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FLAME SPRAYING EMPLOYING LASER HEATING

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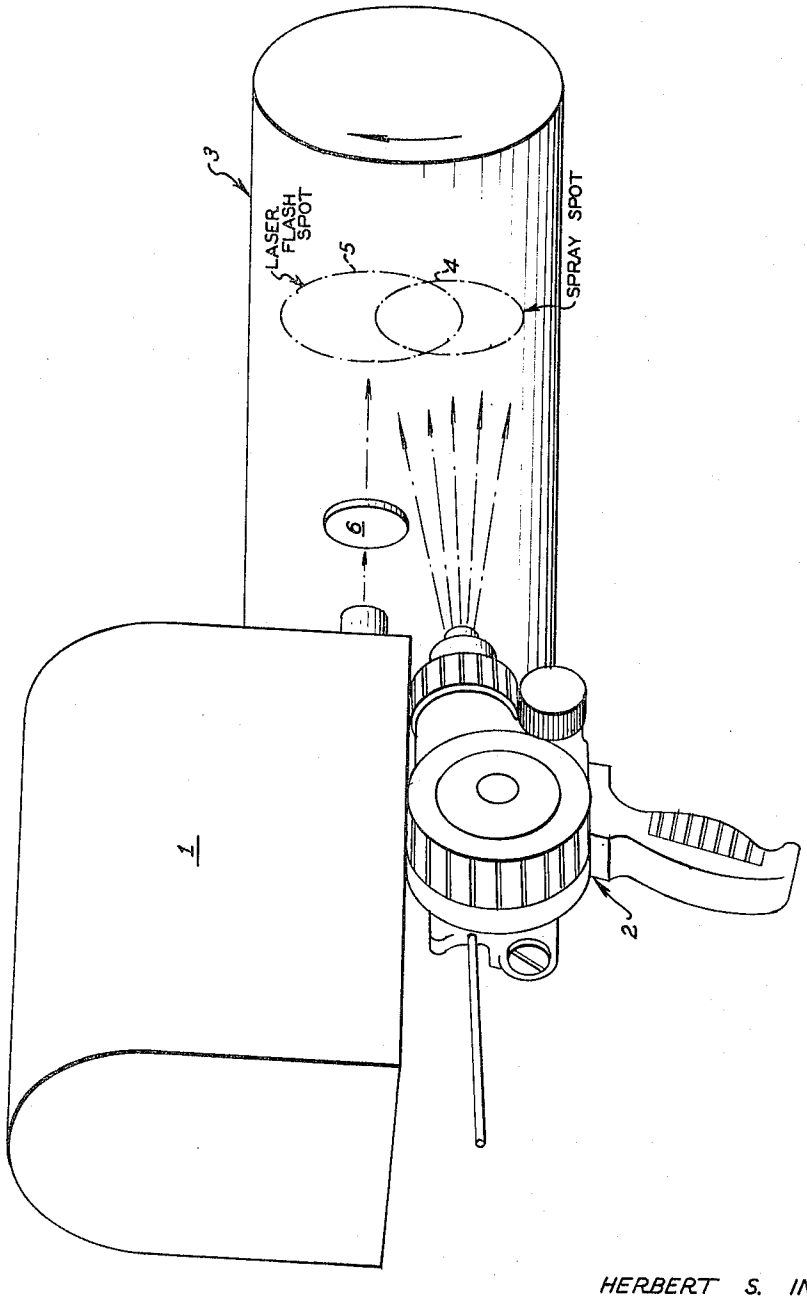

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FLAME SPRAYING EMPLOYING LASER HEATING

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This invention relates to improvements in flame spraying. The invention more particularly relates to the selective heating of flame sprayed particles with an instantaneous burst of energy, as for example, produced with an optical maser in order to improve the flame-sprayed coating.

The application of a coating of a heat-fusible material, as for example a metal or ceramic, to a surface may be effected by flame spraying which is a well-known technical process frequently used in industry. Broadly, flame-spraying involves the projecting of particles of the heat-fusible material in molten or heat plastic condition against the surface to be covered in the form of a spray. In the initial period of its development and use, flame-spraying was primarily used in connection with the spraying of metal, and therefore is sometimes referred to as metal spraying or metallizing.

In addition to spraying metal, flame-spraying is now commonly used to spray other materials, as for example refractories and ceramics.

