Flame Spraying

Its Scope and Potential

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The process of applying films of metals over surfaces by flame spraying had reached commercial significance around 1935. Most of the early applications were for protective coatings for steel but during the war much work was done for building up in reclaiming worn components. Since then the process has made steady progress and is now in regular use in various industries for those applications for which it has proved most suitable. With the high melting metals and alloys, the refractory oxides and plastics added to the range of material that can be flame sprayed successfully, the scope for this process has recently become much wider.

Methods and Equipment

The process is based on the phenomenon that if molten metal is atomized and projected on to a suitably prepared surface at a high velocity it can form an adherent coating.

Dr. Schoop of Switzerland who was responsible for most of the early pioneering work on metal spraying, carried out his first experiment with the aid of a tool into which molten metal previously melted in a furnace was poured and then atomized and sprayed by a compressed air stream. Modern pistols using molten metal are used mainly for some of the low melting metals and alloys. They have not found favour for any but these jobs because they are cumbersome in use and cannot handle the required range of metals.

As some of the metals can be obtained in powder form, equipment and techniques have been developed in which the powder is fed into a heating flame and atomized and sprayed when in a molten condition, by means of a stream of compressed gas or air. This technique is used mainly for spraying zinc in the application of protective coatings on steel and to an extent for spraying aluminium, special hardfacing alloys, plastics and ceramics in powder form. Oxy-fuel gas flames and plasma flames (which will be discussed in detail later) are used in this process. The powder should be very finely divided and dry so that it can be fluidised easily and conveyed to the flame by the carrier gas. Special devices dispense the powder at the required flow rates.

The wire spraying process is the most commonly used of the three systems. Any metal or alloy which can be drawn in the form of wire can be sprayed. Heating media can be the oxy-fuel gas flame or the electric arc, and for special purposes, the plasma flame. In the USA, France and the UK, oxy-fuel gas equipment is almost exclusively used while in Germany and many other continental countries, arc spraying equipment seem to be popular. In India, almost all the installations use the oxy-acetylene flame.

A modern oxy-fuel gas spraying tool for manual operation (fig. 1) consists of a wire feed device which is operated by means of a compressed air-driven turbine and a nozzle unit in which the wire is melted and sprayed. The wire feed rate is usually infinitely variable to permit the use of various types of methods. A heavy duty version suitable for mounting on the tool post of a lathe may either be compressed air-driven or incorporate an electric motor with suitable reduction gearing and speed control.

Arc spraying tools generally use two wires across which an arc is struck and maintained. As the wires melt, a compressed air jet atomizes the molten metal

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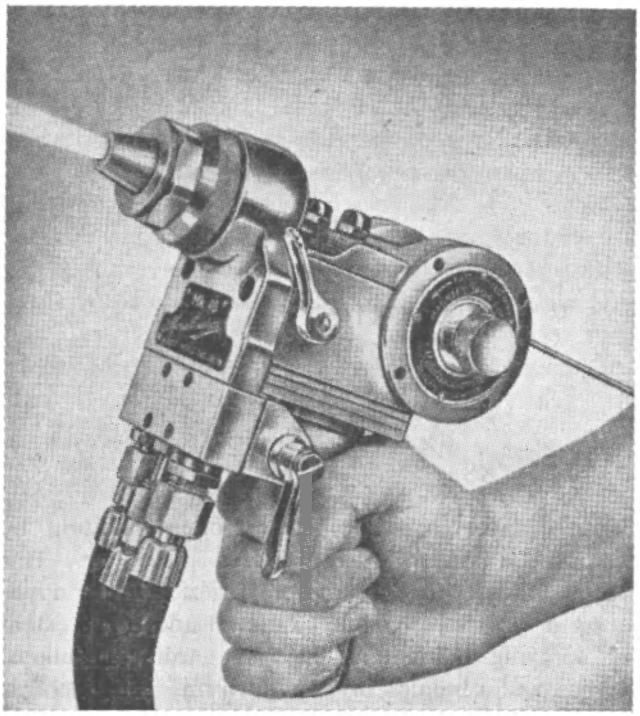

