

Saint-Gobain - Coating Solutions

Thermal spray procedure

Flame spraying

Introduction.

Thermal spray technology is used for producing coatings on OEM's new components or to reconditioning damaged parts.

The main application of thermal spray coatings are :

- + Protecting against corrosion or oxidation,
- + Improving the wear resistance,
- + Increasing or decreasing the friction coefficient,
- + Reconditioning a damaged surface,
- + Acting as a thermal barrier coating,
- + Insulating electrically,
- + Acting as an electrical conductor coating,
- + Acting as a reaction barrier coating,
- + Bringing a decorative effect...

Basic description of the process.

Thermal spray technology consists in fusing a material in a thermal spray unit, then atomizing the fused droplets of material (sprayed particles).

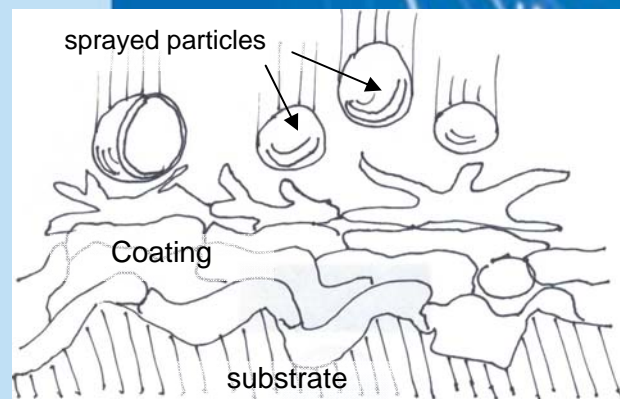
These fines and fused droplets of molten material are sprayed onto the part to be coated. We will use the terminology of substrate to name the part to be coated.

The size of the droplet is between $\sim 5\mu\text{m}$ to $\sim 100\mu\text{m}$. When the droplets are in the air stream, they do not have the time to cool down. The droplets are cooling down only when they impact the substrate. At impact they immediately bond at the surface of the substrate.

Difference between the spray processes.

Several processes are existing: combustion flames or electric arc can be used as a source to fuse the material. For atomizing the "droplets" of metal, a stream of compressed air can be used, or the thermal expansion of the gas is used to spray the droplets.

- + Electrical sources : Plasma Spray or Arc Spray
- + Combustion sources : Flame spraying, powder spraying, HVOF spraying.



Materials to be sprayed with our flame spray units :

A wide range of material can be sprayed with our flame spray equipment :

Wire spraying

- Copper alloys,
- Nickel alloys,
- Steels,
- Molybdenum
- Aluminum, Tin, Babbit,
- Zinc & Zinc / aluminum,
- Copper alloys,
- Nickel alloys,
- Steels.

Flexi-cords spraying

- Nialide, NiCrAlY bondcoat,
- Alumina, Alumina Titania,
- Chromium oxide, Iron oxide,
- Spinel, Mullite, Zirconia,
- Rocdur Self-fluxing alloys,
- Rocdur Tungsten carbides.

Ceramic rod spraying

ROKIDE A, MA,
ROKIDE MBA, MBAT,
ROKIDE C, MBC, TC,
ROKIDE AS, AM,
ROKIDE Z, EZ.

Main properties of the flame spray coatings

Bonding of thermal sprayed coatings :

The spray particles have high kinetic energy and high thermal mass, so that the particles are bonding onto the substrate and they are bonding together. These particles shrink due to their temperature loss, by this way gripping these roughness peaks.

The bonding is only a mechanical bonding. Flame spray coatings have higher particle-to- particle cohesive bonding making possible to produce thick coatings. The bond strength of a coating onto the substrate varies from 1200 PSI to 8000 PSI.

Physical adhesion (Atomic diffusion on a few atomic layers only) can also helps adhesion of flame sprayed coatings. This mechanism is activated by temperature, for example by pre-heating the substrate, lowering plasma gun / substrate relative speed (thus increasing thermal flux). When one intends to start development of a new couple coating substrate, it can be useful to test if this mechanism can activate by performing a test with preheating and comparing adhesion gained.

