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In Situ Synthesis of Heat Resistant Gradient Composite on Steel Surface

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Abstract: A heat resistant gradient composite was synthesized in situ on steel with the self-propagating high temperature synthesis (SHS) reaction of 3Ni-Al-Ti-C system during casting. The phases, microstructure, and composition of the composite were analyzed by using an X-ray diffractometer (XRD), and a scanning electron microscope (SEM) coupled with an energy-dispersive X-ray spectroscope (EDS). The formation mechanism of the composite is also discussed. TiC/Ni_3Al/steel gradient composite is achieved by forming the gradient distributions of Fe, Ni, and Al, accompanied with the gradient variation of the microstructure from TiC/Ni_3Al, to TiC/Ni_3Al/steel, and to steel. The composite is in situ synthesized through whole reaction of 3Ni-Al-Ti-C system in liquid steel and densification procedure, and the liquid steel infiltrates into pores in the SHS product and forces liquid Ni_3Al to form self-compaction further.

Key words: steel; heat resistant composite; synthesis; microstructure

Nickel aluminides based upon NiAl and Ni_3Al have been considered as the potential candidates in high-temperature structural materials[1-4]. However, the structural use of nickel aluminides suffers from low ductility at the ambient temperature, poor fracture toughness, and inadequate strength at elevated temperatures[5]. Therefore, much effort has been invested in attempts to improve the performance of nickel aluminides by the addition of reinforcing phases. TiC particulate possesses many desirable properties, such as high hardness, low density, high melting temperature, high modulus, and high corrosion resistance[6-8]. If TiC-reinforced Ni_3Al composite on steel substrate is obtained, the oxidation and corrosion resistance, the hardness as well as the wear resistance of the substrate will be totally improved, especially at an elevated temperature.

Nickel aluminides coatings or nickel aluminide matrix composite coatings are normally produced by means of PVD, laser deposition, and so on. All of these techniques are so expensive or complex that they cannot be applied universally in industry[9-11]. It was also reported that La P Q has obtained Ni_3Al coatings on carbon steel by SHS-casting route[12]. It is well known that a casting process is the most effective way to obtain low cost MMCs in conventional process. Hence, in the present study, in situ synthesis of TiC/Ni_3Al/steel gradient composite on steel via SHS reaction of 3Ni-Al-Ti-C system in the sand mold during casting was investigated. The purpose of this study is to produce a heat resistant gradient composite on steel surface with a simplified casting process route combined with SHS technique. It was expected that the research could be significant in enlarging application of steel.

1 Experimental Procedure

The starting materials of preforms were made from commercial powders of Ni (99.0% purity, 74 μm), Al (99.0% purity, 74 μm), Ti (99.0% purity, 74 μm), and C (99.9% purity, $\geqslant$30 μm) (in mass percent). Powder mixtures were prepared with the composition corresponding to the molar ratios of Ni : Al=3 : 1 and Ti : C=1 : 1 with TiC of 35% (in mass percent).

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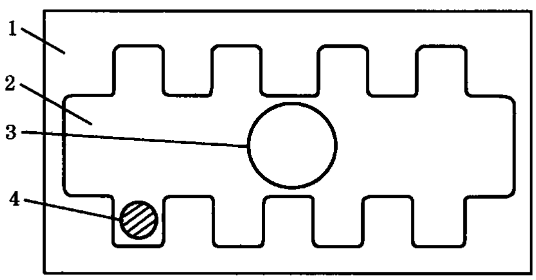
Powders were mixed in a ball milling machine for 24 h, and then, were pressed uniaxially into cylindrical preforms (20 mm in diameter and 4 mm in length) at pressures of 20 MPa. The nominal compositions of the steel as substrate are shown in Table 1.

The preforms were pasted in a sand mold with 3% (in volume percent) PVA water solution, as shown in Fig. 1. The sand mold was preheated to 300 ℃ together with the performs before casting. The steel was melted in a 20 kg medium frequency induction furnace with non-oxidation method. On reaching 1 600 ℃, the melt was deoxidized with Al, and then poured into the sand mold. Subsequently, the combustion synthesis reaction of 3Ni-Al-Ti-C system was initiated by the heat of melted steel. After solidification, the composite with 4 mm of thickness was formed on the steel. The self-propagating high-temperature synthesis reaction of the 3Ni-Al-Ti-C system was studied by DSC (differential scanning calorimetry). Metallographic samples were prepared in accordance with standard procedures used for metallographic preparation of samples and etched with 5% (in volume percent) HNO_3 ethylalcohol solution for 5 — 10 s at 25 ℃. Microstructures, compositions, and phases of the composite were investigated by using an AMRA-1000B type scanning electron microscope (SEM) coupled with an energy-dispersive X-ray spectroscope (EDS) and a D/Max-2500/pc type X-ray diffractometer (XRD).

Table 1 Nominal composition of steel (mass percent, %)

C	Cr	Mo	V	Si	Mn	S	P
0.35	3.0	2.0	0.3	0.43	0.28	0.012	0.018



1—Sand mold; 2—Cavity; 3—Pouring channel; 4—Perform

Fig. 1 Schematic diagram of mold

2 Results and Discussion

Fig. 2 presents the XRD pattern of composite surface. It can be seen that the composite consists of two phases: Ni_3Al and TiC, without any contamination. It should be noted that TiC and Ni_3Al were achieved as expected through full reaction of 3Ni-Al-Ti-C system. The microstructure of the interface between the composite and the steel is illustrated in Fig. 3 (a). The left is the steel, and the right is the composite. No pores and cracks are found in the composite and the interface, which shows that the interface bonding is firm and the composite is compact.

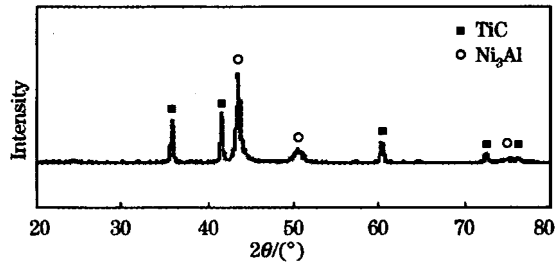


Fig. 2 XRD pattern of composite surface

Fig. 3 (b) and (c) is the magnified microstructure of the composite. It is clear that TiC is a granular form with sizes of 0.5—2 μm and is relatively uniformly distributed in Ni_3Al matrix. TiC particulates are sparsely scattered in the area adjacent to interface and is relatively densely distributed in the composite.

The results of EDS analysis for the composite are shown in Fig. 4. Ni, Al, Ti, and C are found on the composite surface, which conform to the XRD analysis. However, except for the above-mentioned elements, Fe appears in the composite with relatively more amount of Fe present at the interface. Therefore, it can be suggested that convection and diffusion should occur between the melted steel and the reacted preform during formation of the composite. This is helpful to form firm metallurgic bonding between the composite and steel. The distribution patterns of Fe, Ni, Al, and Ti are revealed in Fig. 5.

It is found that Ti remains relatively unchanged in the composite. These are the same situations for Ni and Al near the composite surface. However, near interface, Ni and Al increase with the gradient variation, on the contrary, Fe decreases. So, it can be concluded that the gradient variation of the microstructure from TiC/Ni_3Al, to TiC/Ni_3Al/steel, and to steel is present. The steel and TiC/Ni_3Al coexist in the composite.

In 3Ni-Al-Ti-C system, the self-propagating high temperature synthesis reaction is composed of the reactions as follows: