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Technical Note

Arc Spraying in China

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Although arc spraying is not a new technique, recent development of arc spraying device systems, spray wires, research on the coating mechanism, and the dynamic behavior of spraying make it a most active thermal spray process. In China, the arc spraying technique is the most efficient way for long life corrosion protection of steel structures. In addition, the arc spraying process is widely used for renovation and surface modification of machine components, mold making for plastic products, high-temperature corrosion resistance for waterwalls of boilers, antisliding coatings, self-lubricating coatings, *etc.*

Keywords arc spraying, engineering applications, technological advances

1. Introduction

With arc spraying, the need for fuel gases and oxygen is eliminated. Two metallizing wires are feed simultaneously at a fixed angle through the spray equipment, and an electric arc is established between the wires. On leaving the nozzles, the two wires approaching one another are melted in the arc. Compressed air distributes the molten material as in flame spraying and spreads it over the prepared surface of the component, leading to the buildup of a layer.[1] The main advantages of arc spraying over plasma spraying, flame spraying, and high velocity oxy-fuel spraying are detailed below.[1,2,3]

The high spray capacity of arc spraying depends on the current density. Arc spraying of aluminum wire reaches 15 kg h^{-1} at 300 A, whereas for zinc wire, it is 30 kg h^{-1}. These rates are about three times higher than that of flame spraying. The excellent bonding of arc-sprayed coatings is a result of the relatively large particle sizes of the sprayed particles. Arc technology has a high heat efficiency, where almost all the heat that the arc generates is used for melting the metal wires. The investment costs are low, and the operating and maintenance costs are also low.

Development and application of arc spray began in the early 1980s in China. Because of its capability of extremely high spray rates, high adhesive and cohesive strength, and less operator-sensitive equipment, arc spraying technology found a wide range of applications in China.

2. Advances of Arc Spraying Technology in China

2.1. Arc Spray Device System

Since 1986, different types of arc spray devices are produced and applied to engineering, with high deposition rates of Al, Zn, and stainless and aluminum bronze wire. Most of the arc spray devices employ a pushing type of wire feeder, which can be controlled by manual adjustment or a computer processor. In addition, this arc spray device can use both 3 mm ϕ and 2 mm ϕ wires with the same power supply.

A novel arc spraying process has been developed, by using the supersonic hot gas stream, which is generated by an air-alcohol internal burner as the atomizing media. The outside surface of the combustion chamber is cooled by compressed air. The droplets of sprayed metal are protected from oxidation by the supersonic combustion product. Very high velocity and low oxidation of the atomizing gas stream result in high coating quality.[4]

A high velocity arc spray gun has been recently introduced, which uses high velocity air, which is compressed and accelerated through a specially designed tube. Superior arc-sprayed coatings can be produced with a high velocity arc spray gun and cored wires, which include amorphous materials.[5,6]

2.2 Development in Spraying Materials

Cored wires are a promising alternative for the spray process (Table 1).[7,8] A special kind of aluminum wire with a suitable quantity of mixed, light, rare earth elements was developed to increase the microdensity and anticorrosion ability of coatings.[9] Also, several pseudo-alloy coatings, including steel-copper, steel-bronze, and aluminum-zinc, have been obtained by feeding different wires into the arc spray gun.[10]

2.3 Research on Dynamic Behavior of Arc Spraying Process

The spraying process occurs in an extremely short time and the spray particles are very fine; therefore, it is difficult to directly observe particles in flight and during their flattening and solidification. However, in order to understand further the formation phenomena of sprayed coatings, it is important to study the dynamic behavior of particles. Research on these aspects has been performed in China with high-speed cameras or numerical modeling calculations.[11,12,13] The main points concluded concerning the behavior of fused particles in air are as follows.

- The motion of molten droplets in air is a straight line.
- The wires are molten by the arc and some large droplets are produced and move at a relatively low rate in the arc zone. The larger droplets are immediately blown apart by the at-

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Table 1 Some cored wires and their main applications

Type	Chemical compositions	Main property and applied fields
7Cr13	FeCCrMn	Martensite stainless coatings with hardness HRC48; adhesive strength is higher than 40 MPa. Renovation coatings for paper-mill drying cylinders, cylinder pillars, and shafts
DM	FeCrNiMo	Low-carbon martensite stainless self-bonding coatings £¬HRC35; adhesive strength is higher than 50 MPa. Because of low shrinkage and expansion rate, city thicker coatings can be produced. Aluminum bronze can be substituted for the bonding material without pungent and noxious gas as spraying
18-8	FeCrNi	Austenite stainless self-bonding coating has excellent corrosion resistance ability for crevice corrosion and intercrystalline corrosion
TY-C60	FeCrNiBSi	Self-bonding amorphous coatings for sliding wear and fly ash erosion

omizing gas, resulting in relatively small droplets and high speed; then, they reach a peak velocity and retain a lower speed over a long distance.

- The speed of fused particles over a cross section of the axial distance is Gaussian in nature.
- Besides electromagnetic force, aerodynamic behavior has an important effect on the stability of the burning arc. The uneven distribution of gas pressure within the arc gap induces turbulent gas flow close to the twin wire tips. This turbulent gas flow creates a mixing effect of the thin molten metal film melted by the electric arc on the electrode tip surfaces. The mixing effect has great significance when composite and cored wires are sprayed.

3. Applications of Arc Spraying in China

Advances in arc spray equipment and wires have given impetus to the application of arc spray technology in China.