Flame spraying is generally effected with a flame spray gun which is provided with a heating zone into which the heat-fusible material is fed for the melting or heat-softening and from which the same is propelled in a finely divided form onto the surface to be coated. Heat-fusible material spray guns are generally of the wire type or powder type. In the wire type heat-fusible material spray guns, the material to be sprayed is fed into the heating zone in the form of a rod of wire where it is melted or heat-softened, atomized and propelled in finely divided form onto the surface. The atomization and propelling is generally effected with the use of a blast gas, such as air, which impinges on the tip of the wire being melted in the heating zone.

In addition, to ordinary wires, wires are used which consist of finely divided material, such as powder sintered together in wire or rod form, or bound together in wire or rod form in a plastic or other suitable binder which disintegrates from the heat of the heating zone.

In powder-type flame-spray guns, the material to be sprayed is fed into the heating zone in the form of finely divided particles, such as powder, usually conveyed by means of a carrier gas.

The heat in the heating zone is generally produced by means of a combustion flame, as for example by burning fuels, such as acetylene, propane, natural gas, or the like with air, enriched air, or pure oxygen. In addition the heat may be produced by electric arcs, constricted arcs, or gas forced into an arc in contact with an arc, or constricting an arc, forming a plasma. Flame spray guns of these latter types are generally known as plasma flame spray guns.

In addiion to the above-mentioned heating modes, other heating modes, such as electric resistance heating, induction heating, or the like may be used.

The application of the sprayed coating is carried out for a variety of purposes, as for example, to provide improved wear, temperature, and/or corrosion-resistant characteristics; to build up worn sections of parts; to provide improved bearing characteristics; improved chemical resistance, and the like.

It is generally desirable that the flame-sprayed coating adheres to the base surface with a high degree of bond.

This required and desirable degree of bond is generally not achieved by simply spraying the heat-fusible material onto the surface, and usually a severe mechanical roughening which actually forms key-like cavities is required which roughening may be achieved for example by sand or grit blasting or machine roughening. The bonding may also be effected or aided by initially spraying at least a flash coating of molybdenum as described in United States Patent 2,588,421 of Mar. 11, 1952.

One of the characteristics of flame spraying is that the base surface is not melted or unduly heated as in welding. Even when spraying relatively high melting point materials, the base surface being sprayed may remain relatively cool, particularly when the spraying is effected with the use of a blast gas which further serves the function of surface cooling.

The flame-sprayed coatings generally have distinctive characteristics and are generally somewhat porous and less dense than a fused or welded coating of the same material.

It is, of course, possible to subsequently fuse the flame sprayed coating in order to increase its density and bond but many of the flame spray materials cannot be satisfactorily fused. It is generally necessary to use a specific type of flame-spray material if the coating is to be subsequently fused. Such materials may contain a fluxing element, such as boron, and are used in a specialized process known as "spray-welding" wherein the flame-sprayed coating is fused or welded to the base in a subsequent operation. A very limited group of materials, as for example nickle and/or cobalt alloys containing boron and silicon, which are known as self-fluxing spray-weld alloys are suitable for the spray-weld process and the subsequent fusing operation involves the heating of the base surface to a relatively high temperature which is not permissible or satisfactory in many instances where conventional flame spraying is used.

It is an object of this invention to produce a superior bond and/or a denser and more coherent coating by the flame-spray process without the necessity of a subsequent fusing operation or an excessive heating of the surface being coated.

It is a further object of this invention to effect the flame-spray process without the requirement of severe mechanical roughening or other surface treatment in order to obtain a satisfactory bond and to render the sprayed particles "self-bonding".

These and still further objects will become apparent from the following description read in conjunction with the drawing which diagrammatically shows an arrangement for flame spraying in accordance with the invention.

In accordance with the invention, I have discovered that the temperature of the sprayed particles may be sufficiently raised to improve the bonding characteristics, density, and other characteristics without a corresponding heating of the base if the heating is effected with an instantaneous burst of energy.

By "instantaneous," as used herein, there is meant a burst of energy having a duration of not more than a fraction of a second as for example not more than a millisecond, and preferably not more than 10 microseconds and most preferably not more than several microseconds, as for example, around one microsecond in duration. Quite specifically, the time of duration of the burst of energy defined herein, and in the claims as instantaneous, must be of a sufficiently short duration so that the temperature rise of the flame-sprayed particles occurs before there is substantial heat transfer to the base. The burst of energy may be, for example, a coherent light beam or a burst of heat energy.

