Study on the Integrated Technology of Materials Preparation and Formation Based High Velocity Arc Spraying Technology

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Abstract

The integrated technology of materials preparation and formation is one of key technologies of remanufacturing. For some materials, which is difficult to synthesize or process, high velocity arc sprayed cored wires method can be introduced to synchronous realize the materials synthesis and formation through the rapid and dynamic metallurgy of arc area. That means to realize the new materials synthesis and preparation during remanufacturing rapid forming process. On one hand, for different parts, the protection coatings processing anti-corrosion, wear-resisting and high-temperature performances can be obtained by means of new-style materials component design. On the other hand, the traditional conception that thermal spray technology can only be applied for thin coatings is broken, and the study of rapid thick forming coatings for parts manufacture is innovatively developed. The integrated technology of materials preparation and formation has wide application foreground in various fields, such as steel structure long-term prevention of corrosion, boiler pipe protection, parts forming manufacture and remanufacture and so on.

Key words: cored wire; high velocity arc spray; surface coating; rapid forming; remanufacture

1. Introduction

Remanufacturing engineering is the industrialization of high technology maintenance to the waste productions. The important character of remanufacturing engineering is that the quality of the remanufactured productions is the same as or superior to that of the new productions. The core of cycle economy is the high efficient using and cycle using, the principle is Reduce, Reuse, Recycle and Remanufacture (4R). Remanufacturing is one of the most active and advanced factors in the cycle economy [1].

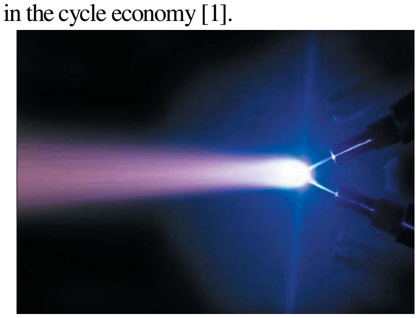

Fig.1 Arc and particles flame of arc spraying

Integrated technology of materials preparation and formation by high speed electrical arc spraying (HVAS) create the metallic droplet spray by striking a DC arc between two consumable conductive wires tips, and a high-pressure gas atomizes the molten material and propels the resulting droplets towards a substrate. HVAS is considered as a simple, low cost, high efficient coating process. The morphology of arc and beam current is shown in Fig.1.

Material system design is a basic of the integrated technology of new materials preparation and formation. In order to fulfill the requirement of multifunction and high properties of materials, the application and investigation of new alloys, amorphous and nano-materials are the main trend of developing thermal spraying materials. However, these materials are hard to produce wires and the yield period is long. In order to widen industrial application, cored wires are commonly used. It can adjust compositions of alloys easily and fulfill the requirement of hard conditions.

2. Ideas of integrated technology of new materials preparation and formation

For some materials, which is difficult to synthesize or process, high velocity arc sprayed cored wires method can be introduced to synchronous realize the materials synthesis and formation through the rapid and dynamic metallurgy of arc area. That means to realize the new materials synthesis and preparation during remanufacturing rapid forming process. On one hand, for different parts, the protection coatings processing anti-corrosion, wear-resisting and high-temperature performances can be obtained by means of new-style materials component design.

3. HVAS process

3.1 sprayed air flow field

The air flow field of HVAS gun is calculated by Flotran software. It can be seen that expand and contract wave with some intensity is generated in the contract and expand nozzle. Its speed change smooth, which is propitious to accelerate and atomize of sprayed droplets. When the wire is used, the eddy will be raised in the tips. And the angle of two wires is an important parameter for eddy, which is beneficial for mixing sufficiently of molten metal. The optimized angle is 40°and the air flow speed around the nozzle is greater than 500 m/s. The speed distributions of air flow field in nozzle and central axe are shown in Fig.2 and Fig.3 respectively.

3.2 characterization of eddy field and materials solidification

HVAS is a dynamic, non-equilibrium and rapid metallurgy process. The molten of the two electrodes is anisomerous. The cathode is molten rapidly and form litter droplets. The air flow in the tips exist strong eddy (see Fig.4 of tips eddy field by high speed photograph), which is propitious to the uniformity of size and alloying of droplets [3].