Fig. 1. A modern oxy-fuel gas spraying tool.

and sprays it on to the prepared surface. It is claimed that arc spraying equipment have the advantage that they are capable of faster rates of spraying and running costs are generally lower than with oxy-fuel gas pistols. The disadvantages appear to be that the deposit composition varies considerably from that of the wire because of the burn-off of many elements at the high temperature of the arc. Special quality wires are quite often required to get the desired results. Furthermore, power sources which should preferably have flat or rising characteristics are quite expensive and exhaust arrangements in the spraying area have to be more elaborate than with oxy-fuel gas equipment.

Plasma Flame Spraying

When there is an electrical discharge through a gas, the gas in the path gets ionised. The mass of gas in this ionised state is known as plasma. Plasma is present in an ordinary arc or in a vacuum tube and is considered as a stream of particles at very high temperatures. The temperature of an arc would depend on the collision frequency of ionised particles and the electrons in the plasma. Higher pressures and the resultant increase in the number of particles per unit volume would give higher temperatures. In plasma arc torches such a condition is achieved by constricting the arc to a very narrow zone in the centre thereby succeeding in producing a very hot flame with temperatures ranging from 5,000°C to 16,000°C. Plasma arc equipment can be of the transferred or non-transferred arc type. The difference is that in the former the arc is between the electrode and the work, the nozzle being used merely for constricting the arc. In the latter, the arc is between the electrode and the nozzle itself which acts as the anode in addition to its other function of constricting the arc. The non-transferred arc 5 is used for all heating applications including spraying. A variety of gases including argon and nitrogen have been used. The material to be sprayed can be introduced as a powder near the central electrode or as a wire which replaces the non-consumable electrode. While for very high melting point metals and ceramics such as for example, Chromium, Tungsten, Tungsten Carbide, Tantalum Carbide and Beryllium Oxide, this process appears most suitable, it has been used quite successfully for spraying even thermo-plastics with suitably modified equipment.

The Formation, Structure and Properties of Sprayed Metal

It has to be closely understood that the structure of sprayed metal is quite unlike that of the same metal in its cast or wrought form. In the process, molten metal droplets are atomized into very fine particles which are then propelled forward at a high velocity by a jet of high pressure air. Although the spray from the nozzle is very hot, with individual particles in the molten condition, it loses heat so rapidly when being carried by the compressed air jet that at a distance of even a few inches from the nozzle, the surface treated remains reasonably cool. The minute particles striking the surface at a high velocity in a more or less plastic condition flatten on impact and there is interlocking among the particles and with the prepared surface by a formation of microscopic devetailing. Except in special cases, there is no welding between the deposited metal and the base material and the bond is generally mechanical only. In the absence of fusion between the deposit and the base material, the user is free to choose the material to be sprayed keeping in view the particular service conditions rather than the base material involved. The resulting structure is slightly porous. Instead of being a disadvantage, this is a useful property in sprayed bearing surfaces such as on shafts due to the retention of the lubricating oil film. The sprayed metal by its nature of formation has low tensile strength but it has great resistance to compressive loads.

The hardness of the deposit in the as-sprayed condition is not easily assessable with conventional hardness testing methods. For instance with Brinell equipment, the ball has a tendency to squeeze down the porous deposit giving low hardness readings. Such readings would not reflect truly the capacity for abrasion resistance of sprayed coatings. In the matrix of the sprayed metal are a number of oxide particles which have much higher hardness than the metal and these play an important part in determining the wearing property of the component sprayed.

Preparation of Surface for Spraying

The surface to be sprayed has to be carefully prepared as this is perhaps the most important factor influencing the bonding between the sprayed and base material. The ideal surface for receiving sprayed deposits is one which is clean, free from scale, rust and grease and has been roughened to provide a key for the sprayed metal. The roughening treatment should be such as to make the hills and valleys on the surface of comparable size to the particles themselves. Abrasive blasting with angular chilled iron grit or ground fused alumina is an ideal method of producing such surfaces and is very popular. The size of the abrasive used and pressures employed would depend on the type of material being treated. In the case of site work where recovery of the comparatively expensive abrasive may be difficult, flint sand can be employed.