Normally, as energy is imparted to a sprayed particle on a base to raise its temperature, as for example during ordinary fusing of a flame-sprayed self-fluxing alloy, a portion of this energy is transferred to the base which acts as a heat sink causing a corresponding rise in temperature of the base. There is thus a continual transfer of heat energy and sensible heat to the particle and to the base and the rate of temperature rise in the particle only slightly exceeds the rate of temperature rise in the adjacent portion of the base so that a substantially greater quantity of heat is required to raise a particle to a given temperature than would be theoretically calculated based on the mass of the particle. Visualized in another manner, the heat energy is running off from the particle almost as fast as it is being pumped into the particle so that a relatively large amount of energy is required, a substantial portion of which transfers to the base detrimentally heating the same.

In accordance with the invention, with the application of the energy, by means of the instantaneous burst, the energy is transferred to the particles so rapidly that very little has a chance to run off into the base during the transfer and thus the temperature of the particle is raised without substantial heat transfer to the base. To be sure, as the particle cools, heat will be transferred to the base but the amount of heat (when considering the mass of the particle) is extremely low and will not substantially raise the temperature of the base when considering its much larger mass.

Ideally, the particles should be heated with the burst of energy just as they are striking the base. When, however, considering the statistical distribution of particles being sprayed during the time period of the instantaneous burst of energy, a very small percentage of the particles are actually striking the base during said time period. It is, therefore, preferable to heat the particles while the same are depositing. The term "depositing" as used herein and in the claims is intended to designate the particles from the time just immediately prior to striking the base until the time that they have solidified and given up a substantial portion of their heat energy or have been covered by layers of further sprayed particles.

The instantaneous burst of energy should be sufficient to substantially raise the temperature of the particles and thus in effect give the same a "super-heat" as compared to the normal temperature which the same would have on being flame-sprayed under the conditions in question. Preferably, the amount of heat energy should be sufficient to raise the temperature of the particles to above the softening temperature of the base surface and most preferably high enough above the softening temperature of the base surface to cause at least some alloying between the sprayed particles and the base, or, alternately high enough above their own softening temperature to cause fusing with previously sprayed layers. With this higher temperature, the particles will self bond to the base surface or the previous layers of sprayed material and in certain cases alloying with a very thin layer of the substrate, as for example a layer less than 0.5 micron thick.

With the imparting of the instantaneous burst of energy to the particles as the same are depositing, certain of the particles are in the act of just striking the surface and the kinetic effect of these striking particles per se and as transmitted to the other particles enhances the effect. Within the very broadest aspects of the invention, however, it is merely necessary that the particles being heated with this instantaneous burst of energy do not have any substantial layers of particles therebeneath which have not been so heat treated. If, for instance, a flame-spray coating is merely built up in the conventional manner, and the finished coating subjected to the instantaneous burst of energy, this will only affect the very top layer and will not appreciably affect the overall bond or the sprayed coating in toto. If, on the other hand, a thin

layer of the sprayed coating is laid down on the base, as for example, a layer not in excess of an average .003" in thickness, and preferably not in excess of an average of .001" thickness, which may be considered as a single layer herein, and this layer subjected to the burst of heat energy, and thereafter a further layer of this thickness deposited and subjected to the heat energy burst, and so forth, the effect in accordance with the invention will be achieved. Thus, while not as preferable as the heating of the depositing particles with the instantaneous burst of heat energy, it is possible to heat a substantially single layer, i.e. a layer with thickness not more than an average of .003".

I have found it preferable to heat the particles with an instantaneous burst of light energy emitted from a pulsed optical laser.

Of the lasers presently commercially available, I have found the use of a ruby laser, doped with chromium most preferable. The laser may be fired with an xenon flashlamp in the conventional manner and may, for example, operate with energy outputs as low as 5 joules up to the maximum outputs available. With larger, higher energy lasers, it is, of course, possible to cover a larger area and thus spray with a larger spray pattern at a higher rate while with the lower energy lasers, it may be necessary to focus the same down to a very narrow beam so that the spray output must be accordingly reduced. The spot size, distance, and energy of the laser may be readily calculated for given spray conditions or may be empirically determined. It is generally necessary that the heat energy absorbed by the particles be sufficient to raise the temperature of the particles at least above the softening point of the base. The laser may be continuously flashed, as for example with from 0.1 to 10 seconds' cycling time and preferably each flash should be of the shortest possible duration. In connection with a ruby laser, I have found it preferable to operate at room temperature since at this temperature the laser flash consists of many sub-flashes or "spikes" of approximately 1 microsecond duration each. When flashing a laser continuously, the same will be heated considerably so that cooling should preferably be effected so that during the operation the laser will be approximately at room temperature at the time of each firing. For this purpose, at high energy output, as for example above several thousand joules, it is preferable to cool with liquid nitrogen. While operation at the temperature of liquid nitrogen will not produce the desirable spikes, with the continuously flashing laser, the liquid nitrogen will simply serve to cool the same to around room temperature at each firing time.