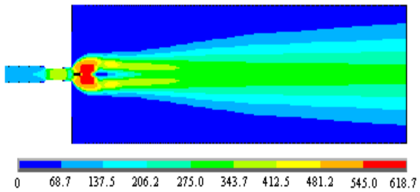

Fig.2 Optimum spraying gas velocity distribution

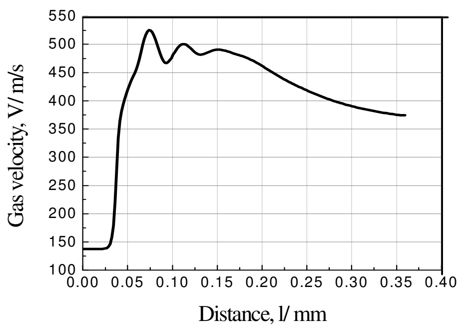

Fig.3 spraying gas velocity along gun center axis

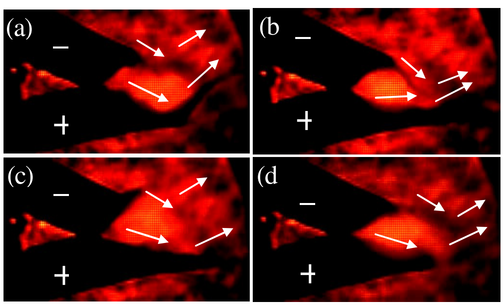

Fig.4 Arc bow wave area between spraying wire tips

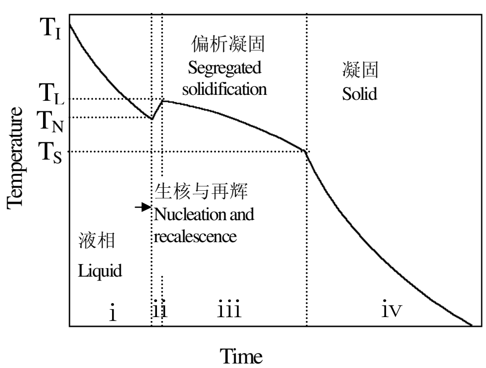

Fig.5 Stages of spraying particles cooling and solidification

The droplets have high degree of superheat (1200-2000K) because of the begin speed of atomized air flow of 500 m/s. Then at the stage of atomization, most of droplets are not solidified. The solidification process of sprayed materials has four stages: liquid phase cooling, nucleation and recalescence (instant), segregation and solidification and solid state cooling (Fig.5). The nucleation and recalescence state is the important function in formation of new materials.

4. Remanufacturing coating materials

Thermal spraying can prepare some properties coating such as wear resistance, anticorrosion and so on by designing metallic compounds and other special alloys system.

4.1 metallic compounds

Fe-Al/Cr3C2 metallic compound coatings have excellent high temperature corrosion resistance and erosion resistance, which prepared by high speed electrical arc spraying Fe-Al/Cr3C2 cored wire. It forms Fe3Al and FeAl metallic compounds during spraying. Fe-Al alloy has excellent wear resistance at room and high temperature, especially elevated temperature erosion resistance. However, Fe-Al alloy has some disadvantages, such as inductile at room temperature and low fracture toughness, which influence forming performance and limit application.

The wear resistance of the coatings is related to their hardness. It can improve erosion resistance by addition ceramic hardness phases. When the working temperature is 550-980℃, the Cr3C2 hardness phase is used. Cr3C2 compound has the highest oxidation resistance in the metallic carbide and it has high hardness at room and elevated temperature. Fig.6 is the SEM image of the Fe-Al coating. The microstructure of the coating consists of sub-microcrystalline and microcrystalline. The size of the crystalline is 0.3-0.8μm. in some area, the nanocrystalline grains and amorphous are found in the coating. Fig.7 shows the two order Fe3Al and FeAl metallic compounds in the flat particles [3].

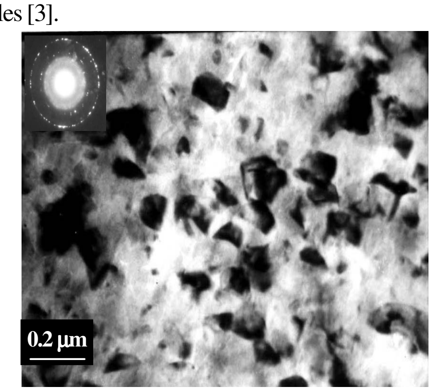

Fig.6 Microstructure of Fe-Al arc spraying coating (TEM)

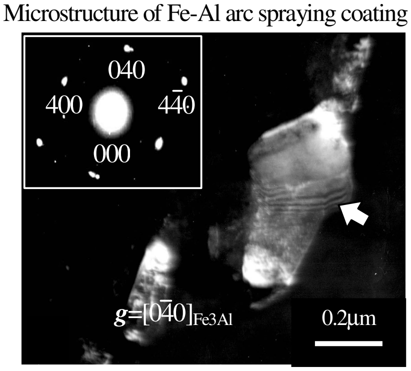

Fig.7 Fe_3Al phase in Fe-Al arc spraying coating (TEM)

Compared with the Fe-Al metallic compound coating and 20 steel, the Cr3C2 reinforced phase composite coating has better heat corrosion resistance at 450℃, 650℃ and 800℃. The heat corrosion resistance of Fe-Al/Cr3C2 composite coating is over 2 times than that of other coatings at 800℃ (Fig.8). The Fe-Al metallic compound coatings has lower erosion rate at 30° impact angle. But the 20 steel has the highest erosion rates at experimental temperatures. Compared with other materials, the Fe-Al/Cr3C2 composite coating exhibits lower erosion rate at 650□ (Fig.9) [4].

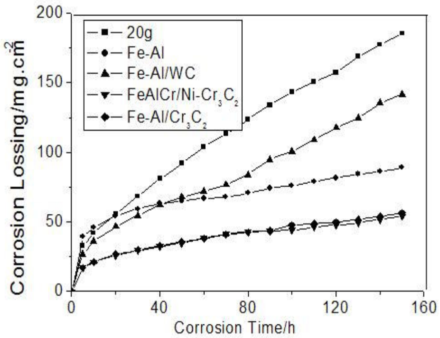

Fig.8 Thermal corrosion dynamic curves at 800□

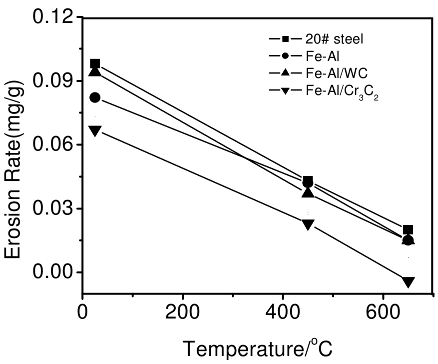

Fig.9 Erosion rate with 30°at different temperature

The average safety age limit of Fe-Al/Cr3C2 and TAFA-45CT coatings（NiCr system）prepared by HVAS is 3-5 years, but the cost of maintaining the Fe-Al/Cr3C2 composite coating is 1/2 of that of TAFA-45CT coating. The Fe-Al/Cr3C2 composite coating prepared by HVAS process is successfully applied to elevated temperature corrosion/wear resistance in boilers and pipes and it gains excellent application effect and yields good economic returns.

4.2 self-sealing anticorrosion coatings

The Zn-Al-Mg-RE coating has excellent self-sealing function by means of forming more compact corrosion products. Nanometer corrosion products were produced on the surface of Zn-Al-Mg-RE coating, and microstructure of the corrosion products was very compact, which improve self-sealing function of the coating.

The composite anticorrosion coatings had self-sealing characteristics. In corrosive environment, corrosion products were produced on the surface of the coating, and microstructure of the corrosion products was very compact. Micro-pores in both the organic coatings and the metallic coating can be blocked by the corrosion products, which prolonged the permeating time of corrosive medium to substrate and improved the anticorrosion property of the composite coatings.

After the artificial defect coating dips in 5% NaCl solution for 430h, it can be seen that artificial pores are sealed by Zn-Al-Mg-RE corrosion production. The microstructure of the corrosion productions is very compact by SEM analyzed, indicating that the anticorrosion coatings can seal the micro-defects (Fig.10) [5].

The electrochemical impedance patterns of the Zn-Al-Mg-RE coating dipped at 43h and 221h exhibit two semicircle arcs (Fig.11), and then changed to single semicircle. It shows that the electrochemical impedance patterns can not reflect the condition of interface between coating and substrate, which indicates that Cl－can not penetrate into pores or defects in the coating and reach interface between coating and substrate.