Chemical adhesion can be decisive in particular cases like molybdenum spraying on iron based substrates (FeMo or Fe₂Mo formation, thanks to high thermal energy of molybdenum particles with melting point at 2800°C)

Deposit efficiency :

The deposits efficiency is the ratio (%) between coating weight / weight of used material.

The deposit efficiency of the flame spray process doesn't dependent on the thickness of the coating. Usually, according to the material to be sprayed, the deposit efficiency varies between 40 to 85%.

Limitation of thickness :

When spraying on steel, we consider that the maximum possible thickness can be 0,6mm (0,02") to 0,8mm (0,03"). According to application, higher thickness can be reached such as:

- 1,5 to 3mm for special ceramic coatings
- 2mm to 7mm for special carbon steel coatings
- Refer to us for more details.

Roughness of the coatings :

Usually thermal sprayed coatings are rough : between Ra 4 μ m to Ra 15 μ m (160 μ inches to 600 μ inches). Often, the roughness of the coating increases with the coating thickness.

Porosity of the coatings :

The thermal spray coatings are porous. The porosity is comprised between a 3 % to 15%. The size of the pore varies from 1 to 10 μ m.

In order to avoid misunderstanding, it is important to notice : Even if our coating materials are corrosion resistant, they don't protect the substrate against the corrosion. In fact our coating are porous and they let the corrosive liquid/gas to be in contact with the base material.

Oxydation of the coatings :

During spraying, the flame affects the sprayed materials especially the metals spray material. It results a slight oxidation of the coating ranging from a few percent to 10%.

Stresses of the coatings :

Basically two kind of stresses are present in thermal sprayed coatings :

Quenching stresses – each particle cools after its arrival on the substrate. This particle is already bonded on the substrate when its temperature lower even more. This particle would like to shrink but can't do so : it keeps quenching stresses. These stresses are summed on each particle. Quenching stresses are higher when thermal expansion coefficient of sprayed material is high, particle temperature is high and substrate temperature is low, and also when elastic modulus of sprayed material is high.

Macrostressses of differential shrinkage – When coating operation ends, the coating and the substrate may have different mean temperatures and/or different coefficient of thermal expansion. Result is stresses formation while the coated component cools down. In critical cases (where CTE of substrate and coating are dramatically different), it is advised to keep the temperature as low as possible during spraying.

In order to limit stresses in coatings, strategy depends on each particular case and specially on CTE values : if coating and substrate CTE are close, it can be good to preheat before coating (will lower quenching stresses). If CTE are strongly different, it's usually better to limit temperature rise during spraying with a good cooling.

Procedure to produce coatings :

Degreasing:

Due to the fact that the bonding is mechanically ensured, it is very important to clean properly the parts to be coated. The part must be free of grease, oil, graphite, gum, silicon lubricant...

Alcohol, acetone, or industrial solvent are the usual solvents used to clean the parts. For choosing the adapted solvent, refer to your local specialized supplier.

Refer also to your local regulation, to know the list of prohibited solvents.

Blasting of the surface

For a proper mechanical bonding of the coating, the surface must be blasted with an abrasive.

The abrasive blasting (sometimes, improperly names sandblasting) consists in blasting the substrate an abrasive material with a powerful stream of compressed air. The purpose is to clean, remove oxide flakes and make the surface rough.



Blasting machine and blasting material requirement :

Portable or cabinet blasting machines are suitable to prepare the surface. The blasting gun must be set with nozzles diameter 6mm or 8mm or 10mm.

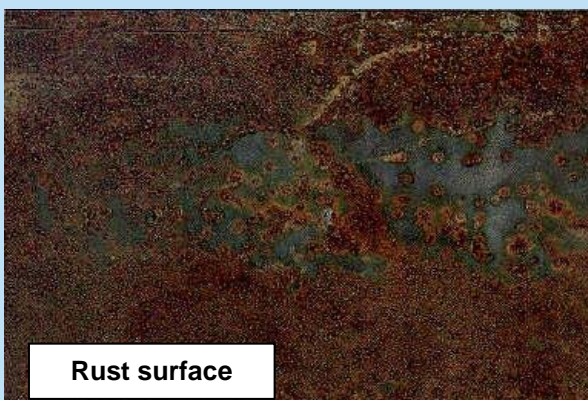
The usual size of the blasting grains is ranging from F36 to F46 for corundum media and WG40 to WG 50 for angular steel media. Only steel grit or brown corundum or white aluminum oxide or alumina-zirconia are approved media for blasting before thermal spraying; The shape of the grains must be angular.