For certain applications different types of surface preparations are in common use and this will be dealt with in detail later on in the paper. It must, however, be remembered that with all these methods the aim is to provide a surface that has been suitably roughened to provide a key to the sprayed metal.

Building up of Worn or Under-sized Parts

As a process of building up for reclaiming worn parts, metal spraying finds wide use in many industries. During the earlier stages of development of the process, mainly because of lack of sufficient knowledge of the nature, the potential and the limitations of this new tool, indiscriminate use of the process was made by users under the impression that any component worn out could be built up by spraying. Understandably enough, this resulted in failures in some cases. Further progress of the process was slowed down by such setbacks but with better realization of the implications, sprayed deposits have now been accepted and are in regular use in many industries. I mention this just to emphasize that for building up by flame spraying the jobs have to be chosen carefully.

As already mentioned, sprayed deposits have low tensile strength and the coatings are not recommended for parts which may be subjected to high tensile loading or shear stresses. For example, metal spraying can not be used for building up threads or splines. The compressive strength of sprayed metal is quite high and hence the coatings are well suited as bearing surfaces where the major load is in compression.

As the sprayed deposit does not add significantly to the strength of the part to be built up, it must first be considered if the part has sufficient residual strength to be relied upon for future service. The next step is to ensure that sufficient thickness of deposit will be left when the sprayed part is finished to size.

For building up work where cylindrical surfaces such as shafts and pins have to be treated, while grit blasting can be used as a method of preparation, alternative methods of preparation are available which use the normal facilities in a machine shop. In the rough threading technique, a Vee thread 20 to 30 to the inch and 1/32″ in depth is cut on the shaft, taking special care to see that a rough torn thread is obtained as roughness is the most important feature required. This can be arranged by mounting the cutting tool a little below centre to permit a certain amount of "chatter". In the USA a different technique which consists of grooving and knurling using a special tool seems to be more in vogue. The idea seems to be to form a mechanical dovetail by knurling down the ridges.

It may appear to some that application of such threads and grooves to highly stressed parts could be dangerous as anything in the nature of a sharp indent could be a starting point for fatigue cracks. Research work done on this as well as actual experience over the last 25 years or so has shown that there is little danger of such failures. On some highly stressed components, it is usual to grit blast the rough thread as this helps to improve the resistance to fatigue failures.

When the surface of the material to be sprayed is too hard for blasting or machining, an electrical arc method of preparation is sometimes used. This consists of spattering the surface with a low power welding set using a bundle of nickel wires as electrodes, these being surrounded by a compressed air jet. The surface prepared in this manner has a great many irregular shaped cavities which help the sprayed metal to bond to the surface. The peak height of the spatter metal can be upto 30 mils. The process is comparatively slow and the other disadvantage is that in the case of heavily stressed parts, this preparation could be far more dangerous than others from a fatigue point of view. It has, therefore, limited applications.

When molybdenum became obtainable in wire form on a commercial scale, it was found that this metal had some curious properties. It was observed that if molybdenum is sprayed on to a clean surface slightly roughened by emery cloth, it adhered to the surface quite well and this could provide a base for further coats of sprayed metal of any other type. Molybdenum underlays have come into commercial use and are quite useful on most steels including stainless steel, nickel and nickel alloys, cast iron and most aluminium alloys. It is not, however, suitable for copper and copper alloys and for chromium plated or nitrided surfaces. This method is considered a better alternative to electric arc bonding for surfaces difficult to prepare by machining or grit blasting methods. It may even be found that molybdenum underlay would be cheaper in some cases which would normally be prepared by the conventional methods. A great advantage of molybdenum is that it is possible to bring the coating to a feather edge. Molybdenum has been found useful also in touching up wear on flat surfaces such as lathe beds, slides etc.

After a surface is prepared, spraying has to follow soon after and has to be completed preferably in one continuous operation. Care is to be taken to ensure that overheating does not occur. The usual practice is to mount the spraying tool on the tool post and move it at controlled speeds along the length of the job.

For finishing the sprayed deposit, grinding is strongly recommended. If certain precautions are observed, there is no difficulty in getting an excellent finish.

Where grinding is for some reason not possible, turning may be adopted. Only very light cuts should be taken and the shape of the tool and cutting angles are important.

Principal applications for building up by spraying are shafts and pins of all types, hydraulic rams and pump rods, necks of certain types of rolls in steel rolling and flat areas such as lathe beds and slide rests. Spraying has been used for repair of defects in castings. The inner surfaces of bearings give rise to some difficulty because the tendency for the sprayed metal on cooling is to shrink away from the surface sprayed and this creates a slight weakness. Such problems have, however, been overcome and there are many instances where bearings have been successfully built up. On the continent work has been carried out on spraying of "Pseudo" alloys for manufacture of bearings. The different metals are sprayed as two different wires or as one composite wire. Success has been claimed. There are also patented methods of manufacture of moulds.

Protective Coatings

The earliest commercial application for flame sprayed deposits was the protection of steel against corrosion. This method has a number of advantages over other metal coating processes. There is no limit to the size of component that can be treated, as the equipment is completely portable and, where required, work can be carried out on site. Bridges, gas holders and chimney stacks and fabricated steel structures (Fig. 2) are examples of work of this nature. As, by the time the sprayed metal reaches the surface of the job, it becomes reasonably cold there is no danger of overheating the part that is treated. Heat distortion is, therefore, eliminated. It is also possible to increase the coating thickness as desired for conditions where a long service life is required or there are severe corrosive conditions. The surface of sprayed metal coatings being slightly porous and matt in finish provides an excellent bond for paints. Combinations of sprayed metal and a suitable paint scheme are widely in use. The life of the paint coat is prolonged considerably by the elimination of rust formation which, in most cases, caused paint failure.

It is possible to choose any metal or alloy that can be melted by the flame, keeping in view the particular conditions of corrosion existing. For protective coatings the two metals most widely used are zinc and aluminium. Zinc coatings are used for steel work exposed to rural atmospheres, to moist environments and most conditions involving immersion in water. Aluminium coatings are used for protection in heavy industrial atmospheres where sulphur pollution is high, for the protection of parts to operate at high temperatures and for immersion in hot water, sea water and soft water of an acidic nature.

Many major bridges constructed in recent years have been protected by sprayed metal coatings. Examples are the Volta River Bridge in Ghana, the road bridge over the river Forth in Scotland, the Severn road bridge and the Karuma Falls Bridge over the river Nile. In all these cases, zinc has been used as the protective coat. As a considerable proportion of the cost of spraying such large structures is in handling and in labour, full advantage is taken of new techniques of mechanized spraying (Fig. 3). The various sections required are treated in the shops by passing them successively through automatic grit blasting machines and

