are relatively cold, so the formation of the bulk during impact is from the solid state only. The process involves low oxidation of the spray material, therefore, surfaces stay clean which improves bonding. The solid state deposition and relatively low temperatures result in very low shrinkage during cooling. Additionally, because of plastic deformation at impact, the coatings tend to compressive residual stresses and not to tensile stresses like liquid/solid state reactions of most of the other thermal spraying processes. Low temperatures also enhance the transformation of the original powder chemistry to the coating, which can only change due to deformation and cold working.

Up today, coatings applied by the cold spraying process are limited to ductile materials like aluminum, stainless steel, copper, titanium and other metal alloys. Hard and brittle materials like ceramics can not be sprayed in the pure form, but may be applied as composites with a ductile matrix phase. Substrate materials are also limited to those that can withstand the aggressive interaction with the spray particles. Soft or friable substrates will erode rather than be coated.

### 2.3 Surface pre-treatment and bonding mechanisms

Prior to the coating of a surface, an activation process to ensure a good bonding between substrate and coating is necessary. Different methods to modify and activate the surface of a substrate can be used. These methods pursue:
• To eliminate rust, grease, oils and dust from the substrate surface
• To increase the contact area between the coating and the substrate and, therefore, intensify the different bonding mechanisms
• To obtain compressive stresses in the surface of the substrate to achieve improved adhesive conditions

Adhesion mechanisms

Surfaces for thermal spraying have to be chemically and mechanically well prepared for good adhesion. The flattening of thermally sprayed particles and wetting of the substrate strongly depends on the surface structure. The wetting of the surface is an important factor determining the adhesion strength of the coatings. The adhesive strength is also greatly influenced by the roughness or topography of the substrate. It has been suggested that the adhesive bonding strength is caused by such factors as [Ref 3]:

1) mechanical anchorage of molten particles into cave-like spaces of the roughened substrate
2) physical interaction of the van der Waals force
3) chemical interaction or metal bonds caused by diffusion of molten particles into the substrate or partial melting of the substrate by hot molten particles.

The importance of each one of these bonding mechanisms is difficult to assess. However, it can be assumed that the mechanical anchoring between substrate and coating is the main factor regarding bonding strength (the mechanical friction between the substrate and the coating primarily influences the adhesive strength). Roughening of the surface (e.g. by grit blasting) physically and chemically activates the surface, improving the connection between the surface and the coating. A rough profile also increases the contact area, improving conditions for mechanical as well as physical and chemical bonding.

The correlation between roughness and bonding strength can be expressed as [Ref 3]:

\[ F = \mu \cdot P \cdot R = k \cdot R \]
where $F$ is the adhesive strength, $P$ is the pressure, $R$ is the roughness and $\mu$ is the friction coefficient. The adhesive strength is expressed as a linear equation of the characterized roughness “$R$” (bond strength roughness).

Moreover, many other factors have a significant influence on the bonding between coating and substrate. The coating adhesion will depend on:

- **Surface pre-treatment**
  - Cleanliness: substrate is washed and degreased
  - Surface activation: surface roughening to obtain a rough profile, e.g. water jet, grit blasting, precision machining or laser structuring
  - Contact area: increased by surface pretreatment

- **Substrate properties**
  - Topography or profile
  - Roughness (very important for a good coating adhesion)
  - Temperature: higher preheating temperatures for the substrate increase diffusion bonding, but also increase oxidation of the substrate
  - Physical and chemical properties of the substrate

- **Technology and coating parameters**
  - Used thermal spraying technique: e.g. APS, HVOF, FS,…
  - Temperature during coating: increase in thermal energy increases chances of metallurgical bonding
  - Velocity of the particles: increase in kinetic energy increases chances of metallurgical bonding and reduces the porosity, increasing the mechanical anchoring
  - Coating material: e.g. metals, metal alloys, ceramic cermet, polymers,…

Prior to the coating process, a pre-treatment of the surface is necessary. The following operations, which will be described above, are typical [Ref 1], see fig. 2.12:

- cleaning and degreasing (using common organic solvents)
- shaping (if necessary)
- masking prior to surface roughening
2.3.1 Cleaning and degreasing

The first step in surface preparation should be the attainment of a clean surface free from grease, oil and corrosion products. The cleaning method used can strongly affect the coating properties, particularly concerning the coating, adhesion and deposition rate. Thus, the choice of the cleaning method may be influenced by factors apart of cleaning efficiency. Four different cleaning and degreasing principles can be identified [Ref 7]:

- Deterge
- Solve
- Chemical reaction
- Mechanical reaction

These categories are not mutually exclusive, but correspond broadly with the following main types of cleaners, see fig. 2.13:

- Alkaline cleaners
- Solvent cleaners
- Acid cleaners
- Mechanical cleaning methods
The choice of method must be influenced by the types of impurities to be removed. Most metals used in industry are covered with a thin film of oil for protection during transportation and storage. Other soils are formed during the fabrication of the metal: finely distributed metal particles and residues of rolling oils (in order to facilitate metal-forming operations, various types of lubricants and drawing compounds are applied).

During storage, transport, handling and fabrication, a variety of other soils and identification markings may be acquired. Where metal is stored for any length of time or under hard storage conditions, in particular when it is stored outdoors, corrosion products develop on the metal surface. All the above soils must be removed in the pre-processing step before coating application.

2.3.2 Roughening methods. State of the art

After the surface cleaning, a second step is necessary prior to the coating process. The adherence between the substrate and the coating is improved by activation of the surface (preparation of the surface by means of abrasive methods to obtain a surface roughness).

Grit blasting, laser pretreatment, water jet and mechanical methods are some techniques employed to activate the surface of the substrate before the coating deposition.
• **Laser pre-treatment**
The laser is a light source that produces coherent monochromatic radiation. Therefore, the total power of the beam can be focused onto a very small spot. Hence, high intensities (mega-watts per cm²) can be obtained. For surface modification, a high energy density as well as a high total power is necessary. The latter restrictions causes that infra red laser are most suitable for surface treatment applications. The basic principles of a laser are shown in fig. 2.15 [Ref 10].

---

![Energy pump](image)

**Energy pump**

High reflector  
Laser active medium  
Outcouple mirror

**Fig. 2.15. Basic principles of a laser. High reflector and outcouple mirror build a resonator**
Two types of high power infra-red lasers are available at this moment:

- Nd-YAG lasers have a mean maximum power of several hundreds of Watts. The low wavelength (1.06 µm) makes high power densities as well as transport through fibres possible. Most lasers of this type operate in a pulse-mode, using a flash light as pump source. The active medium is Neodymium-Yttrium Aluminum Garnet. Among the application are cutting and welding of plate materials as well as laser ablation.

- CW-CO\textsubscript{2} lasers have a maximum power in the multi-kW range. The active medium is a gas mixture of N\textsubscript{2} and CO\textsubscript{2}. Vibrational transitions in the CO\textsubscript{2} molecule give rise to the laser effect. Helium is added as a cooling medium. The 9% efficiency is almost an order of magnitude better than most of the other (non semi-conductor) laser types. Beside the cutting and welding applications, they are used for surface hardening, cladding and alloying.

The longer wavelength (10.6 µm) of the CO\textsubscript{2} laser leads to a lower absorption by metals compared to Nd-YAG laser. The higher power, however, makes the use of this laser necessary when a metal surface is melted to reasonable depths. It must be noted, however, that YAG lasers with higher output power are available nowadays, but their divergence angle is larger than the low power types. This results in a decreased maximum power density. As a consequence, such a laser is not suitable for cutting applications, but may be useful in laser melting applications of metals like aluminum and cooper, that exhibit low absorption.

**Advantages and disadvantages**

The advantages of the laser pretreatment for the activation of the surface previous to the coating process are:

- The process can be completely automated for industrial request
- It can be combined with coating treatment in only one step-process

The disadvantages of the laser pretreatment are:

- The capital requested to support the process and its investment cost is very high
- This process may cause structural changes in the surface of the substrate due to the high energy transfer
• It needs specialized personnel to carry out the pretreatment
• Actually, there is insufficient experience for a serial application

• **Grit blasting**

The grit blasting consist of a pressurized stream of hard metals or oxide grit material in order to clean and/or roughen the surface prior to coating deposition \(\rightarrow\) surface activation. A typical equipment used for grit blasting process is shown in the fig. 2.16. The equipment is composed of an air compressor, a hose to feed the abrasive particle and a blasting nozzle for throwing the stream.

Grit blasting is an abrasive method. The term ‘abrasive’ in blasting refers to a wide range of materials (blasting media) used to establish a rough profile on different substrates and remove unwanted coatings or contaminants from the surface of the substrates.

![Grit blasting facilities of IFKB](image)

Fig. 2.16 Grit blasting facilities of IFKB

There are a number of physical considerations in the selection of a suitable media. As the grains impact the surface, there is a tendency for them to break down forming a potentially harmful dust. In addition, it influences the energy transfer from the abrasive to the substrate. As the kinetic energy is proportional to the mass of the grain and the square of its velocity, a small, heavy grain moving at high speed will have more effect on a substrate than a larger, lighter grain. From this, it can be seen that heavier (denser) materials such as steel and
garnet are more efficient blasting media than lighter (less dense) media, such as sand and slag.

Two different nozzles are available to carry out grit blasting process. One system uses the same hose to feed the air pressure and the abrasive particles (see fig. 2.17), with this system is possible achieve a velocity of particle around 140 m/s. The other one uses a hose to feed air pressure and a second hose to provide the abrasive, see fig. 2.18, with a velocity of particle around 80 m/s.

Grain shape is also very important as rounded and angular grains behave differently when they impact a substrate such as steel. Angular grains tend to give rise to more broken particles and more dust whilst more rounded particles present a larger proportion of their surface to the substrate and lead to reduced problems with the embedding of media into the surface. Another very important property of abrasive media is its hardness. Hardness is a relative measure of the media’s resistance to abrasion by other materials.

**Particle behavior**
Behavior of small particles thrown or blown against a work piece.

1. Particles cannot effectively do the required amount of work on the work surface if the “cloud” of particles arriving at the surface is too dense. This is particularly critical in cases where the fine particles are used. A very close spacing of particles leads to increased particle interference. The component surface can be covered by a layer of moving particles, which interfere with the trajectory of new on-coming particles.

2. Particles decelerate, or loose their speed rapidly after leaving the accelerating device. The lighter and the smaller the particle the more rapid the rate of deceleration. Thus, nozzle distance is a factor in optimizing the blasting process (a small particle traveling
at a high speed can indent a surface to the same extent as a larger particle traveling at a lower speed).

