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Microstructural evolution and bonding characteristic in multi-layer laser cladding of NiCoCr alloy on compacted graphite cast iron

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ABSTRACT

Laser cladding of NiCoCr alloy powder on cast iron was performed with a 1 kW Nd:YAG continuous laser. Despite numerous advantages, one of the most critical issues is the formation of martensite and a brittle layer in the vicinity of the bonding interface due to the inherent rapid cooling, which might result in cracking nearby and a decrease in bonding strength. The objective of this research is to produce well bonded NiCrCo alloy coating that is free of pores and cracks on cast iron without preheating the whole substrate. Considering the poor weldability of cast iron, the strategy of reciprocated deposition, namely multi-layer laser cladding, was applied. The microstructural evolution of the multi-layer coating on the cast iron was investigated with the emphasis on the variation of the bonding zone. The results showed that NiCoCr coatings with different layers consisted of fine solid solution dendrites surrounded by an inter-dendritic network of precipitates. The multi-layer clad coating had a gradual distribution of elements, which was different from that in the single layer coating. The martensite near the bonding interface was transformed into tempered sorbite under the thermal influence of multi-layer deposition, leading to a decrease in the high micro-hardness zone width. A bending test confirmed that the bonding brittleness was reduced and the mechanical properties were improved through the use of the multi-layer laser cladding approach.

1. Introduction

Cast iron is an Fe–C alloy which is widely used in the manufacture of various components with complex shapes and cavities due to its good castability, excellent machinability, low cost, and excellent vibration damping. A large number of these components, such as pistons and cylinders used in the automotive industry, suffer from severe cyclic thermal and mechanical loads simultaneously produced by localised intense fire, explosion pressure, or clamping of the components. Unfortunately, the thermal fatigue resistance of cast iron is undesirable owing to the presence of a high percentage of free graphite, as well as the interfaces between the free graphite and metallic matrix. Therefore, cyclic thermal loading usually results in cracking on the surface of cast iron, leading to failures. It is essential to modify the surface properties of cast iron for higher reliability and a longer service life.

Laser cladding is an advanced surface modification method used to produce metallurgical bonded, high-performance, fully dense coatings on metallic substrates with specific advantages over conventional surface modification processes. These include: fine microstructure, a narrow heat-affected zone, low distortion, and ease of automation. In laser cladding, a high-power-density laser beam is used to create a melt pool on a substrate. Meanwhile, the additive powder material is injected toward the melt pool by an inert gas. The melt pool solidifies and a deposited layer with special performance is produced after the laser beam moves away. A laser coating of up to 2 mm could be deposited by overlapping successive tracks (Smurov et al., 2013; El Cheikh et al., 2012a), providing a way to protect the base metal from thermal shock.

Several experiments and simulations have been carried out to investigate laser processing of cast iron surfaces. Benyounis et al. (2005) investigated the surface melting of nodular cast iron by Nd-YAG laser: it was found that the laser-melted zone was composed of finer dendrites of retained austenite surrounded by a continuous network of cementite and some acicular martensite. Alabeedi et al. (2009) performed laser surface melting of nodular graphite cast iron using a 3 kW CW CO_2 laser. They found a simi-

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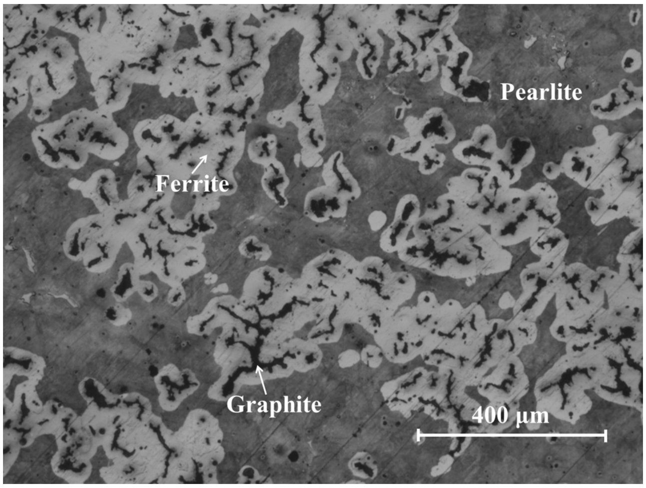

Fig. 1. Microstructure of compacted graphite cast iron.

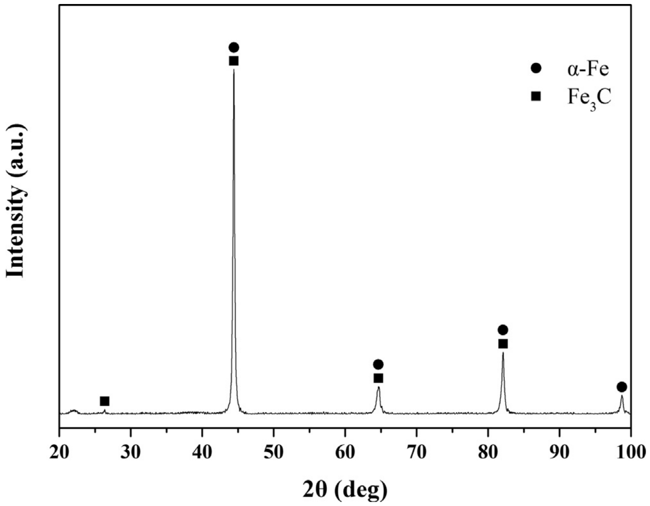

Fig. 2. XRD pattern of compacted graphite cast iron.