On metal substrate, it is recommended to have an approx. 60° angle between nozzle axis and surface to be blasted to avoid corundum anchoring in the surface.



For flame spray application, the abrasive blasting preparation must meet two requirements:

- 1- The surface cleanness must conform to the "**white metal blast cleaning**" according to the European standard SA3 quality cleaning or the American standard SSPC SP5.



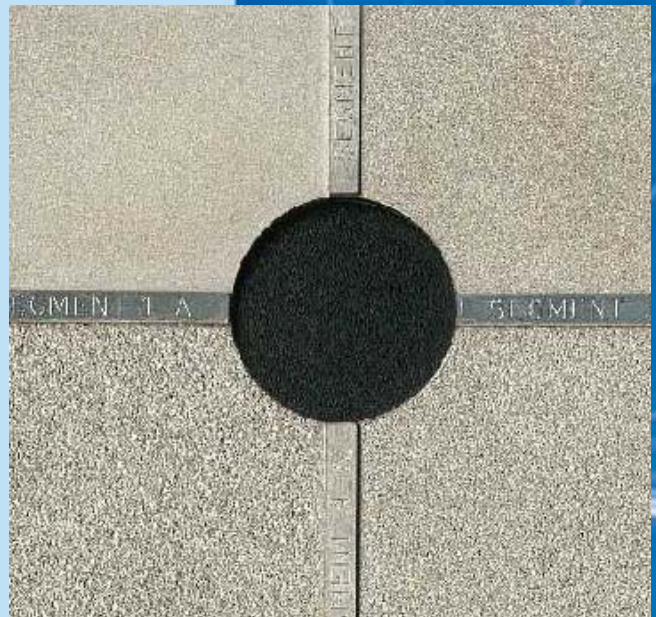
2- Surface must be **rough** enough in order to create an interface on which the coating bond strength will depend.

The value of this roughness is usually defined with the R_a scale. R_a 6 to $8\mu\text{m}$ (232 to $315\mu\text{inches}$). Some special applications could require lower roughness (R_a $4\mu\text{m}$) or higher roughness (R_a $10\mu\text{m}$).

The tool required to measure the roughness must conform the ISO 8503 standard.

For proper roughening, the surface should have a hardness less than Rockwell HRC-50. This assures maximum adherence of the sprayed coating.

After blasting, the surface must be free of residual abrasive grains.



Spraying the bond coat (undercoat)

As explained before the bonding of the coating versus the substrate is a mechanical bonding. This bonding should be strong enough to ensure the performance of the coating. A category of materials called self bonding, under coat or bond coat. They must be applied before the top layer, and they provide the highest bonding onto the substrate (5000 to 8000PSI). The Expansion Coefficient (C.T.E) of the substrate is different than the expansion coefficient of the (top-)coating. The difference between C.T.E, could create a delaminating phenomena between the coating and the substrate. This phenomena is accentuated when the coating is exposed at high temperature. The use of the bond coat helps for CTE adjustment.

It is important that grit blasting must be followed with a nickel-chrome based or nickel-aluminum based material. The bond coat is required for increasing the bond strength and minimizing problems associated with the differential of thermal expansion.

- The bond coat is applied as the first layer,
- The top coat is applied as the second layer,

Spray parameters for bondcoat:

- Follow the instructions given in the operating manual of the gun or given by the material data sheet.
- Spray distance : according to the material to be sprayed, the distance substrate versus the out-let of the nozzle is ranging from 120mm to 150mm.
- The relative speed between the flame spray gun and the torch must be between 30 m/min to 90 m/min. Notice that a low relative speed increases the roughness.

