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Laser-assisted selective fusing of thermal sprayed Ni-based self-fluxing alloys by using high-power diode lasers

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ABSTRACT

Fusing treatment of Ni-based self-fluxing alloys (Metco-16C and 1276F) was performed using high-power diode lasers to control the temperature of the substrate's surface in real time. The effects of the fusing treatment temperature on the microstructural change and hardness distribution were also investigated. For Metco-16C and 1276F, the macrostructural inhomogeneity (voids) within the thermal sprayed layer decreased considerably as the fusing temperature increased. For both self-fluxing alloys, the optimal temperature for fusing was approximately 1423 K (for Metco-16C) and 1373 K (for 1276F), both of which are within the solid state temperature range; these temperatures maximize the alloy hardness together with the macrostructural homogeneity. In this temperature range, the microstructure consists of a lamellar-structured matrix phase with fine (<5 μm) carbides and borides. Selective fusing for a thermal sprayed layer 0.2–0.5 mm in thickness could be successfully achieved in a high-power diode laser system.

1. Introduction

Thermal spraying of self-fluxing alloys is widely used to produce substrate materials for wear- and corrosion-resistant coatings in the chemical and mechanical industries. In general, self-fluxing alloys are produced by adding small amounts of carbon (C), boron (B) and silicon (Si) to nickel (Ni), cobalt (Co) and iron (Fe)-based alloys [1–7]. In particular, adding C and B leads to the precipitation of carbides and borides in the matrix, which contribute to the increased hardness and wear-resistance of the coating layer [2,3,5]. However, since the thermal-sprayed layer contains macrostructural inhomogeneity (voids and macrosegregation of specific elements) after spraying, nitriding upon the sprayed layer, modifying with hard particulates and fusing treatment of the sprayed layer etc [3,6,8,9]. have been employed to improve the inhomogeneity. Among the mentioned before techniques, fusing treatment is usually needed at a certain temperature range to achieve macrostructural homogeneity and increased hardness compared to the as-sprayed state. Fusing treatment has been normally performed in a furnace. When dissimilar substrate and self-fluxing alloy materials are used in this environment however, desquamation of the thermal-sprayed layer (self-fluxing alloy) can occur during the fusing treatment due to distortion caused by different thermal expansion coefficients between the thermal-sprayed layer and the substrate.

Among the numerous available manufacturing processes, laser beam-assisted processes are particularly versatile because of their diverse application range and superior manufacturing efficiency, including welding [10–12], cladding [13–16], surface alloying [17], cutting [18], micromachining [19,20] and peening [21]. Selective control of the material properties at the surface is also possible through laser processing. A high-power diode laser is often used in this type of hardening process [22–25], because of its high absorptivity of metals and the typical rectangular beam shape (approximately a top hat in both directions) which allows for a larger treatment area compared with CO2 [26], Nd:YAG [27,28] and fiber lasers [29,30]. Therefore, the diode laser is a strong candidate for use in fusing treatment of dissimilar material combinations as mentioned above. While there are numerous surface hardening studies using diode lasers [22–25,31–33], almost all of them have focused on steels with phase transformation behavior, and fundamental investigation of Ni-based self-fluxing alloys is still insufficient in this regard. In particular, in almost of these previous studies of surface hardening using diode lasers, the degree of surface hardening was controlled primarily by the laser power and the irradiation speed. However, to maximize the fusing effect in self-fluxing alloys, precipitation of the secondary phases (carbides

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Table 1
Chemical compositions of self-fluxing alloy powders used in this study (wt.%).

Materials	Ni	C	Cr	W	B	Si	Fe	Mo	Cu
Metco-16C®	Bal.	0.6	17.0	-	3.7	4.0	3.0	2.5	2.5
#1276F®	Bal.	0.8	14.3	16.2	2.9	3.8	3.3	5.0	–

Table 2
Conditions for thermal spraying of self-fluxing alloys.

Parameters	Value
Thermal sprayer	JP-5000®
Powder flow rate (g/m)	70–100
Oxygen flow rate (ℓ/m)	1000–1200
Gasoline flow rate (ℓ/m)	3–5
Thickness of sprayed layer (mm)	0.2 (Metco-16C), 0.5 (1276F)

Table 3
Conditions for laser-assisted fusing treatment.