3. A wheel or mechanical throwing device throws all size particles, for instance, steel shot, at the same speed. Wheel speed is varied to alter particle speed. A compressed air operated nozzle at a given pressure throws the large particles at a lower speed than the small particles. Two things can be varied to alter the speed of particles coming out of an air nozzle:

   a. the air pressure can be varied - this alters the air speed
   
   b. the weight of particles fed into the nozzle can be varied. A “rich” feed means low particle speed, a “lean” feed means higher particle speed

4. The weight of a particle of a given size varies with the specific gravity (density) of the particle material. High specific gravity particles (steel grits and steel shot) can be accelerated (thrown) by mechanical devices (wheels) and by compressed air nozzles. Low specific gravity particles (sand, aluminum oxide, glass beads) cannot be as effectively thrown by mechanical devices, but are effectively accelerated by compressed air.

5. In a mechanical device, the power is purely dependent on the weight of abrasive thrown per minute and the speed the abrasive is thrown at - which is a matter of wheel speed and wheel diameter.

6. In a compressed air nozzle, the kinetic energy of compressed air is used more dependent on other factors:

   a. compressed air throwing no abrasive will have more energy than one which has abrasive feeding through it. The volume or air passed through the nozzle decreases as abrasive is introduced into the air stream.
   
   b. the richer the feed, the less the air consumption.
   
   c. the leaner the feed, the more the air consumption.
   
   d. with feed rates that most effectively use the particular abrasive being blasted, the highest specific gravity particles use less air.
Tab. 2.2 Summary of abrasive characteristics [Ref 16].

<table>
<thead>
<tr>
<th>Abrasive</th>
<th>Composition</th>
<th>Mohs Hardness</th>
<th>Density (gms./cu. cm)</th>
<th>Dusting</th>
<th>Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica Sand</td>
<td>Crystalline Silica</td>
<td>7.0</td>
<td>1.6</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Best Quality</td>
<td>Same</td>
<td>6.5</td>
<td>1.6</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Average Quality</td>
<td>Staurolite/Zircon</td>
<td>7.5</td>
<td>2.0</td>
<td>Mod</td>
<td>No</td>
</tr>
<tr>
<td>Garnet</td>
<td>Iron Aluminium Silicate</td>
<td>7.5</td>
<td>2.0</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Almandine</td>
<td>Calcium Silicate</td>
<td>6.5</td>
<td>1.8</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Andradite</td>
<td>Iron Silicate</td>
<td>6.5</td>
<td>1.9</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Oliveine</td>
<td>Iron Oxide</td>
<td>6.0</td>
<td>2.3</td>
<td>Mod</td>
<td>Yes</td>
</tr>
<tr>
<td>Spec. Abrasive 1</td>
<td>Iron Silicate Glass</td>
<td>6.0</td>
<td>1.6</td>
<td>Mod</td>
<td>No</td>
</tr>
<tr>
<td>Copper Slag</td>
<td>Nickel Iron Glass</td>
<td>6.0</td>
<td>1.6</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Nickel Slag</td>
<td>Iron Silicate Glass</td>
<td>6.0</td>
<td>1.6</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Iron Slag</td>
<td>Cr. Iron Silicate Glass</td>
<td>6.0</td>
<td>1.4</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Steel Grit/Shot</td>
<td>Iron (Steel)</td>
<td>6.0</td>
<td>2.2</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Baking Soda</td>
<td>Sodium Carbonates</td>
<td>2.0-3.0</td>
<td>1.1</td>
<td>High/Low*</td>
<td>No</td>
</tr>
<tr>
<td>Coal Slag Glass</td>
<td>Alumina Silicate Glass</td>
<td>6.0</td>
<td>1.6</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Organic Media</td>
<td>Various</td>
<td>2-3</td>
<td>0.6-1.0</td>
<td>N/A</td>
<td>No</td>
</tr>
</tbody>
</table>

*High dusting when used dry: low dusting when used with water.

*High dusting when used dry; low dusting when used with water

Advantages and disadvantages

This pretreatment has these advantages:

- The equipment and its operation is very economical, by this way, very low investment cost is required
- This process needs very low process times
- The level of compressive stresses are high compare to the other pretreatments
- It is one of the most industrially applied pre-treatment processes
- Qualification level of the personnel to carry out the process is low

The disadvantages of this pretreatment are the next:

- Danger of incrusted corundum particles on the surface which lead to corrosion or coating failure
- An exhaustive cleaning of the surface with air is necessary to remove corundum particles before the coating step
- The degradation of the corundum particles leads to a variation in the surface properties therefore frequent analysis and replacement of the grit is necessary
• **Water jet**

This method delivers water as an abrasive media under high pressure. For light alloys this method does not required abrasive particles, however, for hard materials different substances mixed with the water are necessary. By adjusting the water pressure, raising or lowering the velocity of the water stream, or by changing nozzles, and therefore altering the spray pattern of water emitted, the jet characteristics can be adjusted to specific compound materials or different applications.

Water jet uses high pressure water blasting not only to clean surface of machining operations and lubricants, but also to attack the pores of the microstructure in order to produce a surface texture. The evolving profile is characterized by small pits with undercuts, comparable to a grit-blasted surface. This kind of surface is excellently suitable for thermal spraying applications. The finely pitted surfaces provide both increased surface area for adhesion and increased texture for mechanical interlocking between substrate and coating. This method is suitable for light weight alloys as aluminum alloys and magnesium alloys, and for nonferrous metal surfaces [Ref 14].

Therefore, water jet can be used as an alternative solution to the problems provided by grit blasting. Another difference between grit blasting and high pressure water jet blasting is the higher degree of texture (i.e. more pitting on the surface).

Water jet can be employed with or without abrasive particle to achieve the rough surface depending on the substrate and the roughness required. An abrasive water jet is a jet of water which contains abrasive material. Usually, the water exits a nozzle at high speed and the abrasive material is injected into the water jet, see fig. 2.19. This process is called entrainment of the abrasive particles. Hence, the water jet becomes the moving mechanism for the particles. However, a high speed jet of a pre-mixture of abrasive and water would also be defined as an abrasive water jet.
Fig. 2.19 Schematic illustration of an abrasive water jet tool with additional abrasive particle feed

**Types of abrasives**

A large number of different types of abrasive materials are used for abrasive water-jet blasting. Can be distinguished two major groups of abrasive material: oxides and silicates, see table 2.3. The evaluation of an abrasive material for abrasive water-jet processes includes the following important parameters [Ref 9]:

- Material structure
- Material hardness
- Mechanical behavior
- Grain shape
- Grain-size distribution
- Average grain size

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Garnet</td>
</tr>
<tr>
<td>Magnetide</td>
<td>Almendine</td>
</tr>
<tr>
<td>Ilmenide</td>
<td>Spessartine</td>
</tr>
<tr>
<td>Corundum</td>
<td>Porype</td>
</tr>
<tr>
<td>Rutile</td>
<td>Grossularite</td>
</tr>
<tr>
<td>Quarz</td>
<td>Andratite</td>
</tr>
<tr>
<td></td>
<td>Other silicate</td>
</tr>
<tr>
<td></td>
<td>Zircone</td>
</tr>
<tr>
<td></td>
<td>Topas</td>
</tr>
<tr>
<td></td>
<td>Olivine</td>
</tr>
<tr>
<td></td>
<td>Staurelite</td>
</tr>
</tbody>
</table>
The choice of the abrasive material depends on cost and material properties. In the following, the general classes of common abrasives are discussed. Silicate is commonly used for abrasive blasting where the grit can not be reclaimed in permanent cyclic use. Such as for hand blasting of large parts. Sand has a rather high breakdown rate, which can result in substantial dust generation. Human exposure to free crystalline silica is to be considered when silica sand is used for abrasive blasting.

Coal and smelter slags are commonly used for abrasive blasting at shipyards. Black Beauty TM, which consists of crushed slag from coal-fired utility boilers, is a commonly used grit. Slags have the advantage of low silica content, but have been documented to release other contaminants, including hazardous air pollutants, into the air.

Oxide abrasives include cast iron and steel balls as well as cast iron grit. Cast iron shot is hard and brittle and is produced by spraying molten cast iron into a water bath. Cast iron grit is produced by crushing oversized and irregular particles formed during the manufacture of cast iron shot. Steel shot is produced by blowing molten steel. Steel shot is not as hard as cast iron shot, but is much more durable. These materials typically are reclaimed and reused.

Synthetic abrasives, such as silicon carbide and aluminum oxide, are becoming popular substitutes for sand. These abrasives are more durable and create less dust than sand. Synthetic abrasives typically are recycled.

Other abrasives include mineral abrasives (such as garnet, olivine, and staurolite), cut plastic, glass beads, crushed glass, and nutshells.

**Equipment**

Water jet blasting equipment is already available commercially, and it is used in a number of processing operations such as the cutting of fabrics, plastics, wood, paper, glass and some metals, and the removal of all kinds of coatings from various substrates.
Specific components of a water jet blasting system include abrasive injectors, pressure generators, water guns, water tanks and a cabin as can be seen in fig. 2.20. An injection metering system controls the amount of abrasive added to the stream. In large systems, the delivery system and injection system may be separate components. Pressure generators increase the pressure of the water stream. Plunger-type intensifier pumps are commonly used to generate high water pressure for water jet cutting, wet or water abrasive blasting and non-abrasive pressure washing or rinsing. Crankshaft driven plunger pumps are also used for pressure generation. They are more efficient with respect to electrical energy costs compared to intensifiers, but, at high pressures seals must be periodically replaced. Crankshaft driven plunger pumps also provide a homogeneous pressure source in comparison to intensifiers. An accumulator may be required to adjust pressure fluctuations if an intensifier pump is used.

There are several considerations regarding the water jet abrasive blasting device. First, the velocity profile across the jet is not uniform. Hence, the particles tend to be concentrated on the side of the jet where the velocity is small. Additionally, as they enter into the jet, the particles tend to increase the turbulence of the jet. Therefore, much effort has been spent on the development of the abrasive particle delivery system.

In the following several other potential designs are given, two of which apply either gravitational force or air pressure for particle acceleration (see fig. 2.21), and the other using a pre-mixture of water and particles prior to jet formation (see fig. 2.22).
Blast cabinets are glove box-like vessels which the operation use to hold the workpiece and throw the water stream on its surface. Blast cabinets can be light from inside.

Blast booths usually consist of a room with internal lighting that holds both the workpiece and the operator. The operator may hold the blasting nozzle on the end of a lance. The workpieces rest on open grid flooring that allows blast water and removed debris to drop through for recycling or disposal.
Water guns or lances are the apparatus within water jetting and water blaster equipment that directs the stream of water through a nozzle and to the appropriate region of the workpiece.

The water tank or hopper is used for storage of water, cleaning agents, blasting media or abrasive-water slurry mixtures.