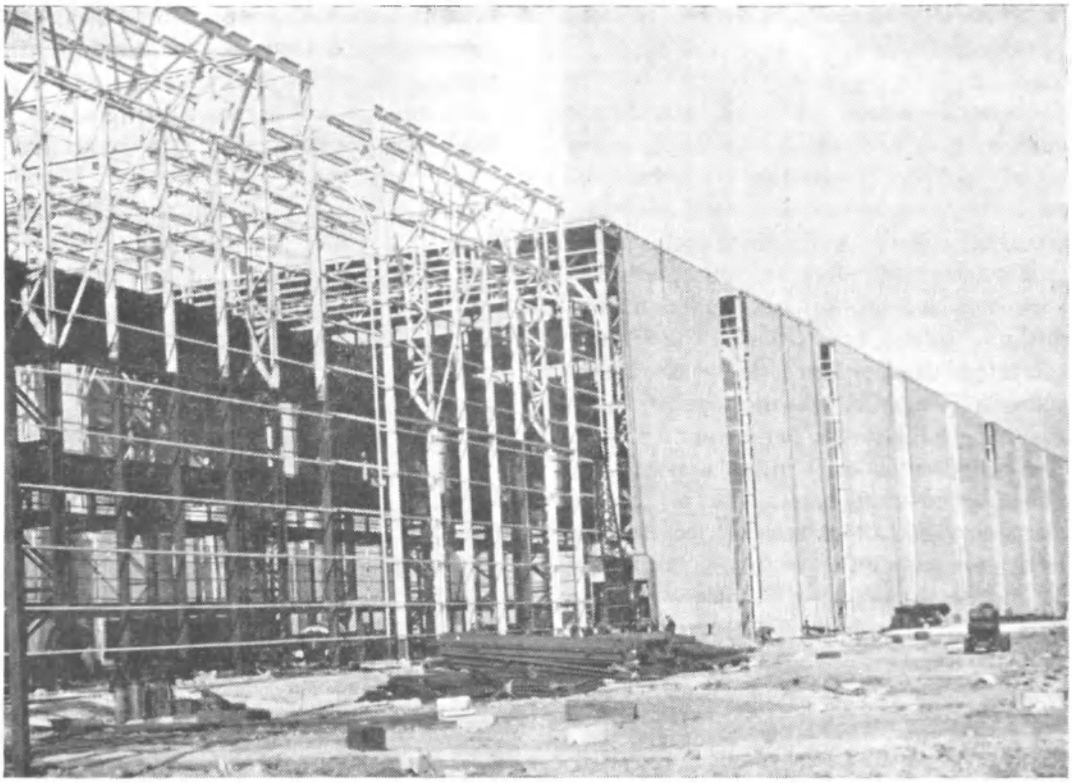

Fig. 2. Steel structures sprayed with aluminium for protection against corrosion.

then under multiple head spraying arrangements so that at the other end of the line they come out fully treated. The only site spraying done is that part which unavoidably has to be done after erection.

Sprayed metal coatings on items such as sluice gates have given excellent results. One interesting example is that of lock gates on the St. Denis canal in France which were sprayed with a 5 mil thick coating of zinc in 1922. The gates were examined after 30 years and it was found that although the zinc coating had been disrupted in a few places, it had succeeded in affording protection to the steel by sacrificial action and there was no trace of rust on the structure.

A 4 mil thick aluminium coating was used for all above-crane level structures at the Steel Company of Wales at Margam. This was considered then to be the largest single metal spraying contract. Other applications for aluminium are internal spraying of large pipelines, transmission pylons and transformer stations exposed to industrial atmospheres.

Tin coatings are used by the food industry as they are not attacked by weak organic acids and also protect the food from contamination. They are useful for water storage tanks even when the water has an alkaline reaction but do not give good service in strong solutions of citric or acetic acid. Lead coatings can be applied by spraying and are in fact being used successfully for the prevention of attack by acid laden air. Elaborate precautions have, however, to be taken to safeguard the health of the operator from the hazard of lead poisoning. Furthermore for immersed conditions in chemical vats which require heavy lead

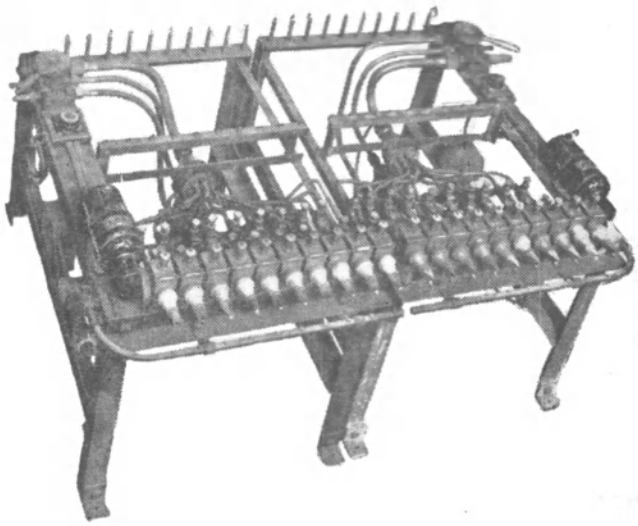

Fig. 3. Mechanised spraying unit for treating structural steelwork.

coatings, homogeneous lead lining is to be preferred to sprayed coatings.