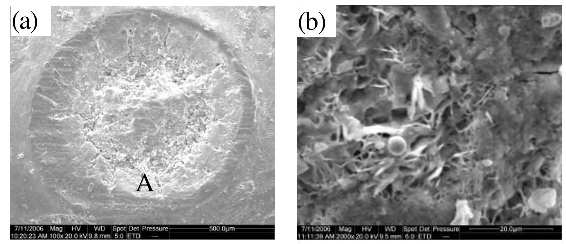

Fig.10 Microstructure of Zn-Al-Mg-Re coating after 430h corrosion

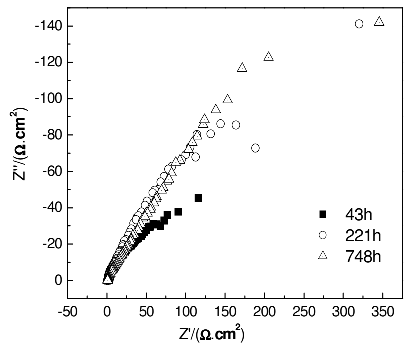

Fig.11Electrochemical impedance spectroscopy of Zn-Al-Mg-RE coating after different corrosion time

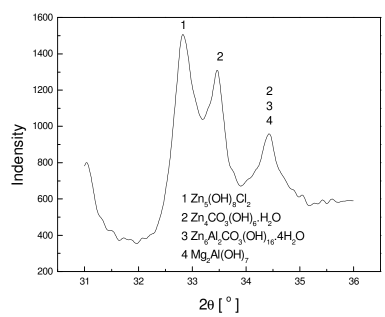

Fig.12 XRD pattern of Zn-Al-Mg-RE coating after 210d corrosion

When the coating is dipped in 5% NaCl solution for 210 days, the grain size of corrosion products is 15-30nm by XRD analyzed, indicating that the corrosion products are nanometer (Fig.12). And the microstructure of the coating is changed to full density by these nano-corrosion products [6].

The Zn-Al-Mg-RE coating has been successfully used in the general anti-corrosion engineering of naval destroyer and frigate. This technology has exhibited expansive application prospect and performed tremendous potential benefits in military and economy affairs. And its service life is estimated over 10 years.

5. Remanufacturing forming materials

A collaborative project between Oxford University and the Ford Motor Co developed a radical alternative to CNC machining for the rapid manufacture of production tooling. The process is based on the robot manipulated spray deposition of liquid steel droplets onto a ceramic master pattern to form a dimensionally accurate steel facsimile for direct use in forming operations. During forming, the temperature field is distributed by path planning and Filr systems infrared thermal imaging camera, which can reduce residual stress of the coating. The as-sprayed materials is carbon steel wires（Fe-0.8wt.%C）and the thickness of the rapid tooling is 10 mm. But the wear and corrosion resistance of the rapid tooling must be improved [7-8]. Amorphous coatings are prepared by wire arc spraying 140MXC and SHS7170 cored wires which developed by TAFA and NANOSTEEL companies respectively. Compared with conventional Fe-based coatings, the amorphous coatings have higher bond strength, hardness, deposition efficiency; lower porosity, and oxidation content; excellent wear and corrosion resistance. And it can be used in many industrial fields such as automobile, space flight and so on [9].

The key problem that realized thickness coating by HVAS is to reduce residual stress. Residual stresses are generated during the deposit build-up and originate form two main sources—quenching of the splat after impact while its contraction is restricted by adherence to the substrate or previously deposited layer, and differential thermal expansion of the deposit and the substrate during cooling from the substrate temperature, both of which affect the mechanical performances of the coating [10].

The remanufacturing rapid tooling processes are divided into two aspects. One is spraying Fe-based material. The formation of martensite involve a volumetric expansion with respect to the austentite parent phase that can be contrived to compensate for the steel thermal contraction as it cools during and after sprayforming. The other is to design newly cored wire to reduce oxidation content and residual stress, and then prepare Fe-based amorphous/nanocrystalline thickness coating.