**Advantages and disadvantages**

The principal advantages that this methods provide are:

- High activated area and simultaneous cleaning of the surface is obtained because of the high water pressure and its cleaning effect
- Different fields can be treated with this technology (it can be used as a cleaning, abrasion or cutting process)
- It is easy to control and to automate and low qualification level of the personnel is required

The disadvantages of this process are:

- A high rate of removed material for light metal alloys (see fig. 2.24)
- The surface obtained is not uniform in comparison with other processes as grit blasting
- This process requires high cycle times
- A drying step after blasting is necessary in order to avoid corrosion in the case of water jet blasting without abrasive particles; in the other case, an additional step to clean the surface is required
The cost of the facilities is medium, it is between the laser facilities and the grit blasting facilities

- **Mechanical processes**

There are a lot of different mechanical methods for machining of a surface, but only a few of them can be used as surface activation methods for thermal spraying. Milling and grinding are being used and analyzed in this research. Adhesive strength and the roughness prior to the coating have been compared with grit blasting.

**Grinding**

It is believed that grinding which has not been attempted before for this application, can potentially increase the surface area of a treated substrate to the levels attained through chemical etching. Due to the novelty of this approach, it is important to identify any correlation between the nature of the substrate and the resulting surface area increases [Ref 11].

Grinding is a process of material removal in which a wheel (composed of abrasive grit, e.g. corundum or SiC, bound in polymer or hard metal matrix) wears away a softer material. Almost any material can be ground e.g. aluminum, steel, ceramics or glass. Grinding is used to form countless types of products such as automobile engines, sharp edges on knives, ball bearings and drills.

Grinding is divided into different grades. Clearly the degree of roughness caused is determined by the size of the particles and the process parameters.
Milling

Milling is a process of cutting away material by feeding a workpiece past a rotating multiple tooth cutter. The cutting action of the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The typical types of milling processes are shown in fig. 2.25.

![Peripheral milling](image1)
![Face milling](image2)
![End milling](image3)

**Fig. 2.25 Classification of milling**

**Classification of milling**

- Peripheral milling
  
  In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the workpiece surface to be machined [Ref 12].

- Face milling
  
  In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface. The milled surface results from the action of cutting edges located on the periphery and face of the cutter.

- End milling
  
  The cutter in end milling generally rotates on an axis vertical to the workpiece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.
Methods of milling

- Up-cut Milling

Up milling is also referred to as conventional milling. The direction of the cutter rotation opposes the feed motion. For example, if the cutter rotates clockwise, the workpiece is fed to the right in up milling [Ref 13].

![Fig. 2.26 Up-cut milling](image1)

![Fig. 2.27 Down milling, synchronous milling](image2)

- Down Milling (synchronous milling)

Down milling is also referred to as climb milling. The direction of cutter rotation is same as the feed motion. For example, if the cutter rotates counterclockwise, the workpiece is fed to the right in down milling [Ref 13].

The chip formation in down milling is different from the chip formation in up milling. The figure for down milling shows that the cutter tooth is almost parallel to the top surface of the workpiece. The cutter tooth begins to mill the full chip thickness. Then the chip thickness gradually decreases.

Other milling operations are shown in fig. 2.28 [Ref 12].

![Fig. 2.28 Milling operations](image3)
Advantages and disadvantages

The advantages for the grinding and the milling process are:

- These methods and processes are well known in the industry and they are used frequently in different fields (e.g. cleaning or cutting)
- They are very economical compared to other pre-treatment methods as laser
- The qualification necessary to carry out these processes is relatively low, the most important one is working experience

The disadvantages of these methods are:

- Both methods have a high rate of removed material and very accurate processes are needed to achieve a high level of activated surface
- These processes usually need lubricants, and a second cleaning step is necessary prior to coating deposition in order to avoid the presence of a layer of oil between the substrate and the coating

Needle machining

The machine consists of a head of needles that comes into contact with the workpiece surface with different inclination, usually between 60 and 90° operating angle. The needles are moved by a pneumatic, mechanic or electric source, so that they oscillate in longitudinal direction at same time that a vibration of them is produced (see fig. 2.29). The needles pit the work surface continuously, providing a roughness structure without removal. The final structure depends on the number of needles, the angle and the number of cycles [Ref 15].

Fig. 2.29 Needle machining process (DaimlerChrysler AG patent) [Ref 15].
The material of the needles usually is ceramic, hardened metal or another bulk metal.

With this method, it is tried to eliminate the wash process after blasting in order to avoid corundum particles being pushed into the surface of the substrate before coating, which can cause adhesion or corrosion problems.

By means of this process, bigger compressive strains are obtained in the surface than with other blasting techniques (and without material removal). An activate surface is achieved, suitable for thermal spraying, without additional treatment prior to coating.

**Advantages and disadvantages**

The advantages that are known for this method are:

- There is no material removal
- It is not necessary to apply an additional treatment before the coating step. No oils or lubricants are used
- Higher compressive strains are obtained in the surface than with other blasting techniques

The principal disadvantage of this method is that it is not known in the industry, it is a new process an requires more experience for serial application. Additionally, only relatively simple geometries can be treated.
3 Measurement techniques

3.1 Roughened measurement

The roughness values of the pre-treated surface and its topography are decisive parameters for the subsequent coating adhesion and deposition efficiencies. The equipment employed to obtain these values is shown in fig. 3.1. The results are obtained by using a Mahr Perhometer™ equipment.

This kind of equipment is based on the tactile sampling of the surface topography by a small taster that covers the surface of the substrate. This taster goes along the surface of the substrate and gives us a profile and a roughness measurement. These analyzed roughness measurements will be Ra and Rz, values. To take the measurements, a Taster MFW-250 has been employed.

In order to obtain reliable results, three measurements have been carried out over different places on the surface and the average measure has been calculated (Ra and Rz).

![Fig. 3.1 Mahr Perhometer™ equipment of IFKB used to measure the roughness](image)

3.2 Metallographic preparation

A metallographic preparation is necessary to analyze the metallographic samples and to measure the micro-hardness values. For the preparation of the metallographic samples, first of all the samples must be cut and embedded. After that a grinding and a polishing step takes place.
At first, the sample is cut with a saw to obtain a piece of 25x15 mm approximately. Then it is introduced and embedded into a cylindrical mould (3 cm high and 3 cm in diameter) and a mix with 13 mm³ of Epofix® and a 2 mm³ of hardener is prepared and poured into the mould. Later it is necessary to wait 8 hours for the curing of the sample.

Finally, the cured samples obtained have to be grinded and polished. It was done by a Struers® machine. The sample is held in a cylindrical support which has circular movement, at same time, the sandpaper has another circular movement too. The employed sandpapers are the same for AlMg7 and for St_42, but depending on the material, the grinding time is different. For AlMg7 is necessary 7,5 min per sandpaper with a force of 40KN, and for St_42, 5 min with the same force. After that, the sample has to be polished. Cloth disks were used with different micro-diamante suspensions to polish the samples, which size is 15, 6, 3 and 1 µm. In the case of AlMg7, it is necessary to apply a force of 40 KN during 30 min for a size of 15 and 6 µm, 20 min for 3 µm and 15 min for 1 µm. And in the case of St_42, the same force is applied during 15 min for a micro-diamante suspension of 15, 6 and 3 µm, and during 10 min for 1 µm of size.

### 3.3 Microscope investigating

In order to analyze and compare the profiles of the cross section of the different studied substrates, a LEICA™ light microscope has been used (see fig. 3.4).

In order to have a complete view of the profile, two photos have been taken per sample, one using a magnification of 10x and the other one using a magnification of 50x.
3.4 Micro-hardness measurements

In order to compare mechanical properties of the different substrates micro-hardness measurements by indentation technique were made. The equipment used was Ficherscope™ HCU, shown in fig. 3.5.

The indentation measurements were also used to evaluate the magnitude of the induced compressive stresses along the substrate depth (see fig. 3.6).
In our micro-hardness measurements a maximal force of 1000 mN were used, and the applied load was increased each 20 seconds.

To obtain Hardness-Vickers of our samples without coating, two diagonal lines have been made with six indentations each one to different depth, and the average to each depth has been considered the reliable value.

![Image](image.jpg)

Fig.3.6 Micro-hardness test in TP-TAM7-B (standard conditions)

### 3.5 Adhesion test

In order to determine the adhesion range that can be obtained with the different pre-treatments, adhesion test were made. To carry out this test a preparation of the samples is necessary. In order to obtain reliable results, five tests have been carried out per sample. The obtained measurements are based on the norm ISO 4624.

After cutting the samples, each piece was glued to a standardized nail (DIN 661) using a special glue (HTK ULTRA BOND® 100). To assure a good bonding and curing, the samples are heated in an electric furnace 35 minutes with a temperature of 190°C approximately.
After the curing process, a Zwick® machine model Z100® was used to obtain the adhesion values for each piece. This machine is controlled by computer, which gives the applied force per area unit (N/mm²) when delamination occurs.

![Zwick® machine model Z100® to measure adhesion](image)

Fig. 3.7 Zwick® machine model Z100® to measure adhesion

![Adhesion test for AlMg7 using Zwick® machine model Z100®](image)

Fig. 3.8 Adhesion test for AlMg7 using Zwick® machine model Z100®
3.6 Optical roughness measurements

To obtain topography measurements of the treated samples, an optical microscopy has been used. This microscopy is called confocal microscopy and its principle (as fig. 3.9 shows) consists in a light emitted from a point light source (for example a laser beam focused onto an illumination pinhole) which is imaged onto the object focal plane of a microscope objective MO (the first focusing). A specimen location in focus leads to a maximum flux of light through the detector pinhole (the second focusing), whereas light from defocused object regions is partly suppressed [Ref 17].

![Fig 3.9 The basic principle of confocal microscopy](image)

Thanks to this technique it's possible to obtain an accurate value of the total area of the different samples in order to compare them.
3.7 S.E.M

The pictures of the surface substrate were made by using a scanning electron microscope (SEM) LEO 438VP (variable pressure) as the fig. 3.11 shows.

SEM obtains an accurate image with a clear high resolution of the surface of the samples after using the different surface pretreatments thanks to an electron conduction (e.g. fig. 3.12).
3.8 Residual stresses measurements

The residual stresses can be measured by using the micro hole and milling method. The equipment to carry out this method is shown in fig. 3.13.

First of all, a preparation of the surface is necessary in order to obtain a cleaned surface of oils and dust. Three different grind size papers are used for grinding the samples and acetone for cleaning the removal material. After drying the surface, a gauge is fixed on it and a thin layer of catalyst is applied over the grinded surface prior to the stick of the gauge (bond adhesive). Now, the sample is fixed, and the drilling tool is placed in the center of the gauge as can be seen in fig. 3.13.
To carry out this method, a blind hole (d=1.8 mm) is drilled on the surface of the sample in order to measure the relaxation strains ($\varepsilon_{z0}$) of the material around the hole. This variation in the strains state is measured by means of strains gauges (DMS) and transformed into nominal strains ($\varepsilon_{zn}$) thanks to calibration curves combined with the Young’s modulus and the Poisson’s ration of the sample.

