NiAl intermetallic coatings prepared by thermal plasma assisted thermal explosion process

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This paper describes a new method to prepare NiAl intermetallic compound coating on carbon steel. In this study, NiAl intermetallic compound was firstly obtained by thermal explosion. Subsequently a NiAl coating was prepared on carbon steel by thermal plasma cladding. The results showed that, the final coating layer of single phase NiAl was obtained, the layer had dense microstructure, NiAl layer and carbon steel had high quality metallurgical bond.

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1. Introduction

The NiAl intermetallic compound promises a great potential for high temperature applications [1–4]. It has a combination of important structural properties, such as high mechanical strength, low density (5.86g.cm^{-3}), high melting point (1638° C), high young's modulus (294GPa), excellent oxidation resistance (～1000° C), low cost of its component and easy of production. However, poor room temperature ductility and high temperature strength are significant obstacles for this alloy's structural use [5-7]. The interest in this compound is due to creep and rupture strength that compete with single crystal Ni-based super alloys. The NiAl intermetallic compound has potential applications such as hot sections of gas turbine engines for aircraft propulsion systems, coatings for thermal barrier applications, electronic metallization compounds in advanced semiconductors and surface catalyst.

Application of brittle and hard intermetallic compound to improve the surface properties of metal is expected to be useful to practical use, because it can minimize the metal work for machining and can utilize its superior properties. In this context, many publications in the literature have been reported on application of intermetallic compounds as a coating layer on metal surface [8-10].

Thermal explosion synthesis is a kind of technology of SHS (self-propagating high temperature synthesis). In the thermal explosion mode, the compacted reactant powders are heated up at a rapid rate in a furnace until the reaction is initiated uniformly throughout the sample. Plasma cladding is one of the most important techniques to improve the surface of materials [11,12]. Because of the high energy density and the high solidification rate, plasma cladding treatment can control excessive growth of the grains and eliminate the defects in a coating.

At present, preparation of NiAl intermetallic compound coatings still have some difficulties, for example, NiAl intermetallic compound coatings prepared by combustion synthesis usually have porous structure because of plenty of heat caused by the reaction process[13,14], and the thickness of the layer cannot by controlled easily. The technology of NiAl coatings prepared by laser cladding [15] or HVOF [9,16] has too many powders lose [17]. These technologies severely limit the particle application of NiAl intermetallic compound coatings.

In order to overcome the shortcoming of the technology preparing NiAl coatings, in this work, firstly, NiAl intermetallic compound was in-situ synthesized by thermal explosion. Subsequently, the obtained NiAl intermetallic compound was melted on carbon steel by thermal plasma cladding. The study attempts the new technology to prepared NiAl coating with dense structure, reasonable thickness and good bounding properties with substrate.

2. Experimental

Plate specimens (Φ24×7 mm) of the substrate material were prepared firstly. Prior to coating, the specimens were carefully polished using the abrasive paper. Thereafter, those were buffed and cleaned with acetone by ultrasonic cleaner. Chemical composition of this material is given in Table 1.

Table 1. Chemical composition of substrate (wt.%).

C	Si	Mn	P	S	Mg
3.5	2.56	0.28	0.021	0.006	0.039

The nickel powder and the aluminum powder used were 3μm in size with 99.9% purity. These powders were weighed in 1:1 molar ratio and mixed. A weight of 0.4g of the mixed powder was compacted uniaxially for 2 min by the cold press with the pressure of 200 MPa. The dimension of the cylindrical green pellet was 20 mm in diameter and approximately 1 mm in height after compacting. The schematics of compacting process and a schematic diagram of coating equipment are presented in Figs. 1 respectively

The sequence of coating process can be explained in the following steps.

(a) The plate specimen was set on a ceramic circular plate in the middle.

(b) The compacted NiAl green pellet was placed on the specimen.

(c) The samples were set in an induction heating furnace, and the heating rates were controlled by the current and the voltage of the induction equipment at 10℃/s until the thermal explosion finished and obtained NiAl intermetallic compound.

