Synthesis of a nickel silicide-base composite coating on austenitic steel by laser cladding

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In advanced industrial gas turbines, internal combustion engines and power generation industries, there are many tribological components working under high-temperature aggressive service conditions, demanding the materials with excellent wear, corrosion and oxidation resistance. Development of advanced bulk materials with excellent combination of wear, corrosion and oxidation resistance is one possible choice to solve the above problems. Compared with bulk materials, employing the method of surface modification to fabricate coatings which possess the above properties on components’ surface is more economic and effective. Nickel silicides alloys are well-known for their excellent combination of wear, corrosion and oxidation resistance. Although much interests have been attracted on developing nickel silicides alloys as bulk high-temperature structural materials, the inherent room temperature brittleness prevented them from successful industrial applications. However, the excellent combination of wear, corrosion and oxidation resisting properties makes the nickel silicide alloy a very attractive candidate coating material using under high-temperature aggressive environments [1–3]. Actually, nickel silicides coatings are fabricated on pure silicon substrate by evaporation or sputter deposition of a thin nickel film, followed by a heat treatment at an appropriate temperature, which can be used in silicon integrated circuit technology to provide ohmic contacts, Schottky barriers, diffusion barriers, interconnects and so on. But, up to now, no reports are available on producing nickel silicides as high-temperature functional coating materials [4]. The extreme non-equilibrium condition induced by the interaction between high power laser and materials have provided the feasibility of synthesizing novel materials. Significant development in high power lasers has recently encouraged the commercial application of laser assisted surface modification including heat treating, glazing, alloying and cladding. In particular, laser cladding is a relatively new process in which an alloy powder of a desired composition is melted with minimum mixing to the substrate under laser irradiation and then rapidly solidified to form a dense coating with refined microstructure and metallurgical bonding to the substrate. The objective of the present paper is to explore the feasibility of synthesizing a nickel silicide-base coating on an austenitic stainless steel by laser cladding with Ni, Si and Cr mixed elemental powders. The microstructure of the nickel silicide coating was characterized by OM, SEM, XRD and EDS and microstructural evolution process was discussed.

The commercial austenitic stainless steel 1Cr18Ni9Ti is selected as the substrate. Specimens, 8 × 10 × 40 mm in size, are first sandblasted and then cleaned with ethyl alcohol and acetone before laser cladding. Loose mixed elemental powders (wt%) in proportion of 48Ni-12Cr-40Si, are preplaced on the specimen’s surface in thickness of approximately 1.5–2.0 mm. The addition of Cr in the mixed cladding powders is aimed at improving the oxidation and corrosion-resistance of the laser clad nickel silicide coating. The particle size of the powders ranges from −100 to 320 mesh. The purity of the above powders is 98.0%. Laser cladding is carried out using a 5 kW continuous wave CO2 laser with a 4 axes CNC table under shielding of argon. The laser cladding parameters are: laser output power 2.0 kW, beam diameter 4.0 mm, beam traverse speed 7.5 mm/s. Transverse and longitudinal metallographic cross-sections of the laser clad composite coatings are prepared using conventional procedures and are chemically etched with a water solution of HCl and HNO3 (with a volume ratio of 3:1). Microstructure of the laser clad composite coatings is examined by OM, SEM and EDS. The phases present in the laser clad surface layer are identified by X-ray diffraction method with Cu Kα radiation. The hardness profile along the coating depth direction is measured using a microhardness tester with a load of 300 g and a loading time of 10 s.

During laser cladding process, the mixed elemental powders in the pre-placed powder bed are melted with minimum dilution to the substrate under the direct radiation of laser beam, forming an Ni-Si-Cr ternary alloying melt-pool over the surface of the austenitic stainless steel specimen. After solidification of the alloying melt-pool followed by the forward moving of the laser beam, the nickel silicide-base composite coating was produced on substrate of the stainless steel. The X-ray diffraction analysis indicates that the major phases in the laser clad nickel silicide composite coating are the nickel silicides of Ni5Si and Ni3Si, as indicated in Fig. 1, diffraction peaks of the y-Fe phase of the
stainless steel substrate is also visible due to the small laser clad tracks.

Fig. 2a shows the transverse OM overview photomicrograph of the laser clad composite coating. Single clad track, 1.7 mm in thickness and 4.0 mm in width, was produced on the austenitic stainless substrate. The microstructure within the whole laser clad layer was relatively uniform with a well-defined directionally solidified dendritic structure extending from the coating/substrate bonding zone up to the top surface of the laser clad composite coating, as shown in Fig. 2b. A few microcracks are visible in the lower part of the laser clad composite coating, as shown in Fig. 2a and b. The formation of microcracks was mainly attributed to the high residual stresses as a result of the mismatches in thermal and mechanical properties between the laser clad nickel silicide composite coating and the substrate of austenitic steel and the high cooling rate during laser cladding process. The volumetric dilution ratio of the cladding layer, i.e. the ratio of the maximum depth of remelting layer of the substrate to the whole laser clad layer, was small and was up to 8.5%.

Microstructure of the laser clad composite coating was formed as a result of the rapid non-equilibrium solidification according to the Ni-Si (also add minor Cr) quasi-binary system due to the heat transfer of the substrate. Optical and scanning micrographs of the coating are shown in Fig. 3a and b. Observation of the micrographs revealed two main microstructure existed in the coating. One is the primary or hypereutectic dendrites (white area in Fig. 3a and grey area in Fig. 3b), the other is the dot-like interdendritic eutectic constituents (grey area in Fig. 3a and dark area in Fig. 3b). Fig. 4 is the OM and SEM micrograph of the bonding zone between the coating and the substrate. Obviously the bonding of laser clad coating to substrate is of high metallurgical quality. Close examination of the above micrographs revealed that between the substrate and the laser clad composite coating is a thin planar-front solidified layer (bright band), approximately 20 µm in thickness, epitaxially grown from the substrate, as shown in Fig. 4. Results of EDS analysis indicate that the bright band contains high contents of Fe but relatively little Si and Ni.

EDS analysis show the white area in Fig. 3a and grey area in Fig. 3b is rich in Si and Ni, yet this phase contains some extended solid solution of alloying element Cr, the atom ratio of Ni, Si is approaching to 1:1. Considering Si acts simultaneously as deoxidizers during the cladding, the complex oxides of Si ascend toward the surface through the molten deposit and is removed.