The hole is obtained step by step up a depth of 1mm.
4 Results and discussion

4.1 Experimental program

The following activation methods were studied and compared:

- Grit blasting
- Water jet blasting
- Mechanical methods:
  - Grinding process
  - Milling process

Two different substrates were studied:

- AlMg7
- Steel St42

After surface activation, the samples were coated with identical coating parameters:

- Powder 81,91,3 (GTV mbH), FeCr 13%, -45+5μm.

The following characterization of the samples was carried out:

- Roughness (tactile) and microhardness
- Adhesion test
- Residual stresses (hole drilling method)
- Metallographic investigation
- Optical measurement of surface roughness and topography

In the case of grit blasting and water jet investigation, two different substrates have been studied and compared, AlMg7 and St42. For both substrates, angle, pressure, velocity, passes and distance between them and the nozzle have been combined in order to determinate the properties of the treated surface (roughness, microstructure, micro-hardness) and the posterior coating (adhesive strengths, microstresses).
4.2 Grit blasting experiments

The considered standard conditions for grit blasting were angle 60° degrees, pressure 6 bar, lineal velocity 4 m/min, 3 passes and 150mm between nozzle and substrate. The used grit material was white corundum F60 with a grit size range of 212-300 µm.

In order to determinate the influence of each parameter, they have been modified independently, while the rest of parameters remain constant (see fig. 4.2).
The nozzle used is very important to determine the conditions of the blasting. The used nozzle is the injector grit blasting nozzle (explained in chapter 2.3.2), model Tetabor 3162/8 (internal diameter nozzle 8 mm, outer diameter nozzle 20 mm, length of the nozzle 50mm) shown in the fig. 4.3.

![Injector grit blasting nozzle used at IFKB facilities](image)

Fig 4.3 Injector grit blasting nozzle used at IFKB facilities

The different parameters employed for each sample are shown in the table 4.1. They have been differentiated depending on the used substrate, AlMg7 or St_42.

**AlMg7 samples:**

Tab. 4.1 Parameters combination for the grit blasting of AlMg7 samples

<table>
<thead>
<tr>
<th>Samples</th>
<th>Angle (°)</th>
<th>Pressure (bar)</th>
<th>Velocity (m/min)</th>
<th>Number of passes</th>
<th>Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP-TAM7-A</td>
<td>90°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-B (standard conditions)</td>
<td>60°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-C</td>
<td>30°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-D</td>
<td>60°</td>
<td>4 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-F</td>
<td>60°</td>
<td>8 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-G</td>
<td>60°</td>
<td>6 bar</td>
<td>2 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-I</td>
<td>60°</td>
<td>6 bar</td>
<td>6 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-J</td>
<td>60°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>2 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-L</td>
<td>60°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>4 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TAM7-M</td>
<td>60°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>100 mm</td>
</tr>
<tr>
<td>TP-TAM7-O</td>
<td>60°</td>
<td>6 bar</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>200 mm</td>
</tr>
</tbody>
</table>
St_42 samples:

Tab. 4.2 Parameters combination for the grit blasting of St_42 samples

<table>
<thead>
<tr>
<th>Samples</th>
<th>Angle (°)</th>
<th>Pressure (bar)</th>
<th>Velocity (m/min)</th>
<th>Number of passes</th>
<th>Distance (mm)</th>
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</thead>
<tbody>
<tr>
<td>TP-TSt-A</td>
<td>90°</td>
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<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-B</td>
<td>60° (standard conditions)</td>
<td>6</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-C</td>
<td>30°</td>
<td>6</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-D</td>
<td>60°</td>
<td>4</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-F</td>
<td>60°</td>
<td>8</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-G</td>
<td>60°</td>
<td>6</td>
<td>2 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-I</td>
<td>60°</td>
<td>6</td>
<td>6 m/min</td>
<td>3 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-J</td>
<td>60°</td>
<td>6</td>
<td>4 m/min</td>
<td>2 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-L</td>
<td>60°</td>
<td>6</td>
<td>4 m/min</td>
<td>4 passes</td>
<td>150 mm</td>
</tr>
<tr>
<td>TP-TSt-M</td>
<td>60°</td>
<td>6</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>100 mm</td>
</tr>
<tr>
<td>TP-TSt-O</td>
<td>60°</td>
<td>6</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

4.2.1 Roughness measurements

In order to analyze the roughness profiles of the pre-treated surface, the most useful roughness parameters are described:

**Surface roughness**

The structure of the surface is made up of surface asperities, or peaks and valleys. Surface asperities directly participate in the interaction of the treated surface with the used coating. These asperities are described by parameters of roughness and waviness, as well as flaws in the geometrical structure of the surface.

The profile is constituted by the line of intersection of the surface with a defined orientation relative to the nominal surface. Surface roughness is seen like distances between peaks and valleys. Roughness is defined as a set of asperities of a real surface, conventionally described as deviations of the measured profile from a reference line within the limits of a length along which waviness is not taken account.
The most common used parameter to define the roughness properties are described as follow (ISO 4287/1-1984 (E/F/R)) [Ref 8]:

**Ra.** Mean arithmetical deviation “Ra” of the profile from the center line average where “f(x)” represents absolutes values of distances between profile points and the center line along a length “L” of the measured surface.

The center line “m” of the profile is understood as a line dividing the roughness profile in such a way that the sum of the squares of deviations from the line is minimum; this line is oriented in agreement with the general direction of the profile;

\[ Ra = \frac{1}{L} \int_{0}^{L} |f(x)| \, dx \]

**Rz.** 10 point roughness height “Rz”, being the mean distance of five highest peaks to five lowest valleys along the length “l” of an elementary interval, measured from a reference line, parallel to the center line.

\[ Rz = \frac{1}{5} \left( Y_{p1} + Y_{p2} + Y_{p3} + Y_{p4} + Y_{p5} + Y_{v1} + Y_{v2} + Y_{v3} + Y_{v4} + Y_{v5} \right) \]

Where:
- \( Y_{p1}, Y_{p2}, Y_{p3}, Y_{p4}, Y_{p5} \): Altitudes of the five highest profile peaks of the sampled portion corresponding to the reference length “l”.
- \( Y_{v1}, Y_{v2}, Y_{v3}, Y_{v4}, Y_{v5} \): Altitudes of the five deepest profile bottoms of the sampled portion corresponding to the reference length “l”.
**Rmax.** Highest peak-to-valley height “Rmax”, or maximum distance between two lines, both parallel to the reference line, of which one passes through the highest peak and the other through the lowest valley of the profile, within limits of the elementary length “l”.

![Diagram of Rmax](image)

The roughness measurements for AlMg7 and Stain steel 42 are shown to next.

**Influence of the blasting angle on the roughness**

For the angle, three different inclinations were investigated: $\Theta=90^\circ$, $\Theta=60^\circ$ (standard conditions) and $\Theta=30^\circ$. The roughness measurements obtained for St_42 and AlMg7 are shown in fig 4.4.

![Graph of Roughness Measurements](image)

Fig 4.4 Roughness measurements for different angles in St_42 and AlMg7

These values have been calculated as average of three measurements in different places of the attacked surface to obtain reliable results. As can be seen the roughness for AlMg7 is
higher than for St_42, due to the different physical properties, because with the same parameters and the same grit the modified surface is very different. This is shown in figs 4.5-4.10 by light microscope.

Visually, although the roughness value obtained for $\Theta=90^\circ$ is similar than for $\Theta=30^\circ$, can be observed that the profile for $\Theta=90^\circ$ is abrupter than for $\Theta=30^\circ$. This means that the expected mechanical anchorage between substrate and coating will be better for $\Theta=90^\circ$, what should lead to a better adhesion.

There is a different profile for AlMg7 than for St_42. Although the roughness obtained for AlMg7 is higher, its surface is smoother.

An important influence of the blasting angle on the obtained profile can be observed. The most homogeneous topographies are expected for angles between 90° and 60°.

**Influence of the pressure on the roughness**

The next parameter is the compressed air pressure fed on the blasting gun. Three different pressures have been studied, $p=4$ bar, $p=6$ bar (standard conditions) and $p=8$ bar.

The roughness measurements obtained for different pressures are shown in fig. 4.11.
Fig. 4.11 Roughness measurements for different pressures in St_42 and AlMg7

In the graphic can be seen the importance of this parameter, as the pressure is increased the roughness increases too. Also an increase of the induced compressive stresses are expected (it studied in chapter 4.5.2).

The roughness is magnified with the pressure, Ra as well as Rz. The pictures of the six samples show very different profiles. A higher pressure induce abrupter profiles.
Influence of the velocity on the roughness

The substrates have been studied for different values of velocity, \( v = 2 \, \text{m/min} \), \( v = 4 \, \text{m/min} \) (standard conditions) and \( v = 6 \, \text{m/min} \). The roughness measurements for St_42 and AlMg7 are shown in fig 4.18.

![Roughness St_42-AlMg7 different velocity](image)

**Fig. 4.18 Roughness measurements for different velocities for St_42 and AlMg7**

It can be seen that the importance of this parameter is not so high such the pressure. The values are similar for the three velocities studied for both substrates, St_42 and AlMg7. The slightly lower roughness values for lower velocities could be an effect of the “over blasting” of the surface.

![Fig. 4.19 AlMg7 v=2 m/min](image) ![Fig. 4.20 AlMg7 v=4 m/min](image) ![Fig. 4.21 AlMg7 v=6 m/min](image)
The abrupter and more homogeneous profile was obtained with \( v = 4 \text{ m/min} \). A lower velocity (2m/min) shows an “over blasting” effect on the surface. A higher velocity shows a more heterogeneous profile due probably to a too high velocity that leads to a not suitable blasted surface.

For St_42, however, the “over blasting” effect is not observed, due to the higher hardness of the surface, the pictures obtained by light microscope are very different. It can be observed that the more homogeneous profile is also obtained for \( v = 4 \text{ m/min} \).

**Influence of the number of passes on the roughness**

The number of passes have been studied as well. Three substrates have been blasted changing the number of passes and remaining constant the other parameters. For 2 passes, 3 passes and for 4 passes. In St_42 and AlMg7 our samples obtained following results.

**Fig. 4.25 Roughness measurements for different passes for St_42 and AlMg7**
For AlMg7 by increasing the number of passes, increase also the Ra and the Rz values. The obtain cross sections can be observed in figures 4.26-4.31.

The profile of AlMg7 is abrupter for n=3 passes, but the higher Ra value is for n=2 passes, due to an inhomogeneous blasting of the substrate that origins a waviness. The “over blasting” effect is shown for samples blasted with 4 passes.

The photos for St_42 show that the profile for 2 passes is the abruptest, however its value of Ra is the smallest.

**Influence of the distance on the roughness**

The three used distances to determinate its influence have been d=100 mm, d=150 mm (standard condition) and d=200 mm between nozzle and the substrate. For our samples the obtained graphics are as follow:
It can be seen that for AlMg7 and d=200 mm the higher Ra value is obtained, but with similar results. However, with the light microscope the difference between their profiles can be observed.

For St_42 there are no significant differences for the Ra values for the three different distances.

Fig. 4.32 Roughness measurements for different distances for AlMg7

Fig. 4.33 AlMg7 d=100 mm   Fig. 4.34 AlMg7 d=150 mm   Fig. 4.35 AlMg7 d=200 mm

Fig. 4.36 St_42 d=100 mm   Fig. 4.37 St_42 d=150 mm   Fig. 4.38 St_42 d=200 mm
In AlMg7 for d=200 mm, the obtained profile is smoother than for the other distances. With a distance of d=150 mm the obtained profile is abrupter, however, it has smaller Ra value.

For St_42 and a distance of d=100 mm a very irregular surface is obtained, probably due to a higher kinetic energy of the particles by impacting for this distance, for the AlMg7 substrate, an over blasting effect could appear reducing the roughness, on other side a smooth surface appears by increasing the distance, because an “over blasting” effect could appear by increasing the distance due to a wider blasting beam that leads to the re-blasting of some areas.

### 4.2.2 Micro-hardness measurements

An analysis of the microhardness on the blasted surface has been carried out for the different parameter in order to obtain a relation between the grit blasting parameters and the possible compressive stresses induced on the substrates in to different depths on the cross section.

The fig. 4.39 shows the different indentation carried out to different depths in order to measure the micro-hardness.

![Fig. 4.39 Micro-hardness test for St_42](image)

**Influence of the blasting angle on the micro-hardness**

A micro-hardness research has been made for each sample blasted with different angles (\(\Theta=90^\circ\), \(\Theta=60^\circ\) and \(\Theta=30^\circ\)), the results for AlMg7 are shown in fig. 4.40.
As can be seen, the most important differentiation is achieved by a depth of 50µm, where the sample without grit blasting (HV-Sample) has 83.15 HV. By increasing the grit blasting angle, the induced micro-hardness increases as well, resulting on higher compressive stresses. The variation of the hardness for a higher depth can not be considerer, and it can be assumed that the low variations are related to imprecision in the measurement techniques and to inhomogeneous of the substrate (even for the not-treated substrate a variation on the hardness can be observed).

For St_42 the micro-hardness obtained is also significant for a depth of 50 µm.
It can be assumed that for different angles, and a depth measure, the difference between the sample not treated and the other blasted samples remains constant.

**Influence of the blasting pressure on the micro-hardness**

By changing the pressure for AlMg7 the following results were obtained:

![Microhardness AlMg7 different pressures](image)

As before, the micro-hardness is increased by attacking the surface with grit blasting. As expected, higher Vickers values are obtained by increasing the blasting pressure.

To continue, the micro-hardness measurements of St_42.

![Microhardness St42 different pressures](image)
The most important differences appear to a depth of 50µm, as in other examples. All the blasted samples result in higher micro-hardness and therefore it can be assumed in higher compressive stresses.

**Influence of the velocity on the micro-hardness**

For AlMg7 and for $v=2$ m/min, $v=4$ m/min and $v=6$ m/min these are the obtained results.

![Microhardness AlMg7 different velocity](image)

In the same way, the results for a depth up to 50 µm are always higher for the blasted substrates than for the sample without blasting.

For St_42 the same measurements have been realized.

![Microhardness St42 different velocities](image)

Fig. 4.44 Micro-hardness measurements for different velocities for AlMg7

Fig. 4.45 Micro-hardness measurements for different velocities for St_42
In both substrates (AlMg7 and St_42) a lower blasting velocity results in a higher induced stresses and therefore in a higher micro-hardness values.

**Influence of the number of passes on the micro-hardness**

The compressive stresses have been studied for 2 passes, 3 passes and for 4 passes.

For AlMg7 the results to different depths are shown in fig 4.46.

![Microhardness AlMg7 different passes](image)

Fig. 4.46 Micro-hardness measurements for different passes for AlMg7

The micro-hardness measurements obtained for St_42 have been the next.

![Microhardness St42 different passes](image)

Fig. 4.47 Micro-hardness measurements for different passes for St_42
The influence of the blasting can be specially observed until a depth of 50 µm. The influence of the different passes is difficult of assess.

**Influence of the distance of blasting on the micro-hardness**

The different distance have been 100mm, 150mm and 200mm. At first AlMg7 was researched and the results are shown below.

![Microhardness AlMg7 different distances](image)

Fig. 4.48 Micro-hardness measurements for different distances for AlMg7

As can be seen, the sample without blasting has the smallest micro-hardness to 50 µm of depth, and that when the depth is increased the values are similar.

Micro-hardness measurements were obtained with the next results for St_42.

![Microhardness St42 different distances](image)

Fig. 4.49 Micro-hardness measurements for different distances for St_42
As before, for 50 µm of depth is obtained the most difference between the sample and the rest of probes. In this case is difficult to identify a trend and a difference between the three investigate blasting distances.

The micro-hardness values obtained for AlMg7 and St_42 are very similar and it is not possible to consider a tendency of the measurements. The microstructure of the substrate and the tolerance of the measure equipment induce the different values of micro-hardness for a higher depth.

4.2.3 Adhesion tests

After measuring the roughness and the micro-hardness, every substrate has been coated by using a HVOF equipment, and a FeCr13% 81.91.3 powder from the firm GTV. Afterwards, they have been subjected to a traction test to measure the adhesion between the substrate and the coating (according to a modified ISO-4624) and therefore to establish a correlation between the grit blasting parameters and the coating adhesion.

In case of AlMg7 samples, also a substrate without blasting was coated in order to compare with the adhesion of the coating between a blasted and a non blasted substrate. These results are shown in fig 4.50.

<table>
<thead>
<tr>
<th>AlMg7 Adhesion with grit blasting</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/mm²</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>50</td>
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<tr>
<td>40</td>
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<tr>
<td>20</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>0</td>
</tr>
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</table>

<table>
<thead>
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<th>θ=30°</th>
<th>P=4</th>
<th>P=6</th>
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<th>V=4</th>
<th>V=6</th>
<th>N=2</th>
<th>N=3</th>
<th>N=4</th>
<th>D=100</th>
<th>D=150</th>
<th>D=200</th>
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</thead>
<tbody>
<tr>
<td>Adhesion</td>
<td>37.45</td>
<td>80.1</td>
<td>76.81</td>
<td>76.42</td>
<td>81.14</td>
<td>76.81</td>
<td>80.07</td>
<td>84.8</td>
<td>76.81</td>
<td>82.17</td>
<td>81.79</td>
<td>76.81</td>
<td>81.44</td>
<td>78.82</td>
<td>76.80</td>
</tr>
</tbody>
</table>

Fig. 4.50 Adhesion test for AlMg7 with grit blasting

Failure of the glue.
It can be seen that even for the sample without previous blasting an adhesion up to 37MPa can be obtained, this is due to the “blasting effect” of the semi molten particles with very high kinetic energy by impacting onto the substrate during the coating process (see figs 4.51-4.52). Nevertheless, the adhesion values are far away from the obtained on the previously blasted surface.

With several samples the ultimate strength of the glue was achieve, resulting in a failure of the glue, and therefore the real adhesion value can not be obtained, being always higher than the graphic represented values.

In the case of St_42, due to the higher hardness, the blasting effect during does not take place, and delamination occurs. The fig. 4.53 shows the result of St_42 coated sample without a previous treatment.

![a) Fig. 4.51 Cross section of AlMg7 without blasting](image1)
![b) Fig. 4.52 Cross section of AlMg7 without blasting after the coating.](image2)

![Fig. 4.53 Stain steel coated without pretreatment](image3)
For the St_42 grit blasted samples following measures were obtained.

<table>
<thead>
<tr>
<th>Roughness/Adhesion different angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra (µm)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>90°</td>
</tr>
<tr>
<td>60°</td>
</tr>
<tr>
<td>30°</td>
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<tr>
<td></td>
</tr>
<tr>
<td>N/mm²</td>
</tr>
<tr>
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</tr>
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<td>80°</td>
</tr>
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<td>70°</td>
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<tr>
<td>Ra St_42</td>
</tr>
<tr>
<td>3,803</td>
</tr>
<tr>
<td>3,676</td>
</tr>
<tr>
<td>3,056</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Ra AlMg7</td>
</tr>
<tr>
<td>4,863</td>
</tr>
<tr>
<td>5,316</td>
</tr>
<tr>
<td>4,646</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>N/mm² St_42</td>
</tr>
<tr>
<td>61,96</td>
</tr>
<tr>
<td>51,65</td>
</tr>
<tr>
<td>46,37</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>N/mm² AlMg7</td>
</tr>
<tr>
<td>80,096</td>
</tr>
<tr>
<td>76,805</td>
</tr>
<tr>
<td>76,416</td>
</tr>
</tbody>
</table>

Fig. 4.54 Adhesion test for St_42 with grit blasting

**4.2.4 Roughness vs. adhesion**

In order to identify a relation between the obtained adhesion and the roughness of the surface, both values have been compared. For AlMg7 the next fig. 4.55 shows us the results.
It can be seen that the highest value of adhesion does not correspond with the highest roughness measurement.

In the case of St_42, the adhesion results are lower compared to the adhesion by AlMg7 substrates. In this case the best anchorage between substrate and coating appear when the roughness measurement is higher.

Now for different pressures are shown in fig. 4.56.

![Roughness/adhesion different pressures](image)

<table>
<thead>
<tr>
<th>Roughness/adhesion different pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra (µm)</td>
</tr>
<tr>
<td>Ra St_42</td>
</tr>
<tr>
<td>Ra AlMg7</td>
</tr>
<tr>
<td>N/mm² St_42</td>
</tr>
<tr>
<td>N/mm² AlMg7</td>
</tr>
</tbody>
</table>

Fig. 4.56 Roughness vs. adhesion using grit blasting for different pressures

There are different values of roughness between the studied pressures for AlMg7, however, the adhesion values remain approximately constant. The highest value for AlMg7 is not obtained for the highest roughness measurement.

The higher pressure (p=8 bar) for St_42 result on a higher roughness and adhesion, with Ra= 4,346 and 56,6 MPa.

For different velocities the values shown in fig. 4.57 were obtained.
For AlMg7 with $v=2\ \text{m/min}$ the maximal adhesion is researched. However, the difference between the surface roughness and the obtained adhesion results is not enough to identify a trend.

In the case of St_42 all values are also very similar and is difficult to obtain a reliable conclusion.