(d) The NiAl intermetallic compound was placed on the carbon steel, and the NiAl coating was prepared on carbon steel by thermal plasma cladding.

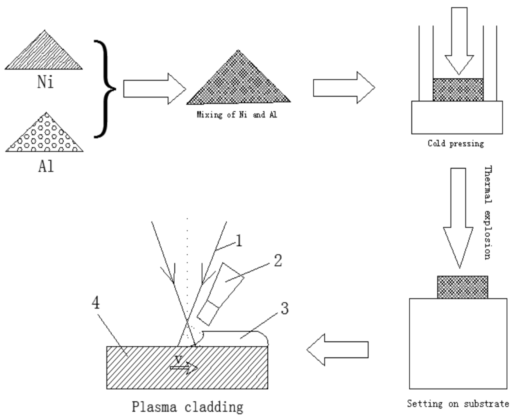

Fig. 1. Schematic diagram of the experiment.

Scanning electron microscopy(SEM)was used to examine the microstructures of the samples polished using standard metallographic techniques. In order to determine phases formed, X-ray diffraction analysis (Cu target, 30kV, 30 mA) was utilized. Micro-hardness measurement was made with a Vickers hardness tester (200g in hardness test, 20kg in indentation test, duration time of 30s).

3. Results and discussions

3.1. Time-temperature diagram of the thermal explosion

Fig. 2 shows the differential scanning calorimeter (DSC) graph of Ni and Al powder mixture (1:1 molar ratio) under a constant heating rate of 10^{o}C/min in thermal explosion.

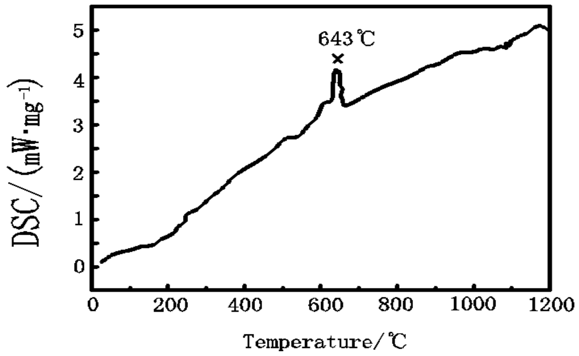

Fig. 2. DSC anasysis of the thermal explosion.

The DSC showed that the exothermic peak occurred at above 640^{o}C, this peak correspond to the thermal explosion. With time increased, the temperature raised, but there was no exothermic peak occurred again. These dates show that the formation of NiAl intermetallic is a one step reaction with the ignition temperature of approximately 643^{o}C which is lower than the Al melting point(660^{o}C) but higher than the Al-rich eutectic temperature(640^{o}C) in the NiAl phase diagram [18].

3.2. Microstructure of coating layer

The results of XRD for the coating on carbon steel are shown in Fig. 3. It can be seen that only NiAl phase corresponding to the initial composition of mixed powder in this study appears in the coating layer.

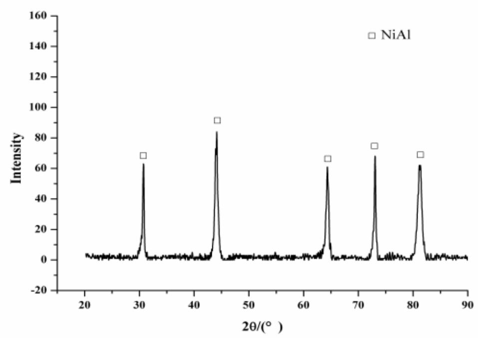

Fig. 3. XRD patterns of NiAl coating.

The formation mechanism of NiAl intermetallic strongly depends on heating rate. Several exothermic and endothermic peaks were observed at lower heating rates. This results in solid-state pre-combustion reaction (two-step reaction) between Ni and Al as well as intermediate reactions in the process of formation of nickel aluminides such as $NiAl_3$and Ni_2Al_3 forming prior to the final products [19].

