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# Twin wire arc spray process modification for production of porous metallic coatings

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ABSTRACT

One approach to protecting surfaces exposed to high temperature gas flows is to form a boundary layer of cooler gas along the surface, typically by allowing cool gas to flow from internal passages through a pattern of holes drilled in the surface of the component. The production of this pattern of fine holes is time consuming and expensive. In this study we have explored the feasibility of creating high fractions of open porosity extending through the outer face of a metallic foam core sandwich structure heat shield by controlling the porosity content of the thermally sprayed faces. The faces were fabricated by twin wire arc spraying of alloy 625 on the filled surface of the metallic foam core. Modification of the spray process was required to obtain the desired level of open porosity in the coatings, since manipulation of the twin wire arc gun operating parameters alone was not sufficient. An external nozzle was mounted in line with the gun axis to spray polyester powder particles, as a pore generating agent, onto the substrate surface during coating deposition. The effects of twin wire arc gun operating parameters and the polyester powder spray conditions were studied using statistical design of experiments to increase the porosity of the deposits. It was found that the feeding rate of the polyester powder is the most significant factor affecting the coating porosity content, while the gun operating parameters have a relatively small influence. Embedding polyester particles in the coating by spraying through the external nozzle resulted in a pore content of up to approximately 20%.



## 1. Introduction

Metallic foam core sandwich structures are of great interest in advanced engineering applications due to attractive properties such as high surface area to volume ratio, high strength to weight ratio, good flexural rigidity, interconnected porosity in the core, and high permeability [1–3]. A novel method for fabrication of metallic foam core sandwich structures is the thermal spray deposition of skins on metallic foam substrates, which enables production of complex shaped structures using high temperature and corrosion resistant materials. Such structures are difficult or impossible to fabricate using traditional techniques due to the low ductility of these materials and the difficulty of bonding skins to curved surfaces [2,4,5].

A potential application of high temperature corrosion resistant open cell metal foam core sandwich structures is in heat shield devices to protect critical parts from exposure to hot gases [6]. In such applications cooling gas would flow through the foam core to remove heat and keep the surface temperature within the desired range. At present, the surfaces of monolithic components exposed to high temperature gases are often protected by a boundary layer of cooler gas along the surface, typically formed by allowing cool gas to flow from internal passages through a pattern of holes drilled in the surface of the component [7]. The performance of metallic foam core heat shields may be improved if the film cooling mechanism is employed in addition to internal cooling by the flow of gas through the core of the sandwich structure. However, the production of the pattern of holes by existing techniques is time consuming and expensive [8].

Several thermal spray methods have been employed in our laboratory to deposit metallic skins on the metallic foam [9,10]. The aim of all previous studies was to deposit a dense skin for applications such as heat exchangers where penetration of gases through the skin is not desirable due to safety and efficiency considerations. In this study, the feasibility of creating a sufficiently high fraction of open pores in the skin of a metallic foam core heat shield that cooling gas could pass through the skin has been explored.

Twin wire arc spraying was chosen as the method to deposit the skin of the sandwich structures as it is known to be a cost-effective deposition process suitable for industrial production. The porosity content of arc sprayed deposits can be controlled by changing process parameters such as power, stand-off distance and spraying angle [11,12]. However, the range of coating porosity obtainable by these changes is limited. The addition of pore generating agents to the coating during deposition in order to further increase the porosity content was investigated in this study. Hard materials have been injected into the hot gas plume downstream of the arc spray gun to produce composite wear resistant coatings

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that could not be fabricated using only wire feedstock material [13–15]. In the present study, a similar approach was employed to incorporate polyester powder particles in the coating during deposition. The objective was to produce skins with a high percentage of open porosity by varying arc spraying process parameters and the amount of polyester powder incorporated in the deposit. Statistical design of experiments was employed to generate the required experimental runs based on variation of arc spraying process parameters and polyester powder feeder operating parameters. Response surface methodology (RSM) was employed to develop empirical relationships relating the parameters to the coating porosity content.

## 2. Methods and materials

### 2.1. Materials

The alloy 625 was deposited using 1.8 mm diameter wire (Ni 58%, Cr 20–23%, Mo 8–10%, Fe 5%, Nb 3–4%; Oerlikon Metco, Westbury, NY, USA). Alloy 625 was chosen as the skin material for fabrication of the metallic foam core sandwich structures due to its high-temperature oxidation resistance [16]. Fig. 1 shows the polyester powder (Metco 600NS, +45–125 μm, Catalog number: DSMTS-0015.3; Oerlikon Metco, Westbury, NY, USA) that was injected into the hot gas jet downstream of the arc.