For different number of passes the results obtained are as follow:

Fig. 4.58 Roughness vs. adhesion using grit blasting for different passes
Now, for AlMg7, there is a clear difference between \(n=3\) passes and \(n=2\) or \(4\) passes. With \(2\) passes the roughness obtained is not very high, and for \(4\) passes there is an excess of blasting. Both cases give a good adhesion, better than for \(3\) passes.

The behavior of the St_42 is very different than the AlMg7, its higher resistance and hardness make that it was necessary an more intensive attack of its surface to obtain similar values than for AlMg7, for this reason with \(4\) passes the roughness measurement reaches approximately \(4\) \(\mu\)m, increasing its adhesion to near \(60\) MPa.

Changing the distance the measurements are shown below.

![Graph](image)

**Fig. 4.59 Roughness vs. adhesion using grit blasting for different distance**

After having studied the different parameters can be observed that for AlMg7 the most important values of adhesion are obtained for a roughness measurement approximately of \(5\) \(\mu\)m. For example when \(d=200\) mm its roughness measurement is \(5.09\) \(\mu\)m and its adhesion measurement is \(80.58\) MPa.

For St_42 the conclusion is different due to theirs properties, to get better adhesion, its roughness measurement must be near of \(4\) \(\mu\)m, and using \(d=100\) mm this is obtained by this way its adhesion value reach \(65\) Mpa, which is the maximum obtained value.
4.2.5 Roughness vs. thickness coating

In order to obtain a possible relation between roughness after pre-treatment and thickness of the coating (related to deposition efficiency), it has been carried out an investigation.

For AlMg7 the graphics obtained are different depending on the studied parameters. The fig. 4.60 shows the relation between roughness and thickness for different parameters using grit blasting.

As it can be seen, an important variation of the coating thickness appears changing the blasting parameters, but it is no possible to obtain a relation between this one and the roughness measurements.

The distance is the most influence parameter for the coating thickness, however, the roughness measurements are very similar for the different chosen distances.

A small coating thickness deviation due to the tolerances of the coating equipment (e.g. powder feeding, gas mixture) can be usual. However, the high obtained deviations in some cases (±20%) indicate the influence of the surface topographic with regard to the deposition efficiency. However, the decisive factor seems to be the topography of the surface, but not the Ra and Rz values.
4.2.6 Roughness vs. adhesion for combined grit blasting parameters

After studying the results can be observed the influence of the profile obtained by grit blasting for the adhesion for St_42. However for AlMg7 is not possible to determine the real values because the limit of the glue is reached. Therefore, the study has been continued working with St_42. A selection of the most important parameters during blasting has been made and they have been combined in order to optimize the adhesion values.

In the table 4.3 are shown the different choused parameters for St_42. The parameters which got the best results in adhesion test were chosen and combined in order to obtained new conclusions.

Tab. 4.3 New parameters for St_42 for grit blasting

<table>
<thead>
<tr>
<th>Samples</th>
<th>Angle (°)</th>
<th>Pressure (bar)</th>
<th>Velocity (m/min)</th>
<th>Number of passes</th>
<th>Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP-St_42-1-2704</td>
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<td>4 m/min</td>
<td>3 passes</td>
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</tr>
<tr>
<td>TP-St_42-2-2705</td>
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<td>4 m/min</td>
<td>3 passes</td>
<td>100 mm</td>
</tr>
<tr>
<td>TP-St_42-3-2706</td>
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<td>3 passes</td>
<td>150 mm</td>
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<tr>
<td>TP-St_42-4-2707</td>
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<td>8</td>
<td>2 m/min</td>
<td>4 passes</td>
<td>100 mm</td>
</tr>
<tr>
<td>TP-St_42-5-2708</td>
<td>60°</td>
<td>8</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>200 mm</td>
</tr>
<tr>
<td>TP-St_42-6-2709</td>
<td>90°</td>
<td>6</td>
<td>4 m/min</td>
<td>3 passes</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

The roughness obtained for these parameters are as follow.

Fig. 4.61 Roughness for St_42 using grit blasting
It can be seen that the values for the roughness are similar than the obtained before. But, in order to compare the results it is necessary to see the adhesion of these samples.

**Roughness-adhesion for St_42 new parameters**

![Graph showing roughness vs. adhesion for St_42 using grit blasting](image)

For these parameters, the adhesion was not improved and the roughness obtained was not increased by combination of the best parameters of the previous investigation.

### 4.3 Mechanical processes

Several mechanical processes have been taken into account as a surface activation method and compared with the grit blasting. Roughness measurements, adhesion test, microscopy and optical topography have been studied and compared.

#### 4.3.1 Roughness measurements

In this case, different millings and grinding have been studied. One difference with grit blasting and other roughening methods is that with these processes a material removal takes place. Furthermore, depending on the obtained surface structuring, strong variations of the profile can be observed depending on the measurement orientation. Therefore, two different directions have been measured.
Four different milling and two different grinding were studied. The parameters introduced by this research are as follow:

Tab. 4.4 Parameters for mechanical processes for testing.

<table>
<thead>
<tr>
<th>Process ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP_MPT1x</td>
<td>M 140n 3z, direction x</td>
</tr>
<tr>
<td>TP_MPT1y</td>
<td>M 140n 3z, direction y</td>
</tr>
<tr>
<td>TP_MPT2x</td>
<td>M 90n 3z, direction x</td>
</tr>
<tr>
<td>TP_MPT2y</td>
<td>M 90n 3z, direction y</td>
</tr>
<tr>
<td>TP_MPT3x</td>
<td>M 140n 6z, direction x</td>
</tr>
<tr>
<td>TP_MPT3y</td>
<td>M 140n 6z, direction y</td>
</tr>
<tr>
<td>TP_MPT4x</td>
<td>M 280n 3z, direction x</td>
</tr>
<tr>
<td>TP_MPT4y</td>
<td>M 280n 3z, direction y</td>
</tr>
<tr>
<td>TP_MPT5x</td>
<td>G 1mm, direction x</td>
</tr>
<tr>
<td>TP_MPT5y</td>
<td>G 1mm, direction y</td>
</tr>
<tr>
<td>TP_MPT6x</td>
<td>G 0.5mm, direction x</td>
</tr>
<tr>
<td>TP_MPT6y</td>
<td>G 0.5mm, direction y</td>
</tr>
</tbody>
</table>

The results obtained with roughness equipment for different millings and grinding are shown in figs 4.65-4.66.

Fig. 4.65 Roughness measurements for different mechanical processes in the direction x
Fig. 4.66 Roughness measurements for different mechanical processes in the direction y

As the graphics show us, for the direction “y” the higher roughness values were obtained, being the highest value achieved by milling n=90, z=3. Significant values are obtained for the two different orientations “x” and “y”.

The roughness measurements for grinding are very similar to the obtained with grit blasting.

In order to compare these results with the ones obtained for grit blasting, a coating of the samples was made, and the adhesion values were studied.

### 4.3.2 Adhesion tests

The adhesion test was carried out for the two mechanical processes with different machining parameters. The name and the parameters employed for each sample are shown in tab. 4.4. In fig. 4.67 can be seen the results for different milling and grinding processes. The coating parameters were identical than the previous coating for the grit blasting investigation.
The obtained values of adhesion are smaller than for grit blasting. Now, the roughness and the adhesion are compared to see its relation.

### 4.3.3 Roughness vs. adhesion for mechanical processes

The two considerate directions have been represented in the next graphic.

![Roughness-adhesion AlMg7 different mechanical processes](image)

![Graph showing the relationship between roughness (Ra) and adhesion for different mechanical processes](image)

Fig. 4.68 Roughness vs. adhesion for AlMg7 using mechanical processes
It can be seen that it is not necessary a high roughness to reach a high adhesion (compare the values for milling (140n 3z) with Ra=10.01 and grinding (1mm) with Ra=4.57). Therefore it is necessary to study the surface topography, to see the relation between the roughness, adhesion and the profile obtained with the different techniques.

In order to get this reference, an electronic microscope has been employed, and the pictures obtained for the different treatments are shown as follow:

Fig. 4.69 Milling n=140, z=3, 30µm
Fig. 4.70 Milling n=140, z=3, 5µm
Fig. 4.71 Milling n=90, z=3, 30µm
Fig. 4.72 Milling n=90, z=3, 5µm
Fig. 4.73 Milling $n=140$, $z=6$, 30µm

Fig. 4.74 Milling $n=140$, $z=6$, 5µm

Fig. 4.75 Milling $n=280$, $z=3$, 30µm

Fig. 4.76 Milling $n=280$, $z=3$, 5µm

Fig. 4.77 Grinding 1mm, 30µm

Fig. 4.78 Grinding 1mm, 5µm
It can be seen that for the figs. 4.73-4.74 (milling n=140, z=6) and the figs. 4.75-4.76 (milling n=280, z=3) the surface obtained has not been modified in the topography, that is because the value of “n” is too high and in the analyzed sample cannot not be appreciated the effect of the tool (their values of adhesion are the smaller because a high area has not been machined). However, for the figs. 4.69-4.70 (milling n=140, z=3), the figs. 4.71-4.72 (milling n=90, z=3), the figs. 4.77-4.78 (grinding 1mm) and the figs. 4.81-4.82 (grit blasting for standard conditions) the surface obtained is more homogeneous, and this coincide with the higher values of adhesion. In the case of milling processes, their roughness measurements are very high, around 10µm, and they have achieved around 76 MPa of adhesion.

The same value of roughness can be obtained for two very different topographies, this is shown in the fig. 4.83. In this case two idealized profile have been represented, the first one represents a profile obtained by grit blasting and the other one which a mechanical process.
The value of Ra is identical but the behavior they have regarding adhesion resistance is very different, because of the different homogeneity of the obtained profiles.

![Fig. 4.83 Schematic drawings of roughness for grit blasting (a) and for a coarse mechanical process (b)](image)

In the case of grinding processes, for the grinding with 1mm of thickness, the surface photographed is abrupt and uniform. The roughness measurement is of 4.57µm, and it achieves 79.7 MPa of adhesion.

For grit blasting in theirs standard conditions the topography obtained is the most homogeneous and uniform of all samples observed. Its roughness measurement is 5.386 µm and its adhesive value is 76.805 MPa.

### 4.4 Water jet blasting

In order to obtain a comparison with water jet blasting, eight samples were sent to WLH (University of Hannover) to be treated with water jet blasting. Water jet blasting was used without abrasive particles and 3000 bar of pressure using the conditions that the table 4.5 shows.