5.1 carbon steel forming materials

By careful selection of the path plan and control of the spraying process, the solidification and thermal contraction stresses that is normally an inherent feature of thick, sprayed carbon steel coatings are eliminated. As austenite is cooled below 723°C at low and intermediate cooling rates, the microstructure transforms to a ferrite-rich, pearlitic microstructure that involves a volumetric contraction with respect to the parent austenite phase. At higher cooling rates, more typical in thermal spray processes, this diffusional transformation of austenite to the equilibrium ferrite phase may be suppressed and martensite is formed by a diffusionless shear transformation. The formation of martensite involves a volumetric expansion with respect to the austentite parent phase that can be contrived to compensate for the steel thermal contraction as it cools during and after spray forming. Fig.13 shows the effect of martensite fraction on the residual stress of the coating. It can be seen that the residual stress in the coating decreases as function of martensite fraction (Fig.14). When martensite fraction is about 42%, the sign of the residual stress is changed. The tensile stress changes to compress stress in the coatings (Fig.14).

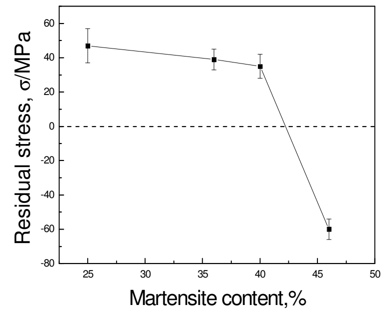

Fig.13 Martensite content versus coatings residual stress

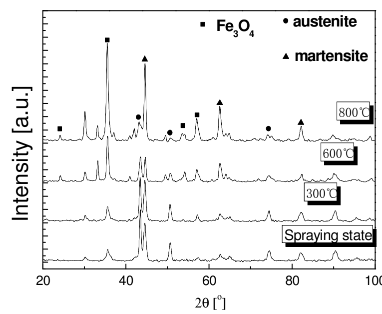

Fig.14 Effect of annealing temperature on phases in coating

5.2 Amorphous and nanocrystalline materials

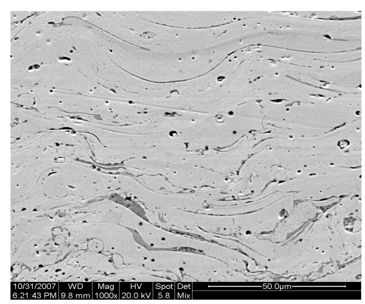

Fig.15 Coating section structure with low oxides of amorphous and nanocrystalline coating

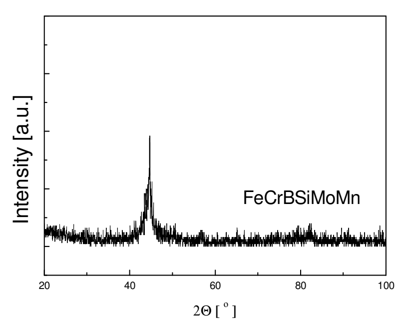

Fig.16 XRD pattern of amorphous and nanocrystalline coating

During wire arc spraying, individual splat was estimated to cool at a rate of □105 K s−1 , which is suitable for forming amorphous phase. The nano-technique can improve wear resistance of the materials. And the absence of grain boundaries of amorphous leads to better resistance to corrosion of these materials. Thus, as a promising advanced material, their application to various engineering components has been widely studied.

Basis on the composition of SHS and self-flux materials, a newly FeCr(MnMo)BSi cored wire are developed, which contains specific atomic ratios of elements to maximize glass forming ability. The addition of B and Si elements acts as self-fluxing and deoxidation. It depresses the melting temperature of the alloy, cleans and activates the substrate and splats surface and enhances wettability. And then the coating with low oxidation content is deposited. The SEN images and XRD pattern of the coating are shown in Fig.15 and Fig.16, respectively.

6. Conclusion

The integrated technology of materials preparation and formation is one of key technologies of remanufacturing. On one hand, for different parts, the protection coatings processing anti-corrosion, wear-resisting and high-temperature performances can be obtained by means of new-style materials component design. On the other hand, the traditional conception that thermal spray technology can only be applied for thin coatings is broken, and the study of rapid thick forming coatings for parts manufacture is innovatively developed. The integrated technology of materials preparation and formation has wide application foreground in various fields, such as steel structure long-term prevention of corrosion, boiler pipe protection, parts forming manufacture and remanufacture and so on.

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