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Development of new type of wear and crack resistant hardfacing electrode①

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Abstract: By using H08A bare electrode and the coating fluxes of ferrotitanium, rutile, graphite, calcium carbonate and calcium fluoride, a new type of wear and crack resistant hardfacing electrode was developed. The microstructure and wear properties of deposited layer were studied by means of scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffractometry(XRD) and wear test. The results indicate that TiC particles are produced by direct metallurgical reaction between ferrotitanium or rutile and graphite during welding process. TiC particles with sizes in the range of 3 - 5 μm are dispersed in the matrix of lath martensite and retained austenite. The deposited layer of the new type of hardfacing electrode possesses better wear and crack resistance than that of D618 and D667 hardfacing electrodes.

Key words: hardfacing electrode; TiC; wear resistance; crack resistance
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1 INTRODUCTION

Wear of machine components or tools is one of the most common problems faced in industry. Hardfacing is an effective technique to improve surface property of components[1-3]. Utilization range of hardfacing varies widely, such as rock crushing, bulldozer blades, ripper teeth, conveyor screws, drill and pump impellers. It not only helps them to resist abrasive wear, but also helps to prevent corrosion and high temperature oxidation[4-6].

Two methods can be used to form the reinforcements[7, 8]: one is to add foreign particles directly into the coating of electrodes, the other is that the particles are produced by exothermal reactions between elements or elements and compounds. For the first method, carbides are easily decomposed and oxidized during the depositing process. Some special carbides are produced in the matrix metal, which causes undesirable embrittlement phase in the deposited layers, such as primary carbides, secondary carbides or twin martensite either separately or in some combination. The consequence is a fissured deposited layer with a strong tendency to spalling. Hence, a complicated welding process (e. g. before and after weld heat treatment) have to be employed during welding. However, the metallurgical reaction formed particles are ultrafine, thermally stable and have cleaner interface in the deposited layers in general, which contributes to the improvement of the strength of the deposited layers and ensures that the matrix has sufficient strength to transfer stress[9-12].

In general, wear resistance is a consequence of a specific favorable combination of hardness and toughness[13]. Due to the brittle nature of pure ceramic materials, they are rarely used for all protective deposited layers. A glance at the recent literature on the hardfacing processing shows increased interest in depositing composite layers at home and abroad. In all of ceramic particles, TiC has high hardness, high modulus and rather high flexural strength, hence, it is widely used as the reinforced phase of composite materials[14-16].

The aim of the present investigation is to produce TiC particles reinforced Fe-based alloy composite deposited layers. TiC particles are formed by metallurgical reaction between the FeTi or rutile and graphite during hardfacing process, rather than the TiC particles being directly added into the welding pool.

2 EXPERIMENTAL

The core wire of electrode was produced by using H08A bare electrode with diameter of 4 mm, and the coating was the CaO-CaF_2-TiO_2 system, adding 35% - 40% ferro-titanium (FeTi), 25% - 30% rutile (TiO_2), 6% - 10% calcium carbonate ($CaCO_3$),

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10% – 14% calcium fluoride (CaF_2) and 8% – 12% graphite (purity 99.5%), 1% – 2% alkali carbonate and 3% – 5% other arc-stabilizer.

Hardfacing was done on the substrate AISI 1045 steel plates by using manual shielded metal arc welding (SMAW) under direct current with a reverse polarity. To assure the dryness of the electrode, it was baked in the furnace at 250 ℃ for 2 h. During welding, to avoid the effect of dilution, hardfacing was deposited in a 2 mm thick layer at first, and then the surfacing on the second and third layer was done with the same electrode, which was about 3 mm. The welding parameters were as follows: welding current 170 – 180 A, arc voltage 25 – 28 V, and electrode traveling speed 0.3 – 0.4 mm/s.

The microstructure was observed by optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The chemical composition was analyzed by means of electron microprobe analysis (EPMA). The XQF-2000 micro-image analyzer with microprocessor was used to determine the carbide volume fraction, carbide particle size in the deposited layer. Structure of deposited layer was analyzed by X-ray diffractometry (XRD). Macrohardness of the deposited layers was determined by using the average of five measurements taken from the surface of the deposited layers.

The abrasive wear properties were performed on a MLS-23 wet sand rubber-type grain wear-testing machine at room temperature. The test specimens were machined to block with the size of 55 mm × 25 mm × 6 mm. The wear conditions were normal load 49 N, sliding speed 200 r/min, and sliding distance 1 000 m. The wear resistances were determined by measuring the mass loss after a certain time interval on an analytical balance with a precision of $\pm 10^{-5}$ g. The specimens were removed and cleaned thoroughly in acetone and dried in warm air before measurement of mass loss.