The SEM micrographs at around interfaces between the coating layer and the substrate are shown in Fig. 4.

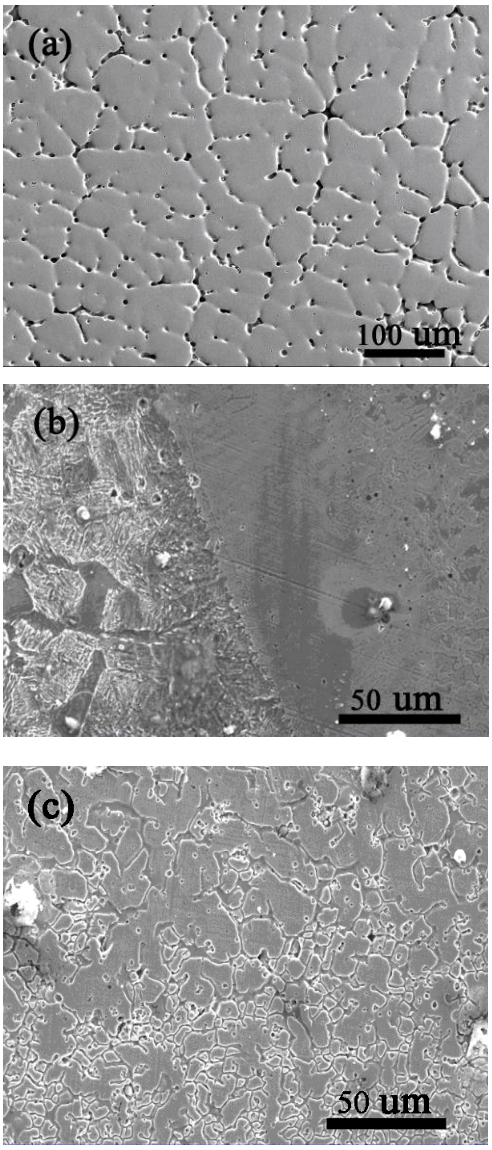

Fig .4. Microstructure of NiAl coating layer.

The SEM micrographs at around interfaces between the coating layer and the substrate are shown in Fig. 5. As shown in Fig. 4 (a), some porous were found in the NiAl intermetallic compound synthesized in thermal explosion. The cause is that the process of thermal explosion is an exothermic reaction, in this reaction, some impurities such like carbon, volatilize in the high temperature. Fig. 4 (b) shows that the NiAl coating and substrate has a distinct interface, which is because thermal plasma can releases enough heat and ensure the metallurgical bonding between NiAl coating layer and substrate. Fig. 4 (c) shows the microstructure of NiAl coating layer, it is clear that seldom porous and no cracks are found in their coating layers, that because the NiAl intermetallic compound was remelted by thermal plasma cladding, The NiAl coating has dense microstructure.

3.3 Microhardness

The hardness variations measured by micro-Vickers hardness tester around the interface for each heating rate are shown in Fig. 5. It can be seen that the hardness of the coating layer is higher than that of the substrate [8].

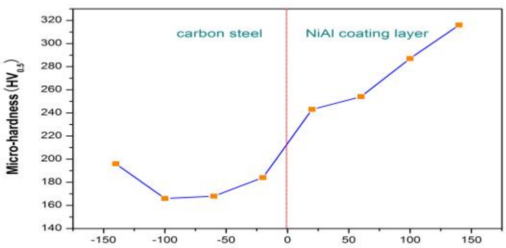

Fig. 5. Microhardness.

4. Conclusions

NiAl intermetallic compound has been successfully synthesized by thermal explosion (TE). Dense and homogeneous NiAl inter- metallic compound coating was obtained by thermal plasma cladding, The NiAl coating and substrate has a distinct interface and high quality metallurgical bonding. The hardness of NiAl coating is above 600 HV and obviously higher than substrate. In all the process there is almost no powder waste, and high performance and quality NiAl coating was prepared by this new technology.

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