<table>
<thead>
<tr>
<th>Tab. 4.5 Parameters for water jet blasting for testing</th>
</tr>
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<tbody>
<tr>
<td><strong>TP-St_42-WJ1-2717</strong></td>
</tr>
<tr>
<td><strong>TP-St_42-WJ2-2718</strong></td>
</tr>
<tr>
<td><strong>TP-St_42-WJ3-2719</strong></td>
</tr>
<tr>
<td><strong>TP-AlMg7-WJ4-2720</strong></td>
</tr>
<tr>
<td><strong>TP-AlMg7-WJ5-2721</strong></td>
</tr>
<tr>
<td><strong>TP-AlMg7-WJ6-2722</strong></td>
</tr>
<tr>
<td><strong>TP-AlMg7-WJ7-2723</strong></td>
</tr>
<tr>
<td><strong>TP-AlMg7-WJ8-2724</strong></td>
</tr>
</tbody>
</table>
4.4.1 Roughness measurements

As before, the roughness is measured with the Perthometer, and the results are shown in figs. 4.84-4.85.

Fig. 4.84 Roughness measurements for different velocities for AlMg7 under water jet blasting

Fig. 4.85 Roughness measurements for different velocities for St_42 under water jet blasting
For water jet blasting the roughness values are very high compared with the grit blasted samples, the test was carried out with a low velocity (for grit blasting the lowest velocity used was 2 m/min and for water jet the highest is 0.1 m/min). A consequence of this is the quantity of material that has been removed with water jet blasting, as the fig. 4.67 shows.

![Removed material](image)

**Fig. 4.86 Picture of the cross section using a digital camera for AlMg7**

It can be observed in fig. 4.85 that for St_42 using v=0.01 m/min, the roughness obtained is higher than expected. However, a specially inhomogeneous in the topography can be observed (see fig. 4.89-4.90).

For the AlMg7 the graphic trend is very clear, when the velocity increases, the roughness decreases. For St_42 samples, compared with grit blasting, the values of roughness are very high.

A good mechanical anchorage bonding of molten particles can be assumed thanks to the profile obtained for water jet blasting samples, as shown in fig. 4.87-4.88.

![Fig. 4.87 AlMg7 sample without coating](image)

![Fig. 4.88 AlMg7 sample after coating](image)
Pictures with electronic microscope have been analyzed in order to have a better vision of the surface.

Fig. 4.89 St_42 p=3000 bar, v=0.01m/min  
Fig. 4.90 St_42 p=3000 bar, v=0.01m/min  
Fig. 4.91 St_42 p=3000 bar, v=0.02m/min  
Fig. 4.92 St_42 p=3000 bar, v=0.02m/min  
Fig. 4.93 St_42 p=3000 bar, v=0.005m/min  
Fig. 4.94 St_42 p=3000 bar, v=0.005m/min
Fig. 4.95 AlMg7 p=3000bar, v=0.01m/min
Fig. 4.96 AlMg7 p=3000bar, v=0.01m/min
Fig. 4.97 AlMg7 p=3000bar, v=0.02m/min
Fig. 4.98 AlMg7 p=3000bar, v=0.02m/min
Fig. 4.99 AlMg7 p=3000bar, v=0.03m/min
Fig. 4.100 AlMg7 p=3000bar, v=0.03m/min
It can be observed that in general the obtained topography is very homogeneous. Compared to grit blasting, more cavities are induced in the substrate what could lead to a better mechanical anchorage.

4.4.2 Roughness vs. adhesion for water jet blasting

An study was carried out in order to determinate the adhesion between substrate and coating. For the samples of AlMg7 the used glue, usually, reach the limit strength. For this reason this test is only compared for St_42, as the figure 4.105 shows.
Fig. 4.105 Roughness vs. adhesion for St_42 using water jet blasting for different velocities

It can be observed that, remaining constant the water jet blasting parameters, there is not a correlation between obtained Ra values and adhesion values for different velocities of water jet.

For St_42, the treated sample using a velocity of 0.02 m/min, very different adhesion values were obtained. For this sample, an adhesion values range between 33.34 and 63.86 N/mm² were obtained. A clear inhomogeneous topography of the surface can be observed in fig. 4.106.
4.5 Comparison of surface pretreatment methods

In order to compare the different surface pretreatments, measurements of the total activated area and residual stresses study have been carried out.

4.5.1 Comparison of the activated areas

A study of the activated area has been carried out in order to compare the surface pretreatments. The active surface measurements were carried out by using an optical equipment (confocal microscopy) at ITO, University of Stuttgart.

The profiles obtained by confocal microscopy for the different surface pretreatments are shown below.

For AlMg7:

Fig. 4.107 Water jet AlMg7 v=0.01m/min

Fig. 4.108 Water jet AlMg7 v=0.03m/min

Fig. 4.109 Water jet AlMg7 v=0.05

Fig. 4.110 Water jet AlMg7 v=0.1
Fig. 4.111 Grit blasting AlMg7 st.cond. 

Fig. 4.112 Milling process $n=140, 3z$ for AlMg7 

Fig. 4.113 Grinding 0.5mm for AlMg7 

For St_42: 

Fig. 4.114 Water jet St_42 $v=0.01$ 

Fig. 4.115 Water jet St_42 $v=0.005$
As can be seen, there are strong differences between the different surface pretreatments. For water jet blasting the higher depth is obtained, followed by grit blasting, milling and grinding process.

The homogeneity of the profiles also is very strongly. Special inhomogeneity can be observed by the milling process. An optimization of the milling parameters would be necessary. Grit blasting offers the most homogeneous profile.

A colour topography (in 2-D) considering the depth of the surface was taken. The results are shown as follow:

For AlMg7:
By using the measurements obtained by optical methods, a complete matrix of a region of each compared samples was taken. By means of Mat Lab, the total contact area was measured, calculated and compared, obtaining the graphic showed in fig 4.123.
As can be seen, water jet blasting obtains the higher contact surface for AlMg7 and for St_42. The high differences between AlMg7 and St_42 was expected, and the results are reliable and agree with the profiles obtained for the different surface pretreatments.

4.5.2 Residual stress - depth profiles

In order to evaluate and to compare the induced residual stresses on the surface for the different surface pretreatment, a previous understanding of the basics of residual stresses is necessary.

Residual stresses

In all materials subjected mechanical, thermal or chemical effects or a combination of any or all of them, there occur non-uniform volume changes, both reversible and irreversible, causing the formation of stresses. Stresses describe the state of internal forces and moments of forces, brought about by the interaction, in given locality, of two parts of the material, situated on either side of an apparent cross-section, the forces in question acting on a unit area of the cross-section.

After the removal of external effects, reversible changes (elastic deformations) undergo atrophy, along with stresses caused by them. However, some irreversible changes (plastic deformation) remain in the material, along with stresses caused by them which are referred to as residual stresses.
Residual stresses, in earlier times referred to as rest or final stresses, are those which are mutual equilibrium within a certain zone of the material which remain after the removal of external loading. Depending on the zone where this equilibrium occurs, the following types are distinguished:

- Macrostresses
- Microstresses

Macrostresses are formed as the result of any external loading, and balanced out in the entire volume of the body. They are regarded as the result of the joint, average interaction of microstresses. We assume the material to be homogenous having isotropic properties. They are formed when external effects in the form of mechanical loading, for example, causes non-uniform expansion of neighboring macrozones. The conservation of body continuity requires the formation, between such macrozones, of mutual interaction, tensile or compressive, which we call macrostresses. Macrostresses are caused directly by non-uniform plastic deformations, temperature changes, changes in the material structure or a combination of the above. They may be regarded as the result of the total average interaction of microstresses, assuming homogeneity (practically never existent in the micro scale) of the material microstructure, isotropic properties. These stresses cause changes of dimensions, deformed or cracking of the object or its superficial layer.

Microstresses are formed as the result of heterogeneity of the material (block of grains, single grains), which usually generate a non-homogenous stress field, often connected with texture and therefore exhibiting preferred orientation (so called stress texture). They are formed as the result of non-homogeneity of metallic structure, consisting of grains and grain blocks. When the grains belong to different phases, greater differences in properties occur. As the result of different changes due to transmittal of mechanical, chemical or thermal effects through grains and blocks, microstresses are formed at their boundaries, balancing out within microzones of grains or within a small number of grains. Microstresses are formed between separate components of microstructure and act upon various microstructure elements which already are subject to different microstresses. Therefore, they create a non-homogenous stress field. For this reason were sometimes referred to as structural stresses. Microstresses often constitute the result of the formation of a superficial layer. Their chief source is different crystal orientation and the associated anisotropy of elastic and plastic properties of the various crystals. Since after treatment (mainly deformation) the
microstructure usually exhibits a definite texture, stresses also exhibits a preferred orientation, called stress texture. Its final result is the anisotropy of the properties of material.

- **Residual Stresses in Thermally Sprayed Layer Composites**

During manufacturing of thermally sprayed layer composites various stress generating effects occur which significantly influence the coating and composite quality. The general reasons for stresses in layer composites are different thermal expansions in the composite material caused by temperature gradients and the mismatch in the mechanical and thermophysical properties ($E$, $\mu$, $\alpha$, $\lambda$, $C_p$) as well as non-uniform elastic and elastic-plastic deformations in the substrate and coating material due to thermal or mechanical loading [Ref 6].

Critical stress gradients cause coating failure, e.g. delamination in coating or interface, crack networks in the micro- and macrostructure, plastic material deformation or a shape distortion of the component. Tensile residual stresses reduce the composite lifetime under dynamic loading since it favors vertical crack formation and propagation. Also condensed corrosive products can penetrate the coating through microcracks, destabilize the coating and attack the substrate material. Therefore tensile stresses in the coating propagate stress corrosion cracks. Compressive stresses in the coating increase bonding and alternating fatigue strength.

The final residual stress situation of thermally spray coated components is superimposed by several individual stress mechanisms. The fig. 4.124 shows the different stress mechanisms in chronological order. The reason for residual stresses during manufacturing are temperature gradients in material combinations with originally incompatible thermophysical properties and mechanical loads occurring during substrate preprocessing, thermal spraying and final composite post-processing.
Substrate preprocessing - grit blasting (compressive stresses)

Thermal Spraying – kinetic energy of impacting particles (compressive stresses)

Thermal spraying – splat solidification (tensile stresses – microcracking)

Thermal spraying – quenching of the coating (tensile stresses – macrocracking)

Thermal spraying – cooling of the composite (tensile $\alpha_c > \alpha_s$ / compressive $\alpha_c < \alpha_s$ stresses)

Substrate processing – mechanical / thermal (polishing, honing, refining)

Manufacturing process of thermally sprayed layer composites

Fig. 4.124 Stress mechanisms during thermal spraying.

Substrate pre-processing in form of grit blasting with corundum of defined particle size induces compressive stresses into the substrate surface due to local non homogenous plastic deformations. The size and depth range of the compressive stresses depend of the blasting conditions (time, distance, velocity, pressure,…), the used shot (size and hardness) and finally the blasted components (geometry, hardness, deformation behavior).