Note 1: before the introduction of Ni-based bond coat, the Molybdenum was used as a bond coat. Due to the price of the molybdenum and its low corrosion resistance, we recommend to use Ni-Based materials, such as our NiAlide, NiCraly or NiChrome flexicords.

Note 2: during spraying the bond coat, the substrate (part to be coated) must be able to withstand coating temperatures of 200-350°F (90-175°C). Additional air stream must be set for cooling the substrate or pause must be made between series of passes.

Note 3 : when spraying onto an aluminum substrate, we recommend to pay attention for keeping low the temperature of the substrate <210°F (<100°C).

Note 4 : For more details, refer to **§ Spraying the top coat**

Spraying the top coat

The topcoat material must be carefully selected to match the following requirements :

- The top-coat matches the specifications of the application : wear resistance, corrosion resistance, electrical features...
- The thickness of the top-coat must not exceed the maximum recommended thickness (usually 0,6mm (0,02") to 0,8mm (0,03"))
- The CTE between substrate and top-coat must be more or less compatible, in function of the operating temperature range,
- The topcoat materials must be chosen according to the available finishing capability (machining, grinding, brushing, polishing...).

Recommendations for spraying the TopCoat:

- Bond coat (reminder) : The Top Coat must be sprayed onto a Bond Coat. If application makes impossible the use of the bond coat, special attention must be paid to keep low the temperature of the substrate.
- Temperature control of the substrate & differential shrinkage:

When coating operation ends, the coating and the substrate may have different mean temperatures and/or different coefficient of thermal expansion. Result is stresses formation while the coated component cools down. In critical cases (where CTE of substrate and coating are dramatically different), it is advised to keep the temperature as low as possible during spraying 200-250°F (90-120°C).

If the CTE of the substrate and the CTE of the coating are much different, delaminating phenomena can appear between the TopCoat and the BondCoat (or the substrate). Additional air stream must be set for cooling the substrate or pause must be made between series of passes.

When spraying onto an aluminum substrate, we recommend to pay attention for keeping low the temperature of the substrate <210°F (<100°C).

- Spray distance : according to the material to be sprayed, the distance between the substrate versus the out-let of the nozzle is ranging from 80mm to 150mm.
- Gun speed and movement
The relative speed between the flame spray gun and the torch must be between 30 m/min to 90 m/min. Notice that a low relative speed increases the roughness. Below this range, heat thermal flux to the substrate is too high and may cause oxidation and stresses in the coating.

Flame spray gun generates a narrow stream of particles (from 3mm to ~10mm width depending on materials and parameters).

Each pass makes a line on the substrate. In order to ensure a perfect overlapping of these lines usually incremental step needs to be around 2 to 4mm

Masking

Masking : the areas defined free of coating must be masked. Special thermal spray tapes, resins or metal masks are used to protect the non-coated areas.

Impregnating thermal spray coatings

For special applications where enhanced electrical or corrosion resistant properties are required, impregnants can be used to fill the pores of the coating. Several solutions are possible:




- Polymer resin such as epoxy, phenolic, polyester and silicone have been used as sealant.
- Ceramic based impregnants such as gel or slurries.

These sealant are usually applied with an air gun or a brush and then dried at ambient temperature or in an oven.

Finishing thermal spray coatings

Flame sprayed surfaces can be successfully ground and finished in many ways. The method chosen can range from simple machining, hand polishing operations to off-hand grinding with coated abrasive belts, to the use of highly sophisticated precision grinders.

Factors which influence the finishing method used include the type of material to be ground, the shape of the part, the finish and tolerance required, the type of equipment available, and the economics involved:

-  Metal coatings bellow 32 HRC can be machined using tungsten carbide tools,
-  Metal coatings over 32 HRC must be ground to excellent surface finishes, using standard grinding equipment with properly specified silicon carbide or diamond grinding wheels.
-  Ceramic coatings are ground to excellent surface finishes. They can be ground to as low as Ra 4μinches (RA <0,2 μm) using standard grinding equipment with properly specified alumina zirconia grinding wheels or diamond grinding wheels (silicon carbide possible, refer to your supplier).