In addition to the use of the single laser, of course, a multiple number of lasers may be used, fired in sequence or simultaneously. In order to impart the bursts of heat energy to the depositing sprayed particles, the center of the laser flash spot or area should be located behind the center of the spray pattern in the direction of spraying and should overlap with the same.

As a specific example of operation, the arrangement as shown in the drawing is used. **1** represents a laser of the type similar to that sold by the Raytheon Company of Waltham, Mass., model LHM–1, designed to operate, however, with one or more flashlamps having between 4,000 and 10,000 joules total output. The laser ruby is doped with 0.05% chromium and has a 5/8" diameter and is 6" long. The laser is cooled with liquid nitrogen so that with the lamp or lamps flashing at about 4,000 joules once each second, the laser will operate at room temperature at the time of each firing. **2** represents a wire type flame-spray gun as sold by Metco, Inc., Westbury, N.Y., model Metco 4E. **3** represents a 3" diameter steel shaft mounted on a lathe for rotation in the direction of the arrow as shown.

The surface of the steel shaft **3** is cleaned by a light sand-blasting but insufficiently roughened to cause bond-

ing with ordinary flame spraying. The gun **2** is operated to spray 20 gauge nickel wire at a rate of ½ lb. per hour using oxy-acetylene gas and air as a blast gas, the oxygen being supplied at 12 p.s.i pressure, 15 c.f.h. flow rate, the acetylene at 10 p.s.i. pressure, 15 c.f.h. flow rate, and the air at 55 p.s.i pressure, 50 c.f.h. flow rate. The gun **2** is positioned a distance of 3" from the surface of shaft **3** so that it will produce the spray spot **4** having a diameter of 0.6". The shaft **3** is rotated in the direction shown by the arrow on the lathe with a surface speed of 36" per minute. The laser is mounted above the gun **2** as shown to produce the flash spot **5** focused with the lens **6** so that it is 0.85" diameter with its center exactly 0.475" from the center of the spray spot **4**. As the shaft **3** is rotated, the spray gun **2** is operated continuously and the laser is flashed each second with 4,000 joules from the flash lamp or lamps. With increasing energy of the laser, or a shorter cycle time, the spraying rate may be correspondingly increased, as for example, if the laser is flashed every half second, the spray rate may be increased to 1 lb. per hour. After each revolution of the shaft **3**, the same is moved axially until the entire length of the shaft is covered and the operation repeated until a nickel-spray layer .015" thick is built up on the shaft. This as-sprayed coating of nickel is extremely dense and coherent and an extremely strong bond is formed so that the coating as sprayed may be considered self-bonded.

In place of simultaneously spraying and flashing as shown, a layer of average .001" thickness, i.e. a single layer, may be sprayed on the shaft, and then this layer subjected to the action of the laser by operation as described but without the spraying with more energy per flash to compensate for cooling of sprayed layer if this has occurred.

In place of the nickel, any other flame-spray material may be sprayed, as for example: carbon steel, stainless steel, aluminum, bronze, molybdenum, monel, zinc, babbitt, copper, tin, lead, brass, nichrome.

In place of using the wire type gun, any other known or conventional flame-spray gun, as for example, a powder type gun, such as a Metco Thermospray gun may be used, or a plasma flame-spray gun, such as Metco model 2MB.

With such guns, for example, the following materials may be sprayed: stainless steels, aluminum, nickel-base self-fluxing alloys, cobalt-base self-fluxing alloys, molybdenum, aluminum oxide, zirconium oxide, nichrome, bonded carbides, tungsten, chromium, cobalt, chromium carbide, tantalum, metal oxides, zirconates, titanates, glass, silver, iron, silicides, columbium, tin, silicon, copper, or mixtures thereof.

When spraying, a self-fluxing alloy in this manner, a subsequent fusing operation is not necessary and a coherent dense coating is obtained. In place of the steel shaft other surfaces may be used, as for example: aluminum, brass, copper, aluminum oxide, titanium, columbium, molybdenum, cast iron, nitrided steel, tantalum, and alloys based on the foregoing metals.