When discussing coatings for resisting chemical attack, the question may be asked if it is not possible to apply sprayed coatings of stainless steel on more common metals and thus reduce the cost of vessels which are now made wholly of stainless steel. While there is no difficulty in spraying stainless steel, the metal in the "as sprayed" form is not unfortunately corrosion resistant. It will be stainless provided the surface is made smooth and polished. Sprayed stainless steel coatings are used on pump rods in chemical works, on large rollers used in the printing trade and in paper making and on rams which work in the presence of various corrosive liquids. Such coatings are successful in these instances as, after spraying, the deposit can be ground to size and given very good finish. It is, however, impractical and uneconomical to spray stainless steel on to irregular surfaces such as that of a tank or a vessel and then polish it by means of grind stones and mops.

There are many applications for flame spraying in the shipbuilding industry. The purpose in most cases, as in other steel structures, is to cut down repainting costs which account for a large part of the maintenance expenses in such items. The hulls of large ships are not usually flame sprayed because none of the metal coatings so applied are themselves anti-fouling compounds and it is necessary to treat the bottoms of ships frequently by applying anti-fouling paint. Zinc coatings have been very successfully used on the hulls of small ships, dredgers and life boats. With the increasing use of light alloy super-structure on vessels for the purpose of reducing weight, problems have arisen of corrosion at the points where the steel is in contact with the aluminium alloys. Spraying the steel component to some distance all around the joint with aluminium has proved most effective. Where steel is used in superstructures, zinc coatings can be useful in preventing corrosion and avoiding the necessity for frequent repainting. Among the other applications of flame spraying are the use of decorative coatings mainly of copper and copper alloys, the production of moulds and forms for the plastics industry, the application of hardfacing alloys in which the coatings are sprayed and subsequently diffused to the surface by heating and the spraying of plastics such as polyethylene and nylon.

Spraying of Ceramic Materials

For a number of years experimental work had been done on flame spraying ceramic materials such as alumina. It has been found that generally those ceramics which form a stable liquid when molten can be flame sprayed successfully. Thus the oxides alumina, silica, titania, zirconia and chromium oxide are sprayable. Some other natural compounds also spray well.

Equipment using the ceramic material in powder form or rod form is available and most of these operate on the oxy-acetylene flame. The very much hotter plasma flame would be a natural choice for these materials but so far no significant advantages of this type of equipment have been noticed for this application.

Sprayed ceramic coatings are, like sprayed metal coatings, somewhat porous. Because of this they are able to withstand more strain than can be expected with such materials. Coatings up to a thickness of 100 mil can be applied. They adhere well to prepared surfaces and withstand impact vibration and thermal shock fairly well. The coatings have good electrical insulation properties but perhaps the most outstanding quality is the low thermal conductivity. For instance, it is possible to heat up a sprayed coating to 2,000°C without the heat melting the steel surfaces underneath.

In conditions of exposure to high temperature oxidation for prolonged periods, the coatings have not been found very successful possibly because the porosity of the coating allows the base material to be affected in course of time.

Sprayed coatings of alumina have been used for exhaust throats of guided missiles, in jet engine starters and for lining of graphite crucibles used for melting rarer metals. Another interesting application is the preparation by spraying of alumina formers for use in automatic welding to prevent the weld metal running.

It appears that sandwich materials of metals and ceramics such as can be prepared by flame spraying have immense possibilities for the various high temperature applications of this space age.

Conclusion

There are applications for flame spraying in almost all industries, which can cut down costs and contribute to higher efficiency. A thorough understanding of the scope and potential of this process, careful selection of the work to be done by this process and use of the techniques that have been developed over the years will ensure success in every case.