Parameters	Value
Oscillator	4 kW direct diode laser (DLS-0970–04000, Teradiode®)
Wavelength of laser beam (nm)	970
Beam dimension (mm)	6 × 4 (square type)
Maximum laser power density during fusing treatment at 1473 K (W/cm^2)	2.5 × 10^3
Direction of beam irradiation	Perpendicular to specimen
Focal length (mm)	310
Defocus distance (mm)	0
Speed of fusing treatment (mm/s)	1.0 (Metco-16C), 0.5 (1276F)
Temperature of fusing treatment (K)	1123–1473

and borides) is essential. Thus, fusing should be performed within an optimal temperature range maintained during the overall fusion process. There have been few studies on surface treatment with high-power diode laser systems featuring real-time temperature control. With this literature gap identified, this study constructs a fusing treatment system consisting of a high-power diode laser linked with in-situ control over the temperature and laser power (referred to as laser-assisted fusing treatment). The effect of the fusing treatment temperature on the microstructural change and hardness distribution was investigated to optimize the fusing conditions.

2. Materials and methods

2.1. Materials

In this study, two types of commercial self-fluxing powder (Metco-16C® and #1276F®) were used for thermal spraying, referred to here as Metco-16C and 1276F respectively. These powders are Ni-based alloys, and Table 1 lists their chemical compositions. The substrate material for thermal spraying consisted of two layers; a pure Cu sheet (commonly used in the molds of continuous casting parts within steel making process) and a pure Ni layer deposited on the pure Cu sheet by electroplating.

2.2. Experimental procedures

Thermal spraying was performed with both powders using a high velocity oxygen fuel (HVOF) method on the substrate (at the pure Ni layer). The thermal spraying conditions are listed in Table 2. The thermal sprayed specimens were fused using a diode laser

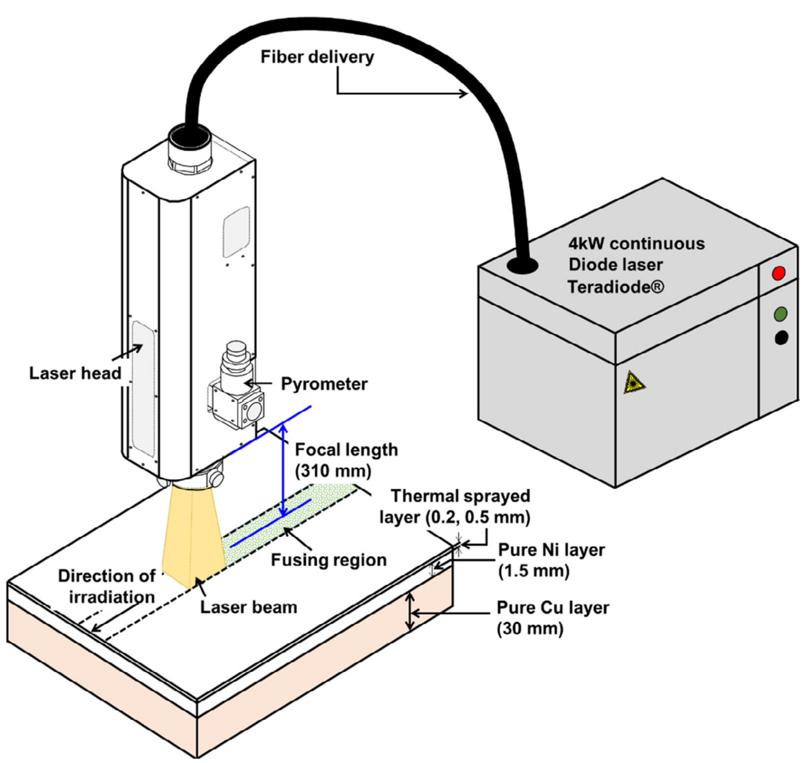

Fig. 1. Schematic diagram of specimen arrangement and laser-assisted fusing treatment.