3 RESULTS AND DISCUSSION

3.1 X-ray diffraction result

The XRD result of deposited layer is given in Fig. 1. It has been shown that the present phases are TiC, Fe_3C, α-Fe, and γ-Fe. This clearly confirms that TiC particulates could be synthesized by direct metallurgical reaction between ferrotitanium or rutile and graphite during hardfacing process. The formation of TiC particles is also confirmed by EPMA. Fig. 2 shows the results of EPMA about elements Ti and C in the deposited layer. The expected microstructure of fine TiC reinforcement in an iron matrix has been achieved.

3.2 Microstructure of deposited layer

The microstructure of the deposited layer is shown in Fig. 3. It can be seen that titanium carbide particles are irregularly round and separated from each other by the matrix. Although some areas show more TiC particles than the others, the distribution of TiC particles is, in general, uniform in the matrix. In the surface of sample, uniform TiC dispersions of 10.4% – 15.6% in volume fraction are achieved with particle size in the range of 3 – 5 μm.

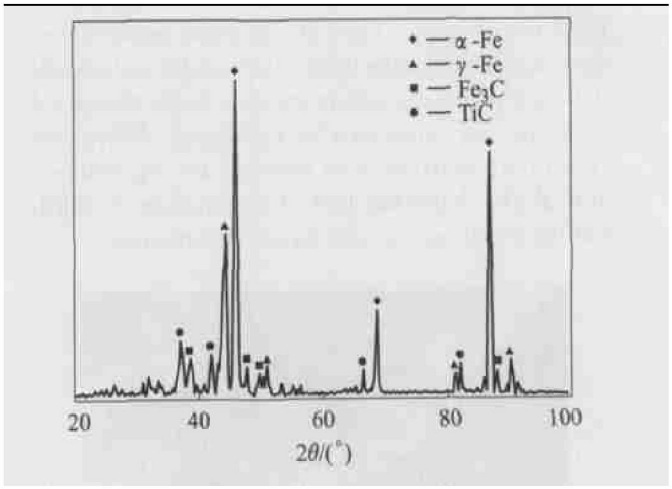

Fig. 1 X-ray diffraction spectrum of deposited layer

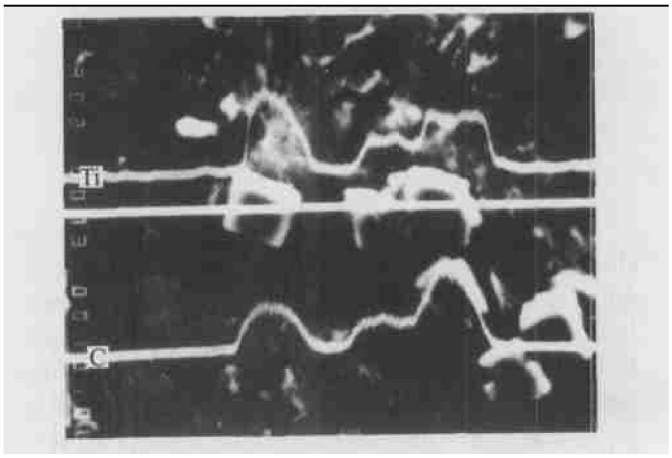

Fig. 2 EPMA profiles of elements Ti and C in deposited layer

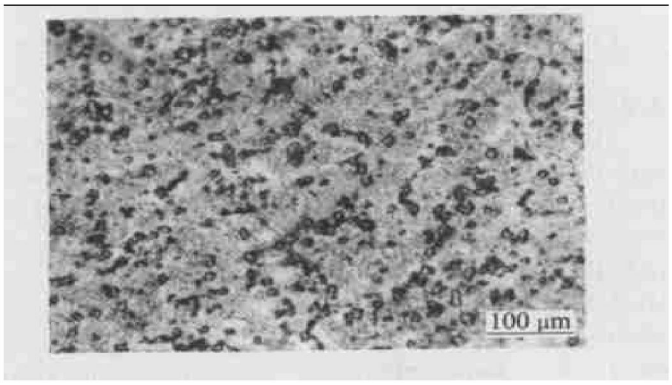

Fig. 3 Distribution of TiC particles in deposited layer

Fig. 4 shows the matrix of lath martensite TEM morphology. TEM observations indicate that there are considerable dislocations in the subcrystal structure inside the lath martensite in the deposited layer, but no twin martensite is found. When low carbon lath martensite is formed, the microstructure of the deposited layer has a higher strength and the toughness is still largely maintained.

Fig. 4 TEM morphology of lath martensite

The impact fractography of deposited layer is shown in Fig. 5. It is found that there are a lot of dimples in the impact fractography. The volume fraction of TiC in the fracture surface is measured to be 10%－13%. It is also possible that such fine dimples are related to the fine particles detected in Fig. 3 and imply that the hardfacing layer possesses a good impact toughness.

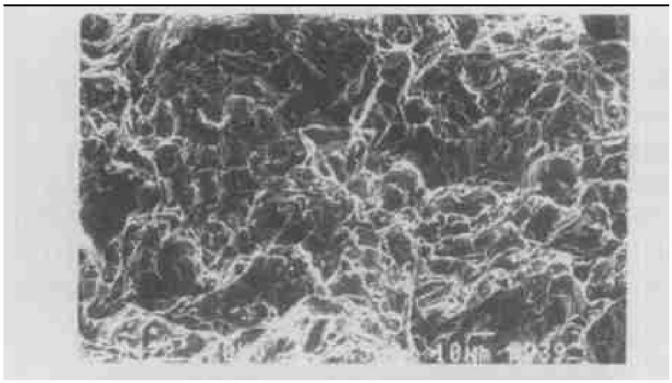

Fig. 5 SEM fractograph of hardfacing layer

3.3 Crack resistance of hardfacing electrode

In order to test the crack resistance of the new type hardfacing electrode, the workpieces are not preheated and heat treated, and the deposited layers are normally cooled in the air. It is also compared to the typical commercial hardfacing electrode D618 and D667. The test results show that the crack resistance of the new type of hardfacing electrode is better than that of the D618 and D667. There are not any cracks checked out in the deposited layer in the first layer, but transverse cracks are found in D618 weld and D667 weld. Cracks are also not found in the second layer and third layer of the new type electrode. However, longitudinal cracks are found in D618 and D667 weld along the fusion line.

The cracking of weld is mainly influenced by the welding restraint stress and plasticity of the weld metal. The weld metal of the new hardfacing electrode has fine TiC particles dispersively distributed in the matrix of low carbon martensite and retained austenite(Fig. 6), which has higher strain ability. However, the D618 and D667 weld metal containing higher carbon, chromium and tungsten is easy to form M_3C and twin martensite phase in fusion zone, and to produce brittle peeling off cracks. Therefore, the crack resistance of the new type of hardfacing electrode is better than that of the D618 and D667.

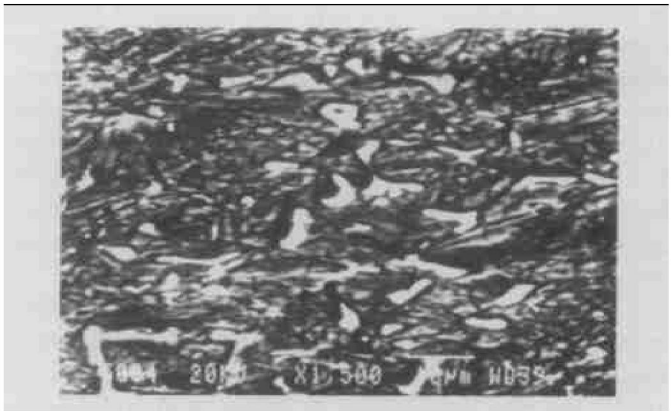

Fig. 6 SEM morphology of low carbon martensite and TiC particles in deposited layer

3.4 Hardness of deposited layer and wear test

The hardness of the deposited layers is HRC 55－60. The investigation shows that the key factors affect the hardness are the contents of FeTi, TiO_2 and graphite. Fig. 7 shows the relationship between the macro-hardness of the deposited layer and content of the coating materials. It can be seen that the macro-hardness increases rapidly with the increase of content of graphite. However, a large quantity of continuous cementite and retained austenite occur when the graphite amount is over 12%. With the increase of retained austenite, the hardness of the deposited layer would decrease. On the other hand, with the increase of the cementite, the crack resistance of the hardfacing layer reduces. Therefore, the amount of graphite should be controlled within 10%－12%. Ti is a strong carbide forming element. With the increase of the contents of FeTi and TiO_2, metallurgical reaction formation of TiC increases in the hardfacing layer, as a result the macro-hardness increases(Figs. 7 (b), (c), respectively). Moreover, due to the diffusion of TiC particles, the amount of TiC increases in the

welding slag, which leads to the increase of melting point and viscosity of slag. Slag detachability and fluidity become bad when the contents of FeTi and TiO_2 in the coat are over 40% and 35%, respectively.

