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A computer-based approach for developing functionally graded and layered coatings with detonation spray coating process

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Many material based technologies are being attempted for developing functionally graded coatings to withstand increasingly demanding conditions like higher temperatures, corrosive atmospheres, erosive attack, etc. This article describes a computerized concept to develop gradient or layered coatings using the detonation spray coating (DSC) technique.

Keywords: Coatings, FGM, Detonation Spray

Introduction

Some commonly used coating processes such as High Velocity Oxy-Fuel Gun[1-2], Plasma Spray[3-5], Detonation Spray Coating[6-8], Laser surface alloying and cladding[9] are widely used in various industries for enhancing the life of critical components. These processes modify the tribological properties or corrosion or oxidation resistance at elevated temperatures[10]. Such improvements in coating properties are all the more beneficial when the composition is graded or layered across the thickness. In this way, coatings can be tailored to suit specific applications. By properly designing the microstructure, abrupt failures of components can be avoided.

In conventional DSC processing, a dedicated powder feeding device is employed to carry powder into the high temperature zone, generated by a detonation. Examples of such feeders are mechanical-disc type of feeding, screw feeding and fluidized bed feeding. In our original DSC system, the fluidized bed type is used to inject a small amount of powder into the detonation stream so that it gathers sufficient heat and acceleration before bombarding the substrate. This process is repeated enough number of times until the deposited particles form homogeneous, well-adhered and moderately smooth surfaces with thicknesses ranging from 40 microns to 1 mm.

However, such a powder feeder system has limitations as only one type of powder can be coated. To overcome this problem, we have used multiple powder feeders, where the quantity of each powder can be dynamically controlled during a process run. This is achieved by electronically controlling the time of opening of the solenoid valves that inject each powder. Thus the quantity and composition of the injected powder mix can be varied, either sequentially or simultaneously as a function of time, so that gradient coatings or layered coatings can be formed. The specific focus of this paper will be on the development of a reliable and repeatable control mechanism to achieve these objectives.

Proposed Scheme of Modifications

Hardware

The modified scheme of gas flow, valves, feeders, mixing and detonation chamber, gun barrel, control PC and other hardware is shown in Fig. 1. Three additional powder feeders have been added to our original DSC system so that a total of four powder feeders PF1 to PF4 are available to hold different powders. Each of these is connected to a solenoid valve that releases the corresponding powder, when energized.

Software

LabVIEW software is used with a PC to develop a program to energize all the valves mentioned above in a preset sequence and for preset durations. External circuitry using MOSFETs and opto-isolators is employed to boost the power output of the low level PC digital output signals to actuate the electromagnetic solenoid valves.

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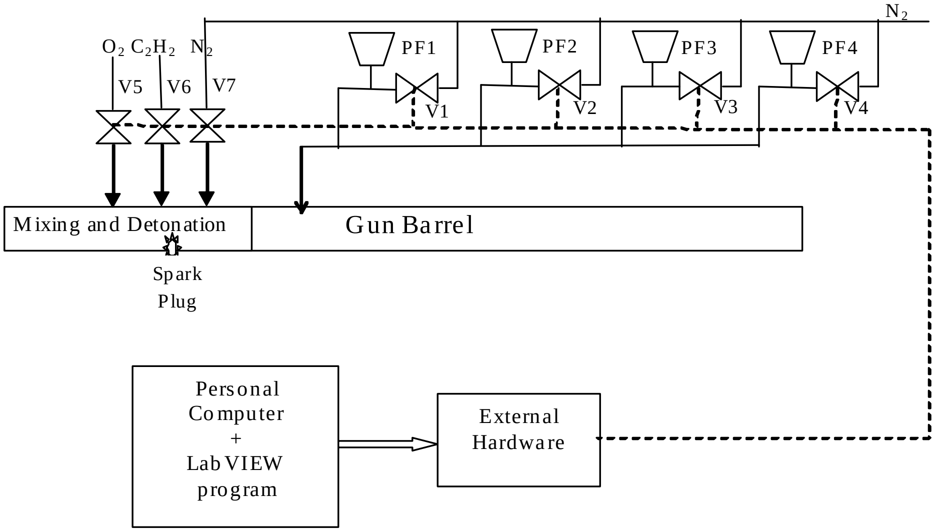