Remark : Flatness readings of less than 3 helium light bands are achievable using standard industrial lapping equipment.

Finishing Methods

Hand Polishing

Hand polishing can be effective on the softer white metals such as aluminum and zinc. These coatings will finish to a bright surface but tend to “load” the face of the abrasive media used. Frequent dressing or cleaning may be needed to restore the cutting ability of the abrasive. When hand finishing, coarse grits are usually used for stock removal, with successively finer grits being used to achieve the desired final finish.

While hand finishing is the most elementary method of generating a desired surface condition, care must be used in order to avoid breaking through the relatively thin sprayed on coatings to insure uniform thickness of the coating . Hand finishing of the harder materials can be very time consuming and is not recommended because of the time-cost factor.

Tumbling and Burnishing

When smooth finishes are required on a large quantity of very small parts or on parts with unusual contours, tumbling or burnishing can be very effective. When tumbling, the parts are placed into a vibrating or rotating tub containing abrasive media and water. The interaction of the abrasive and part polishes the sprayed-on coating. By selecting the proper abrasive and vibratory time cycle, acceptable finishes can be achieved. Burnishing is accomplished in much the same manner as tumbling, however, instead of abrading the surface to a finish, hard metal balls are used to compress the surface of the sprayed-on coating. The more pressure and the greater the frequency of ball to part contact, the smoother the surface will become. As in the case of all flame spray applications, the finer and more uniform the material is applied, the better the final finish will be.

Abrasive Belt Grinding

Sprayed metal and ceramic coatings can be effectively ground and polished with coated abrasive belts. In some instances, abrasive belts are used to improve the surface produced by prior operation, such as machining. In other instances, coated abrasive belts can be used to perform the entire grinding and finishing function. New developments in backing materials and in grain design have produced strong waterproof belts which are extremely sharp and durable. Belts made from these new materials produce excellent finishes and good stock removal rates.

Abrasive belts provide several advantages over other grinding media. Since they are cool cutting and do not require dressing, they can be changed rapidly when worn, and, in certain applications, abrasive belt costs are very favorable when compared to other machining methods. When grinding and polishing with coated abrasive belts, the part is usually fixtured or positioned in a lathe. The part is then either traversed or rotated under the belt head, while the belt is running at speeds of 6000 to 7000 SFPM. Coarse grit belts are used for rapid stock removal, while finer grit belts are used to improve finishes.

Grinding Wheels

Frequently, because of material type, or because of finish and tolerance requirements, the grinding wheel is the only practical means of processing thermal sprayed parts.

The most commonly used machines are O.D. grinders (cylindrical and center-less), surface grinders (horizontal and vertical spindle), and internal grinders. Machines of this type are used to produce uniform parts with good commercial finishes and close tolerances.

When using any abrasive media to grind and polish flame sprayed parts, it is most important to realize that flame sprayed surfaces of a given material are vastly different from the surface of the same material in its solid, wrought, or cast form.

The bond between the substrate, the layers of sprayed material, and between the particles themselves is strictly mechanical. If wheels of excessive hardness are used, or if the wheels do not cut freely, individual particles can be pulled from the surface of the workpiece, or, worse, the whole sprayed-on mass can delaminate from the substrate.

Furthermore, because the ductility of sprayed materials is very low, too much grinding pressure can cause the surface particles to shift or be displaced. It should also be noted that, because of the mechanical bond, heat conduction away from the point of the grind is not as efficient as it would be when grinding similar materials in their solid form. Therefore, burn and blistering can become a problem if the proper wheel and grinding technique is not used.

Rule I. Always use the sharpest wheel possible. Sharp wheels cut cool and fast

Grinding Wheel Selection

Wheel sharpness is governed by several factors, among which are the type of abrasive grain and the grit size.

Grain Type

Of the four major grain types used in the manufacture of grinding wheels, the two most commonly used for grinding flame sprayed surfaces are silicon carbide and diamond. Silicon carbide is chosen for its ability to fracture and present sharp new cutting points during the grinding action. Diamonds are used because of their durability and their ability to cleanly cut the harder alloys, ceramics, and cermets. Aluminum oxide and cubic boron nitride (CBN) are used only on occasion to grind some of the steel-based flame spray alloys.