During thermal spraying a large number of partially molten particles impact on the substrate and subsequent coating layers, deform disc shaped and solidify abruptly. The kinetic energy of the impacting particles induces compressive stresses into the composite material, depending on process velocity, percentage of particle fusion and thermophysical properties. When splats solidify, the contraction, restricted by the substrate, causes tensile stresses in the single splats. These microscopic stresses in the splats are relaxed by microcracking. Due to the temperature difference in the layer composite, quenching of the coating takes place. The expansion of the substrate on the one side and the contraction of the coating on the other side additionally induce macroscopic tensile stresses, so called quenching stresses, into the coating. After temperature compensation between substrate and coating, thermal stresses arise during subsequent cooling. The mismatch in the thermophysical
material properties, mainly the differences in the thermal expansion coefficients, result in tensile stresses for $\alpha_{\text{coating}} > \alpha_{\text{substrate}}$ and in compressive stresses for $\alpha_{\text{coating}} < \alpha_{\text{substrate}}$. The absolute macroscopic stress values depend on the Young’s Modulus ratio $E_{C/S}$, where $E_C$ is reduced by the coating porosity. In order to achieve defined surface qualities, mechanical surface post-treatment by means of grinding, polishing and lapping as well as a thermal treatment of the composites is necessary.

**Comparison of the residual stresses**

By using the micro drilling and milling equipment of IFKB the residual stresses were measured considering two directions in order to obtain the reliable results. Residual stresses were compared for AlMg7 samples. A sample per pretreated surface was studied. The parameters of each sample are:

- ✓ water jet blasting $\quad p=3000$ bar, $v=0.02$ m/min;
- ✓ grit blasting $\quad \Theta=90^\circ$, $p=6$ bar, $v=4$ m/min, $n=3$ passes and $d=150$ mm;
- ✓ mechanical process $\quad$ grinding 1mm;

![Graph showing measured surface strains](image)

**Fig. 4.125 Measured surface strains for different surface pretreatments**
Fig. 4.126 Residual stresses in direction “x” for different surface pretreatments.

For raw surface there were erroneous measurements between 300 and 400 µm of drilling depth and they were not taken into the count. Water jet blasting results in very low residual stresses with very low variation in depth, but due to the high material removal rate for this surface pretreatment compared with the other ones, the used scale for the depth is not reliable. Grit blasting induces the most residual stresses (compressive stresses) into the surface, and grinding shows the same trend as the raw (untreated) surface.

Fig. 4.127 Residual stresses in direction “y” for different surface pretreatments.
### 4.5.3 Evaluation of surface pretreatment methods

<table>
<thead>
<tr>
<th>Surface pretreatments</th>
<th>Adhesive</th>
<th>Active surface</th>
<th>Operation times</th>
<th>Range of application for different geometries</th>
<th>Facilities and investment cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grit blasting</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Water jet blasting</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Mechanical processes</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Laser</td>
<td>No evaluated</td>
<td>No evaluated</td>
<td>No evaluated</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

- **Very good** +++  - **Good** ++  - **Regular** +  - **Bad** -

Five characteristics (adhesion, activated surface, operation times, range of application for different geometries, and facilities and investment cost) of the different studied surface pretreatments methods (grit blasting, water jet blasting, mechanical processes and laser) have been considered to evaluate them.

Grit blasting and water jet blasting seem to be the most suitable methods for the activation of a surface prior to the coating. The main advantage of the grit blasting processes are the low investment cost and the simplicity for the integration in industrial applications. Moreover the operation times are very low compared with the other methods. Regarding the obtained adhesion values of the process, only the water jet blasting system release better results. On the other hand the facilities and investment cost and the operation times are the main...
disadvantages of this activation method. Mechanical processes are not very used as surface pretreatment prior to coating for their bad adhesion values, poor active surface and their little range of application.

To evaluate laser pretreatment, more information is required.
5 Summary and conclusions

The aims of the study were to carry out a comparison of grit blasting and other surface pre-treatment processes and identify the relation between grit blasting parameters and coating adhesion, because it can be assumed that the adhesion between substrate and coating strongly depends on the physical properties of the substrate surface. By this way, in order to improve the bonding between substrate and coating, it is necessary to study the influence of different surface pre-treatment parameters and to compare different pre-treatment techniques.

Grit blasting, water jet blasting and mechanicals processes (milling and grinding) have been studied. In order to compare them, the roughness of the surface, the adhesive straight, the topography, the contact surface and the residual stresses have been the considered parameters to carry out the research. Two different substrates have been studied, AlMg7 and St_42.

For grit blasting, five different blasting parameters have been analyzed and combined to obtain reliable results, attack angle, air pressure, lineal velocity, number of passes, and distance between substrate and nozzle. After measuring the obtained values, the most influence parameters were recombined and analyzed to obtain better surface conditions.

In the case of mechanicals processes (milling and grinding), the samples were studied for different mechanical parameters, analyzed and compared with the other surface pretreatments in order to obtain the most suitable method.

For water jet blasting, eight samples were sent to WLH (University of Hannover) to be treated. To carry out the pretreatment, the velocity of the water jet blasting was modify while the other blasting parameters remained constant, in order to compare the obtained values of roughness, adhesion, activate area and residual stresses for water jet with grit blasting and mechanical processes.

The next conclusions can be assumed:

The roughness is not so important than the topography to obtain the best adhesive bonding between the substrate and the coating, and the best bonding was obtained for homogeneous topographies (obtained for water jet blasting and grit blasting).
Comparing the surface pretreatments is observed that water jet blasting is the surface pretreatment method which leads to the highest bonding between substrate and coating.

It can be assumed that a higher contact surface area leads to a better adhesion between substrate and coating.

The residual stresses strongly depend on the surface pretreatment used. Grit blasting leads to the highest compressive stresses while water jet blasting almost does not cause variations and grinding obtains the same values than for a raw surface (untreated surface).
6 Bibliography


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Ref 16 Journal of Protective Coatings and Linings 2000; Pera 2003

7 Annex

Tab. 7.1. Physical Properties and Comparative Characteristics of Nonmetallic Abrasives.

<table>
<thead>
<tr>
<th>Description</th>
<th>Glass beads (a)</th>
<th>Coarse Mineral Abrasives (b)</th>
<th>Fine Angular Mineral Abrasives (c)</th>
<th>Organic Soft Grit Abrasives (d)</th>
<th>Plastics Abrasives (e)</th>
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</thead>
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<tr>
<td><strong>Physical Properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td>Spherical</td>
<td>Granular</td>
<td>Angular</td>
<td>Irregular</td>
<td>Cylindrical (diameter/length = 1)</td>
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<tr>
<td>Colour</td>
<td>Clear</td>
<td>Tan</td>
<td>Brown/white</td>
<td>Brown/tan</td>
<td>Nylon: white, polycarbonate: orange</td>
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<tr>
<td>Specific gravity</td>
<td>2.45 – 2.50</td>
<td>2.4 – 2.7</td>
<td>2.4 – 4.0</td>
<td>1.3 – 1.4</td>
<td>1.15 – 1.17, polycarbonate: 1.2</td>
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<td>Free silica content</td>
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<td>100%</td>
<td>.1%</td>
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<td>None</td>
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<td>Free iron content</td>
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<td>.1%</td>
<td>.1%</td>
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<td>Toxicity</td>
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<td>Low</td>
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<td>None</td>
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<td>Suitability for Wet Blasting</td>
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</tr>
<tr>
<td>Suitability for Dry Blasting</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Standard Size Ranges</td>
<td>20-325</td>
<td>8-20</td>
<td>90-235</td>
<td>60-325</td>
<td>0.76 by 0.76 mm (0.030 by 0.030 in.)</td>
</tr>
<tr>
<td>U.S. mesh</td>
<td>U.S. mesh</td>
<td>U.S. mesh</td>
<td>U.S. mesh</td>
<td>1.1 by 1.1 mm (0.045 by 0.045 in.)</td>
<td></td>
</tr>
<tr>
<td>Consumption Rate</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Very Low</td>
</tr>
<tr>
<td>Cost Comparison</td>
<td>Medium</td>
<td>Low</td>
<td>High/Medium</td>
<td>High/medium</td>
<td>High/Medium</td>
</tr>
</tbody>
</table>

(a) Glass beads are used for cleaning, finishing, light-to-medium peening and deburring. (b) Coarse mineral abrasives such as sand are used where metal removal and surface contamination are not considered. (c) Fine angular mineral abrasives such as aluminium oxide are used in cleaning when smooth finish and surface contamination are not important. (d) Organic soft grit abrasives, for example, walnut shells, are used in light deburring and cleaning of fragile items. (e) Plastic abrasives such as nylon and polycarbonate are used to deflash thermoset plastic parts and deburr finished machine parts.

Tab. 7.2. Abrasive Media Hazards

<table>
<thead>
<tr>
<th>Material</th>
<th>Particular Hazards</th>
<th>Other Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural Minerals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica Sand</td>
<td>Contains (relatively) high levels of crystalline silica. Possible carcinogen.</td>
<td>Illegal for use as an abrasive blasting media.</td>
</tr>
<tr>
<td>Garnet</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Olivine</td>
<td>Possible asbestos impurities.</td>
<td></td>
</tr>
<tr>
<td>Staurolite</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td><strong>Manufactured Media</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grit/Shot</td>
<td>None</td>
<td>Galvanic corrosion with some metals.</td>
</tr>
<tr>
<td>Glass Beads</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Glass Grit</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Aluminium Oxide</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Plastic Beads</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Sodium Bicarbonate</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Dry Ice</td>
<td>None</td>
<td>CO2 is an asphyxiant. Use ventilation.</td>
</tr>
<tr>
<td><strong>Mineral Slags</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper Slag</td>
<td>Heavy metal contamination possible.</td>
<td></td>
</tr>
<tr>
<td>Nickel Slag</td>
<td>Heavy metal contamination possible.</td>
<td></td>
</tr>
<tr>
<td>Coal Slag</td>
<td>Heavy metal contamination possible.</td>
<td></td>
</tr>
<tr>
<td><strong>Organic Media</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn Cobs</td>
<td>None</td>
<td>Potential for dust explosion.</td>
</tr>
<tr>
<td>Nut Shells</td>
<td>None</td>
<td>Potential for dust explosion.</td>
</tr>
<tr>
<td>Starch</td>
<td>None</td>
<td>Potential for dust explosion.</td>
</tr>
</tbody>
</table>

Certain abrasives such as silica sand (respirable quartz content), olivine (asbestos impurities) and mineral slags (leachable heavy metals, carcinogenicity) have been found to require special health and environmental protection measures when being used. However, all abrasives must be treated with care and used in a controlled measure, as required by legislative requirements such as the Control of Substances Hazardous to Health Regulations, Personal Protective Equipment Regulations and the Environmental Protection Act.

Source: Pera 2003