Fig. 1ð Functional block diagram of set up for developing gradient / layered coatings

Detailed description of functional arrangement of the Powder feeding system

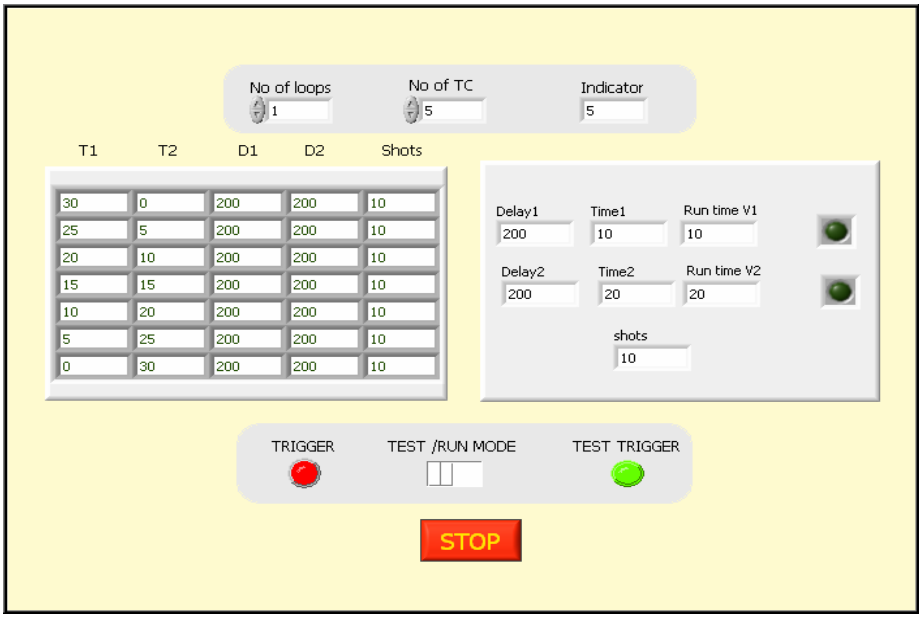
Electromagnetic valves V1 to V7 are all wired to respond to the digital signals generated by the computer program. Valves V1 to V4 control the Nitrogen inflow to the powder feeders PF1 to PF4 that contain different powders. The higher the duration for which a valve is kept open, the higher the amount of the corresponding powder let out. V5, V6 and V7 control the oxygen, fuel gas and purge gas respectively which are required for the detonation spray unit. In the present study, only two powder feeders PF1 and PF2 were used to demonstrate the concept.

Initially, the valve V7 is opened to let in Nitrogen gas into the mixing chamber to flush out any remnant air or products of previous combustions, if any. Then the valves V5 and V6 are opened to allow measured volumes of Oxygen and Acetylene, as determined by the heat requirements of the feedstock material. At this stage, the mixture is ignited by generating a spark. The resulting detonation generates a shock wave that propels the powder particles that are injected in its path to high velocities. During the flight, the high heat flux generated by the detonation melts the particles before they bombard the substrate i.e. component. Thus by controlling valves V1 to V4; the composition of the coatings can be varied. The control system itself is capable of accommodating more number of valves and powder feeders so that a variety of material compositions are possible.

The essence of this technique for generating gradient or layered coatings lies in controlling the time duration for which the solenoid valves V1 to V4 are energized. A computer program has been developed to permit this control using LabVIEW. The program was designed in a user-friendly manner, incorporating all necessary control inputs and indicators on the front-screen. This allows even an unskilled operator to use the program with ease by entering the required data through the keyboard of a personal computer, whose screen-shot is shown in Fig. 2.