lar microstructure with high hardness. Sun et al. (2011) produced wear-resistant layers on nodular cast iron rolls with C–B–W–Cr powder using laser surface alloying techniques. Their research indicated that the bonding area was different from the top part of the alloyed layer. In addition to the typical dendrite structure bonded with the substrate, a coral-like structure was detected in the bonding area. Yan et al. (2010) reported that some acicular martensite and ledeburite, characterised by high hardness and poor toughness, were formed at the interface and in random locations on the laser clad layer on a ductile iron sample. Similar results were found by Arabi Jeshvaghani et al. (2014): they found eutectic ledeburite and a martensite microstructure in the partial melted zone (PMZ) and only a martensitic microstructure in heat affected zone (HAZ). Ocelík et al. (2007) used a 2 kW continuous Nd:YAG laser to fabricate Co-based coatings on compacted graphite and gray cast iron substrates, and established empirical relationships between the process parameters (i.e. laser power, powder feeding rate, and scanning speed) and the geometric features of its single-track. It was found that crack propagated from the bonding interface and layer interior when thicker coatings were deposited on a stiff substrate as a consequence of internal stresses. Lestan et al. (2013) used three different powders for laser deposition of cast iron to investigate the microstructure and cracking of the coating. Many cracks originating from the bonding zone were observed. Xu et al. (2014) established two numerical models which included a macro-laser cladding model, and a micro-graphite model to analyse the stress variation of the graphite area of grey cast iron, and demonstrated that the graphite tip was a hazardous area for microcrack initiation due to tensile stress concentrations thereat. Yan et al. (2014) studied the process of laser cladding a NiCuFeBSi alloy layer on grey cast iron. The formation of martensite in the HAZ was interpreted on the basis of carbon diffusion and cooling rate in their research.

Preheating the substrate has been suggested as a way of reducing the thermal stress, as well as cracking susceptibility, in the laser cladding process. Jendrzejewski et al. (2006) concluded that the calculated strain and stress were reduced in cases using preheating. Crack-free layers were fabricated with a substrate preheated to a temperature of 873 K; Lin et al. (2014) proved that graphite nodules, where microcracks usually were initiated, were dissolved during preheating. Hence, the number of microcracks in the bonding zone decreased. In the preheating process, the base metal must be put in a furnace to heat it to a definite temperature, and then that is maintained for a certain time. This method is accompanied by substantial energy consumption, poor production efficiency, an undesirable working environment, etc. Besides, this method could not be used on work-pieces that are too large to put in a furnace.

It could be concluded, from the aforementioned research, that there are some difficulties and issues arising from the use of laser cladding processes on cast iron; because large amounts of free carbon, in the form of various kinds of graphite, are present, carbon dioxide could be produced in the melt pool when the laser beam radiates to the surface of cast iron, which easily leads to the formation of pores. Another issue is connected with the high laser absorption of the graphite compared with that of the metal matrix. The laser absorption difference makes the graphite act as if it were many heat sources distributed within the cast iron. Therefore, non-homogeneous thermal, and stress, fields may be created. The major issue is involved with the poor weldablity of cast iron. The majority of researchers have revealed that the phases of martensite and ledeburite were formed at the bonding zone due to the high cooling rate. These phases have high hardness but poor plasticity and toughness, resulting in brittleness of the bonding zone between the substrate and the clad layer. Meanwhile, the phase transformation of austenite to martensite may develop microcracking at the bonding interface, due to the specific volume variation and the deformation constraints at the grain boundary.

The objective of this study is to produce well bonded NiCrCo alloy layers on cast iron, without preheating the whole substrate, using a Nd:YAG laser. Taking the material properties of cast iron into account, the strategy of reciprocated deposition, namely multi-layer laser cladding, is applied. The microstructural evolution in the clad layer, as well as the bonding zone of the cast iron, is investigated. The hardness and bending characteristics of cast iron coated by NiCrCo alloy are also examined.

2. Materials and experimental design

2.1. Materials and laser equipment

Compacted graphite cast iron (CGI) cut from a cylinder measuring 120 mm × 60 mm × 30 mm was used as a substrate. The main chemical composition of CGI included (in wt.%): 3.6C, 2.7 Si, 0.2 Mn, <0.05 P, <0.02 S, and the remainder Fe. The microstructure and XRD pattern of CGI were shown in Fig. 1 and Fig. 2, respectively. The microstructure of CGI was a large amount of graphite surrounded by a ferrite-pearlite matrix. The grain size of ferrite was mainly in the range of 100–300 μm. The majority of the graphite was vermicular, while the rest was nodular. The deposited material was a Ni-based alloy with a particle size distribution of 40–150 μm (−100/+325