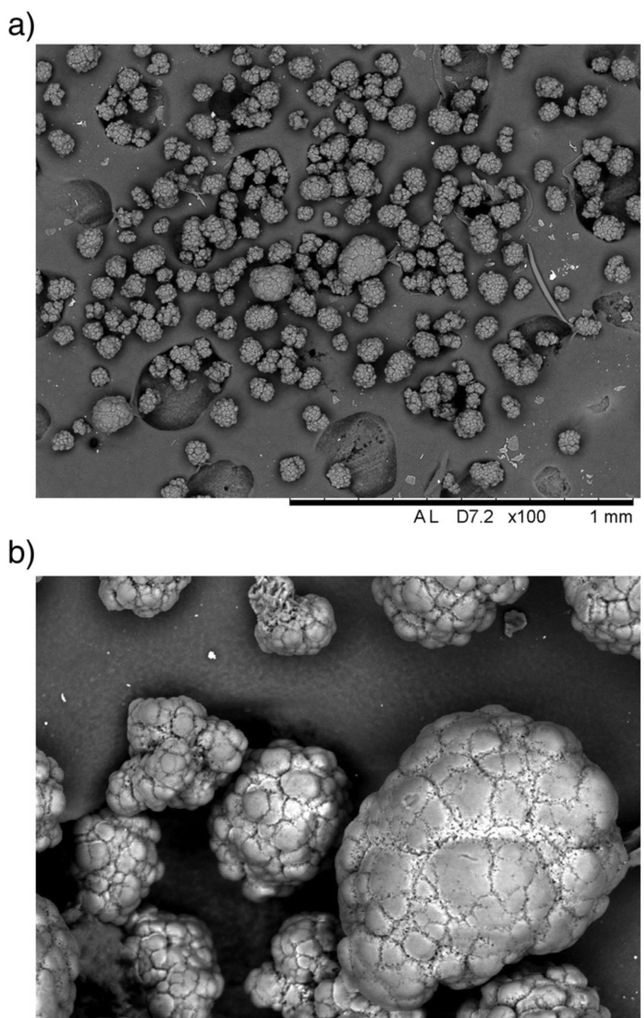


**Fig. 1.** SEM micrograph of the polyester powder a) the visual size distribution b) morphology of the polyester powder particles.

Nickel foam sheets (Yi Gong International, Jiangsu, China), 10 mm thick, with a pore density of 40 pores per linear inch (PPI) were used as the core material for the metallic foam core sandwich structures. A paste consisting of 60 volume percent alloy 625 powder (AMDRY 625 + 45–90 μm, Catalog number DSMTS-0085.6, Oerlikon Metco, Westbury, NY, USA) and 40 vol.% curable thermoplastic resin (Acrodur 950L, BASF, Mississauga, Ontario, Canada) was spread over and into the surface of the nickel foam sheets to make a smooth surface on both faces of the foam. The paste was cured for 8 h by heating gradually in an oven up to 195 °C to produce a stable temporary surface on the foam structure. The filled foam surfaces were grit blasted to expose the foam struts. The average surface roughness ($R_a$, the arithmetic average of irregularities from the mean line measured within sampling length) of the samples after grit-blasting was approximately 32 μm, sufficient to allow good mechanical bonding with the coating. Details of this procedure have been presented previously [9,10,17].

### 2.2. Arc spraying process and gun modification

A twin wire-arc spray system (ValuArc, Oerlikon Metco, Westbury, NY, USA) was used to produce the coatings. A powder feeder (Mettech III powder feeder, Mettech, Vancouver, Canada) with an external powder injection nozzle (internal diameter 3 mm) centered along the wire arc gun axis, was used to inject the polyester powder particles into the hot gas jet at the point where the molten metal droplets reached the substrate surface. In that way the polyester powder particles were embedded between the deposited splats of the thermally sprayed skin before significant decomposition of the polyester occurred. The alignment and position of the nozzle was chosen to provide the most uniform distribution of the powder within the footprint of the arc sprayed metal on the substrate surface, as shown in Fig. 2, based on preliminary experiments. In these experiments a deposit was formed by a single pass of the twin wire arc gun, operated at 34 V and a stand-off distance of 15 cm, on polished 316 stainless steel substrates (McMaster-Carr, Aurora, Canada, catalog number 88885K73). The polyester powder feeder was operated at the maximum feed rate (24 RPM and carrier gas flow rate 26 LPM) with the angle and position of the nozzle varied after each pass.

To produce the skins, the alloy 625 was twin wire arc sprayed on the filled and grit blasted foam surfaces. The process parameters are given in Table 1. The coating thickness was approximately 400 μm for all samples. After coating deposition, the temporary filled resin foam surface and the embedded polyester particles were removed by heating in air to 400 °C at 20 °C/min, then holding for 3 h.

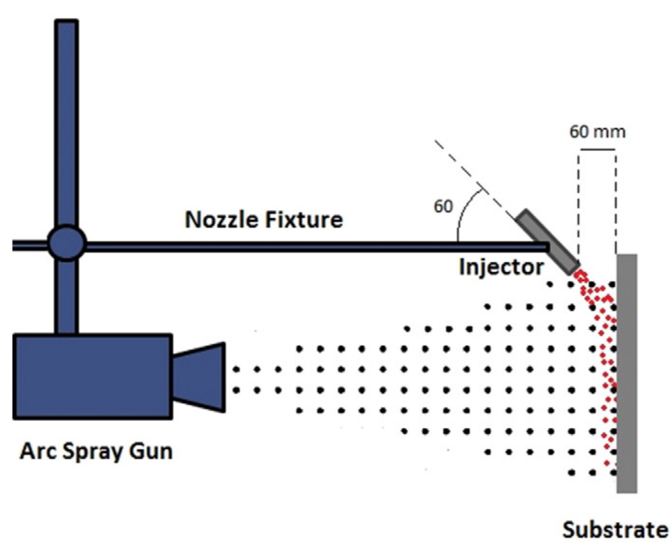


**Fig. 2.** Schematic of external polyester powder injection to the arc spray flame for production of porous coatings.