Grit Size

Because of their smaller surface area and sharper points, fine grit abrasives will penetrate hard materials easier than coarse grit abrasives. The grit sizes normally used to grind flame sprayed surfaces will range from 46 through 80 grit, although finer grits may be used to generate finer finishes.

Rule II. Choose wheels with Structures and grades which provide free cutting action.

Wheel Structure Structure, as it relates to the grinding wheel, is the spacing

between the individual abrasive grains within the grinding wheel. Wheels with an open structure tend to grind more freely since the additional spacing between the abrasive grains provides greater chip clearance. Wheel structures are designated numerically, and, for sprayed materials, structures ranging from 5 to 8 should be employed.

Wheel Grades

Grinding wheels can be manufactured in varying degrees of hardness. While harder wheels will last longer, they also tend to cut more slowly, generate more heat and require more frequent dressing than softer wheels. Grinding wheel grades are designated alphabetically in the grinding wheel marking system. When grinding sprayed materials, grades ranging between F and L are suggested. In general, softer grades are used on large areas of contact or when grinding with wide wheels, when using light grinding pressures, and when attempting to achieve higher stock removal rates. Harder grade wheels are used on small areas of contact or with narrow wheels, when using heavy grinding pressures and when producing finer finishes.

Rule III. Choose the bond type best suited to the operation and equipment.

Vitrified Bond

Vitrified bonds, because of their porosity, rigidity, and strength, can provide high stock removal rates and precision tolerances. They are not affected by water,

acids, oils, or ordinary temperature variations. Most vitrified wheels are, however, limited to a safe operating speed of 6500 SFPM. Although vitrified bonds are the most common type of bond used for grinding flame sprayed materials, they should be used only after it has been established that the operating speed of the machine does not exceed the safe operating speed marked on the wheel.

Resinoid Bond

Designed to operate at speeds of 9500 SFPM resin bond wheels are used for rapid stock removal and to generate fine finishes. The most common application for resin bond in flame spray grinding is in diamond wheels. Although resin bond wheels are generally operated at higher speeds, the machine speed should never exceed the safe operating speed marked on the wheel.

Rule IV. Know the equipment machines and wheels.

Machines

It is important to know the machine being used for a particular grinding job and to understand its limitations. It is difficult, if not impossible, to generate precision ground surfaces and fine finishes on equipment that is not properly maintained. Chucks must be clean and able to hold the work accurately. Gibs and ways must operate smoothly, and machine spindles must run concentric to the wheel face with a minimum of vibration. While these factors may seem obvious, it is

sometimes surprising to note just how many grinders are now operating under less than optimum conditions.

Wheels

Careful attention to wheel mounting is important, because any irregularity in grinding pressures can cause poor finishes, poor tolerances, or, even worse, the destruction of the workpiece. When mounting a wheel, make sure it is in balance and that the wheel center-hole fits the arbor properly, and that the wheel runs true. Wheel sleeves, collets, and flanges should be carefully checked to assure they are not worn or distorted. When using cup, diamond, or CBN wheels, always leave them on their own collet after use. This will facilitate remounting and reduce the need for re-truing on subsequent operations.

Grinding Variables

Through a thorough understanding of the various grinding variables open to him/her, the grinder-person can make his/her job easier and more productive.

Wheel Speed

Wheel speed can have an effect on wheel performance and can affect finish and stock removal rates. Lower wheel speeds will cause a given wheel to act softer, while higher wheel speeds will cause the same wheel to act harder. For example, a K grade wheel normally operated at 5000 SFPM will act like an L grade wheel when operated at 6500 SFPM. Ideally, the speed of the machine should be changed so that the operating

SFPM is maintained at a constant rate as the wheel wears. However, the ability to change the cutting action of a given wheel by changing its speed can be of great help where wheel inventories are limited and finishing problems are encountered.