In general, any of the known or conventional flame-spray materials may be sprayed in any of the known or conventional manners, on any of the known or conventional surfaces applicable for flame spraying utilizing the improvement in accordance with the invention. In general, the flame-sprayed particles, as sprayed, will have sizes between about 150 microns and 1 micron and preferably between about 100 microns and 8 microns.

While the surface being sprayed in accordance with the invention need not have the conventional preparation in order to ensure bonding, but may, for example simply be cleaned and degreased, the conventional flame-spray preparation may, of course, be utilized.

While it is preferable to effect the heating with instantaneous bursts of light energy, from an optical laser, it is possible to effect the heating by any known mode

which is capable of delivering the heat energy in the instantaneously applied burst. Thus, masers, such as infra-red masers may be used, as may a rapid arc discharge or the like.

While the invention has been described with reference to certain specific embodiments, various changes and modifications which fall within the spirit of the invention and scope of the appended claims will become apparent to the skilled artisan. The invention is, therefore, only intended to be limited by the appended claims, or their equivalents wherein I have endeavored to claim all inherent novelty.

I claim:

1. In the flame spray process in which heat softened particles of a heat-fusible flame spray material are sprayed onto a surface to be coated, the improvement which comprises heating the depositing particles with an instantaneous burst of energy to a temperature above the softening temperature of said surface.

2. Improvement according to claim **1** in which said particles are particles of a member selected from the group consisting of nickel, steel, aluminum, bronze, molybdenum, and Monel.

3. Improvement according to claim **2** in which said surface is a metal surface.

4. Improvement according to claim **1** in which said surface has insufficient roughening to satisfactorily bond the said particles without said improvement.

5. Improvement according to claim **1** in which said spraying is effected with the use of a blast gas.

6. In the flame-spray process in which heat softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises heating a substantially single layer of deposited particles with an instantaneous burst of heat energy to a temperature above the softening temperature of said surface and thereafter spraying at least one additional substantially single layer of particles and heating the deposited particles of this additional layer with an instantaneous burst of heat energy to a temperature above the softening temperature of said surface.

7. In the flame-spray process in which heat softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises irradiating the depositing particles with instantaneous light flashes from an optical laser of sufficient intensity to raise the temperature of the particles above the softening temperature of said surface.

8. Improvement according to claim **7** in which said particles are particles of a member selected from the group consisting of nickel, steel, aluminum, molybdenum, and Monel.

9. Improvement according to claim **8** in which said surface is a metal surface.

10. Improvement according to claim **7** in which said surface has insufficient roughening to satisfactorily bond the said particles without said improvement.

11. Improvement according to claim **7** in which said spraying is effected with the use of a blast gas.

12. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises irradiating a substantially single layer of deposited particles with instantaneous light flashes from an optical laser of sufficient intensity to raise the temperature of the particles above the softening temperature of said surface and thereafter spraying at least one additional substantially single layer of particles and irradiating this additional layer of deposited particles with instantaneous light flashes from an optical laser of sufficient temperature to raise the temperature of said particles above the softening temperature of said surface.

13. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement

which comprises irradiating the depositing particles with instantaneous energy flashes from a maser of sufficient energy to raise the temperature of the particles above the softening temperature of said surface.

14. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises at least partially overlapping the depositing spray pattern with instantaneous pulsed flashes from an optical laser of sufficient energy to substantially raise the temperature of the particles.

15. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises at least partially overlapping the depositing spray pattern with instantaneous pulsed flashes from a maser of sufficient energy to substantially raise the temperature of the particles.

16. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises substantially raising the temperature of the depositing particles by heating the same with an instantaneous burst of energy.

17. In the flame-spray process in which heat-softened particles of a heat-fusible flame-spray material are sprayed onto a surface to be coated, the improvement which comprises substantially raising the temperature of a substantially single layer of deposited particles by heating with an instantaneous burst of energy and thereafter depositing at least one further substantially single layer of particles by flame spraying, followed by heating the same with an instantaneous burst of energy to thereby substantially raise the temperature thereof.

18. In the flame-spray process in which heat-softened particles of a heat-fusible material are sprayed onto a surface to be coated, the improvement which comprises scanning a substantially single layer of deposited particles with instantaneous pulsed flashes from an optical laser of sufficient energy to substantially raise the temperature of the particles and thereafter depositing at least one further substantially single layer of particles by flame spraying followed by scanning said further deposited particles with instantaneous pulsed flashes from an optical laser of sufficient energy to substantially raise the temperature thereof.

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