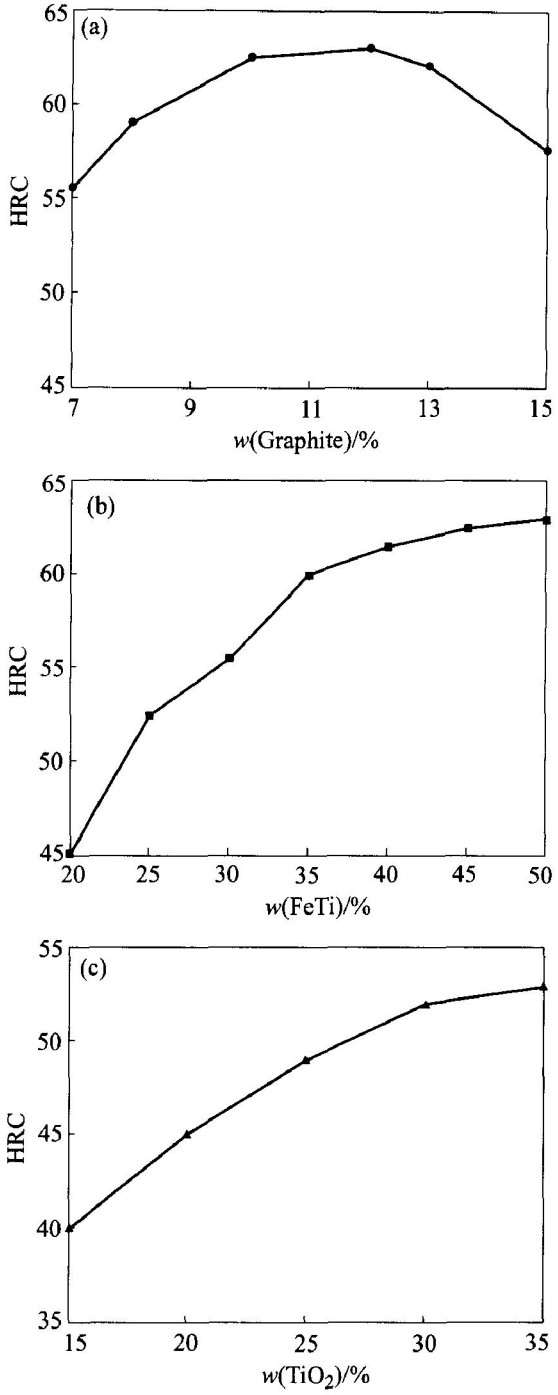

Fig. 7 Relationship of hardness of deposited layer with amount of graphite, TiO_2 and FeTi

Typical plots of wear mass loss the deposited layer and AISI 1045 steel substrate as a function of sliding distance at an applied load of 49 N is shown in Fig. 8. It can be easily observed that the deposited layer shows excellent wear resistance in comparison to 1 045 steel substrate and hardfacing electrode of D618 and D667. Additionally, it can also be seen that an increase of sliding distance increases the wear mass loss.

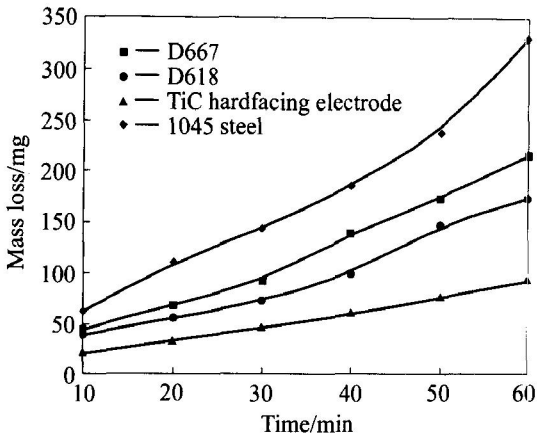

Fig. 8 Wear mass loss of deposited layer related with sliding distance

4 CONCLUSIONS

1) By adding FeTi, TiO_2 and graphite to the coating of the electrode, TiC particles are formed by metallurgical reaction during arc welding. The fine TiC particles with size in the range of 3 - 5 μm are dispersed in the matrix of lath martensite and retained austenite.

2) The cracks resistance of the new hardfacing electrode is better than that of D618 and D667.

3) TiC particles reinforced Fe-based hardfacing layer possess better wear resistance than that of AISI 1045 steel substrate, D618 and D667.

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