The quantity of powder material fed into the DSC system for spraying is a function of many variables like material density, particle size, and carrier gas pressure and feeder geometry. In order to circumvent the influence of these factors, simplified logic has been used for program development However; this simplification necessitates additional tests to be performed to determine the relation between the time of opening of the solenoid valve and the amount of powder delivered per shot. In general, it has been observed that this relationship is linear in nature. This data is the basis for assessing the injection times Tn, which indirectly represent the quantity of powder fed at any point of time.

As described elsewhere [11], a typical detonation shot takes about 333 milliseconds. Most of this time (~200 milliseconds) is taken up for fuel-oxygen valves opening, ignition, combustion, etc. after which the shock wave is generated. Any powder entered into the gun barrel before this time cannot be accelerated or propelled and serves no purpose. The powder entry is therefore delayed by this much duration Dn for achieving synchronization of the process. The time delay Dn also helps in reducing the wastage of powder particles. As powder cost accounts for about 60% of the overall



No of loops: 1
No of TC: 5
Indicator: 5

T1	T2	D1	D2	Shots
30	0	200	200	10
25	5	200	200	10
20	10	200	200	10
15	15	200	200	10
10	20	200	200	10
5	25	200	200	10
0	30	200	200	10

Delay1: 200
Time1: 10
Run time V1: 10
Delay2: 200
Time2: 20
Run time V2: 20
shots: 10

Fig. 2ð Screen shot of display screen of LabVIEW program for developing gradient coatings

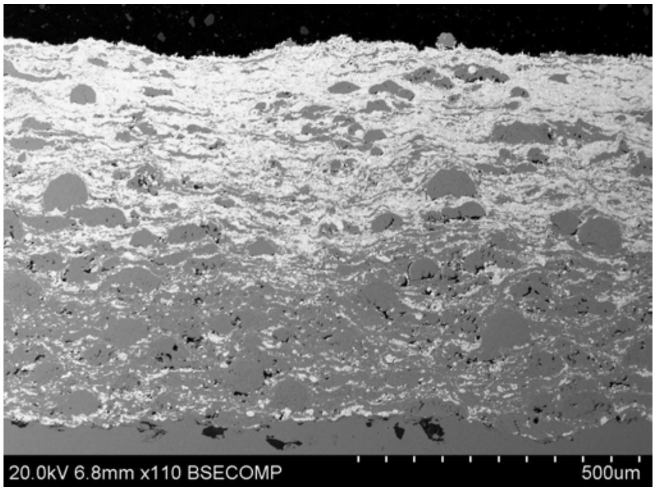


Fig. 3ð Cross-sectional microstructure of graded WC-12Co+NiCrBSiFe coating

coating cost, the process efficiency of the DSC system is thus significantly improved. The second set of parameters is the choice of shot counts.

Experimental

A coating test has been designed and practically conducted to generate a gradient coating with two powders, filled in feeders PF1 and PF2. T1 and T2 are the time durations for which the valves V1 and V2 remain open, after completing the preset time delays D1 and D2. The values of time durations T1 and T2, in successive rows, are entered in such a way that as T1 decreases, T2 is increased correspondingly. Thus, the composition of the powder reaching the detonation waves keeps changing corresponding to the above logic.

In Fig. 2, the data in the first row corresponds to time delays of 200 milliseconds for both valves. Initially valve V1 is opened for 30 milliseconds to permit the required amount of powder from feeder PF1 to enter the gun barrel. The valve V2 does not open as the time value is zero. This particular sequence is continued for 10 shots, which is followed by a change, as shown in the second row of the PC screen. The valve opening times for V1 and V2 are now readjusted as 25 and 5 milliseconds, respectively. Hence, both powder feeders are simultaneously opened for the above durations to inject pre-determined quantities of these two powders. This sequence of operation continues till the valve opening times get reversed, as shown in the last row, where only Powder feeder 2 is opened. The data between these two extremes is linearly distributed so that a linearly graded coating is obtained.