Work Speed

By varying the speed of the work, the cutting action of the wheel can again be altered. By increasing the speed of the work, the wheel will become more aggressive. By traversing the work more slowly, better finishes can be generated.

Area of Contact

The basic principle involved in all types of grinding is unit pressure. The greater the pressure, the greater the depth of abrasive grain penetration. On a given machine of fixed horsepower, a narrow wheel, because of its smaller area of contact, will exert more units of pressure per square inch than will a wider wheel. Because of this fact, narrow wheels are more aggressive than wider wheels. Narrow wheels are very effective where rapid stock removal is required, when very hard materials are being ground, and when low horsepower machines are used.

Wet Grinding

Sprayed materials can be successfully ground dry, as long as proper precautions are taken. However, the advantages of dry grinding are far outweighed by the advantages of wet grinding. When wet grinding, harder wheels may be used without increasing the incidence of

blistering or heat checking, pull-out of surface particles is minimized, and better finishes can be obtained; wheels do not load as fast and less dressing is required. Wet grinding will also help flush out grinding residues that otherwise might become entrapped in the porous structure of the flame sprayed surface. When grinding wet, effective filtration of the grinding fluids and the maintenance of proper concentration is as important to good finishes as is fluid cleanliness. Normally, water soluble oils with anti-welding agents are used when wet grinding flame sprayed materials. The manufacturer's recommendation for fluid concentration should be followed.

Wheel Dressing

During its use, the condition of the grinding wheel cutting face will change. After a period of time, either the abrasive grains on the face of the wheel will wear to the point where the height of the grain will equal the height of the bond, or the wheel face will become loaded with the material being ground. When either of these conditions occur, the cutting ability of the wheel will diminish, and more rubbing than cutting will take place. At this point, the wheel face must be reconditioned or dressed. It is important to note that, when dressing a grinding wheel with a diamond tool, the rate at which the tool is traversed across the face of the wheel governs the final cutting action of the wheel. A fast traverse will open the wheel face, re-sharpen the abrasive grains, and allow the wheel to

cut more freely. A slow traverse of the diamond tool will close the wheel face, dull the abrasive grains, and cause the wheel to act harder. While slow dressing rates can be used to produce finer finishes on conventional materials, slow dressing rates are not recommended for use on flame sprayed materials. The use of sharp diamond tools is also important. Be sure to rotate single point diamond tools periodically.

Finishing Techniques

Good, trouble-free finishes can be generated on flame sprayed parts, provided care is exercised during the finishing process. The following check list of grinding techniques will help make the job easier. • Use softer, free-cutting wheels. Chances of burn and pullout will be greatly reduced. • Keep the wheel face in a clean and sharp condition. Observe proper dressing techniques. • Use coarse grit wheels for stock removal, and fine grit

wheels for finishing. Attempting to generate fine finishes with coarse grit wheels that have been dressed closed can lead to pull-out, smearing, and burn. • Take light cuts. Sprayed coatings are usually very thin. Too much grinding pressure can cause delamination of the sprayed-on surface, or pull-out of surface particles. • Don't spark out on the final pass. Sparking out tends to glaze or dull the wheel face. • Grind wet whenever possible. Improved finishes, less chance of burn, and less part contamination will result. • Use finer grit wheels on hard to penetrate flame-sprayed coatings. • Use narrower wheels on machines with low horsepower, and for more rapid stock removal on hard materials. • When grinding, always attempt to keep the coating under compression. By cutting down through the sprayed surface towards the substrate, delamination and pull-out will be minimized. Vibration or chatter may

cause cracking of the sprayed coating. • If encountering problems with a given wheel, experiment with wheel speeds, feed rates, work speeds, and dressing techniques. Changes in these variables can have a great affect on stock removal rates and finishes.

Summary

To a great extent, the effectiveness of flame spray coatings is dependent upon the finishing techniques employed. The fact that the coatings are not a homogenous mass, but are rather many particles mechanically bonded together, dictates that sprayed coatings be finished with wheels and techniques not normally used on similar materials in their solid form. By carefully observing the rules governing wheel selection and by employing proper grinding techniques, the job of grinding flame spray coatings will become relatively trouble-free.