Results and Discussion

A coating of WC-12Co + NiCrBSiFe was generated using the above program. WC-12Co coatings are very effective in providing enhanced wear resistance whereas NiCrBSiFe is a self-fluxing alloy with enhanced corrosion resistance. However, the corrosion resistance of WC-12Co and wear resistance of NiCrBSiFe is very poor. The objective of our engineered coating is to combine both properties in a single coating. The microstructure of the coating cross section is shown in Fig. 3. As is

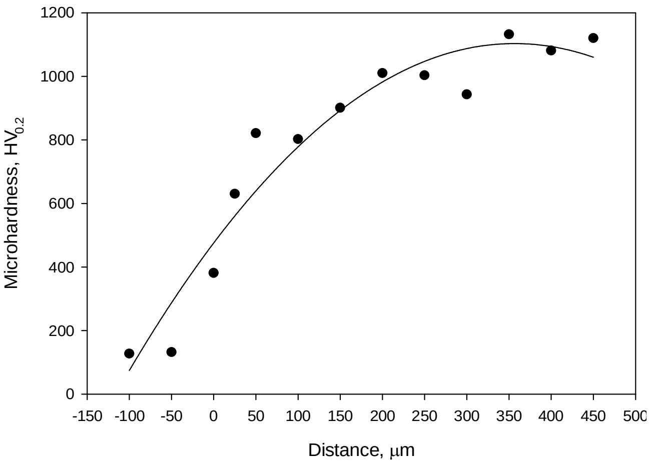


Fig. 4— Microhardness values across WC-12Co + NiCrBSiFe coating thickness

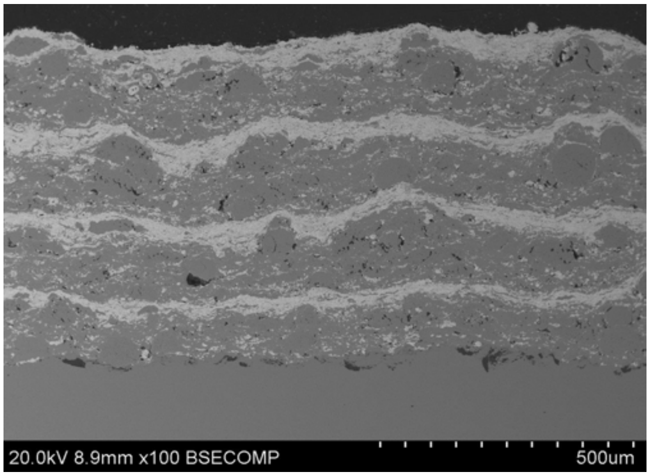


Fig. 5— Cross sectional microstructure of layered WC-12Co + NiCrBSiFe coating

evident in the photograph, there is a clear difference in contrast between the two different material systems. The dark grey feature corresponds to NiCrBSiFe coating and the light colored to WC-12Co.

Additional proof of the gradient structure is provided by measuring the micro hardness across the coating thickness. These values, recorded at 50 micron intervals, exhibited a gradual increase in the values as shown in Fig. 4. Similar logic can be applied to enter appropriate time periods in the table in Fig. 1 to produce coatings having layers of alternate compositions. In this case, the value of T1 in odd rows and T2 in even rows should be zero while the value of T2 in odd rows and T1 in even rows should be an appropriate finite period. A layered coating, obtained by entering such data is shown in Fig. 5

Conclusion

A computer based program and associated hardware were conceptualized and practically tested to obtain functionally graded and layered coatings. This technique offers wide flexibility to tailor the coating microstructure so that exciting coating properties can be obtained. This method is also economically viable when expensive powders are used as coating material.

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