3.1. Long Life Corrosion Protection for Steel Structure

Arc-sprayed zinc and aluminum coatings are used for corrosion resistance of steel structures. The electrode potential of arc-sprayed Al, Zn coatings in corrosion media is more negative than that of iron, which gives them a sacrificial power for anodizing. On the other hand, Al coatings have chemical inertia, which gives them good resistance to acid corrosive environment. An organic paint sealer is used to completely fill the porosity of coatings and prevent the corrosion media from penetrating. In addition, the organic paint also has corrosion resistance ability and works in conjunction with Al and Zn coatings to prolong the service life of iron in corrosion environments. The composite coatings of arc-sprayed Al and Zn coating with an organic sealer provide an excellent corrosion protection method.

A systematic study of arc-sprayed Al coatings followed by a coating of paint to close porosity and then a layer of conventional ship's paint has been carried out on certain ships operat-

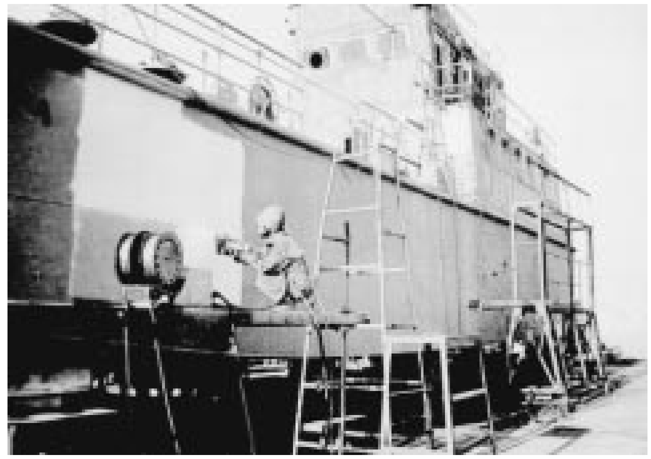

Fig. 1 Arc-sprayed coatings were applied to the anticorrosion of ship steel structure

Fig. 2 Arc-sprayed Al coatings were applied to the steel tower for acid corrosion resistance

ing in the Chinese southern sea area. The areas chosen for experiments were the waterline region, deck parts, enclosure part of the superstructure bottom, and engine room (Fig. 1). Good results have been obtained in service, and it is believed that the technique of arc spraying will be widely used for the corrosion protection of ships in the future.[2]

The top edges of the upper deck of box and girder bridges show contact with cross ties and some slight vibration and movement. These structures are in a harsher environment, which will bear wear and corrosion. Thus, there are ways to protect the upper deck of bridges. One initial method was to spray 120 μm of zinc and paint with a wear resistant primer. A new method consists of a three layered system of 100 μm zinc, 80 μm 18-8 stainless steel and sealer. This coating system provides a good solution for corrosion and wear resistance of the upper deck.

The service life of well casings coated with conventional paint is 3 to 5 years. It is estimated that the loss of revenue in China due to steel corrosion in the coal industry system is over 1 billion yuan per year. Since 1990, arc-sprayed composite protection coatings were employed on the steel structures of well casings in the Jinshan mine of Shanxi province, the Tiewanggou mine of Henan province, and the Huaibei mine of Anhui province. The corrosion protection life is estimated over 30 years.[14]

Dozens of thermal spray factories in China deal with corrosion protection coatings for structural steel works including bridges, towers, TV antenna masts, cranes, and sluice gates, with a total area of about 200,000 square meters per year. In 1985, the Ministry of Broadcasting, Film and TV of China issued a document that demanded all the broadcasting and TV antenna masts erected thereafter be thermal sprayed with Al and Zn coatings for corrosion protection.[15] Arc-sprayed Al coatings were applied to steel towers, rather than conventional galvanizing, for acid corrosion resistance arising from air pollution (Fig. 2).

3.2. Maintenance and Rehabilitation of Machinery Parts

The improvement of hardness, wear resistance and bond strength of arc-sprayed coatings with cored and self-bonding wires allows arc-sprayed coatings to be applied for the maintenance, renovation, and modification of machinery parts.

Aluminum-bronze wire and 1Cr13 wires have been used to repair large paper-mill drying cylinders of several meters in diameter, which need to be replaced after localized dot corrosion and scratching. These large, costly print rolls are often sprayed with steel-chrome alloys to maintain their dimensions.

A large number of electrical machinery shafts and splines and crankshafts of imported automobiles, which have worn, were repaired by arc spraying with high carbon-chrome steel wires. The cost of maintenance is only 20 to 30% that of new replacement parts, and the service life of repaired parts is prolonged because of renovation with antiwear materials.

Arc-sprayed babbit coatings, which exhibit similar properties to casting babbit alloy, are used to lubricate and repair worn bearings and sleeves.

Arc-sprayed Al and Zn coatings are applied to improve electricity conduction and welding characteristics of some electronic parts.

3.3. Others

On the basis of systematic research on oxidation and hot corrosion properties of coatings, a newly developed, multilayer coating system, consisting of a low-carbon martensite stainless self-bonding coating, a Ni-Cr coating, and a silicate high-temperature sealer, which is suitable for high-temperature hot corrosion protection of the boiler tubes, was optimized. Figure 3 shows a multilayer coating system, which was used for the high-temperature corrosion protection of a boiler waterwall. The anticipated life of this coating is 7 to 9 years.[16]

The arc spray tool making technique is a low-cost, high-efficiency method for producing mold of plastic products. The tool making technology process, spray materials, and release agent in tool making have been studied systematically by application of a 2 mm ϕ wire arc spray system.[17]

Arc-sprayed Al coating was applied as an anticorrosion and antisliding coating for the bolting surface of a railway steel bridge. Tests of the antisliding coefficient, porosity, the potentiostatic anodic polarization curves, and the salt mist of arc-

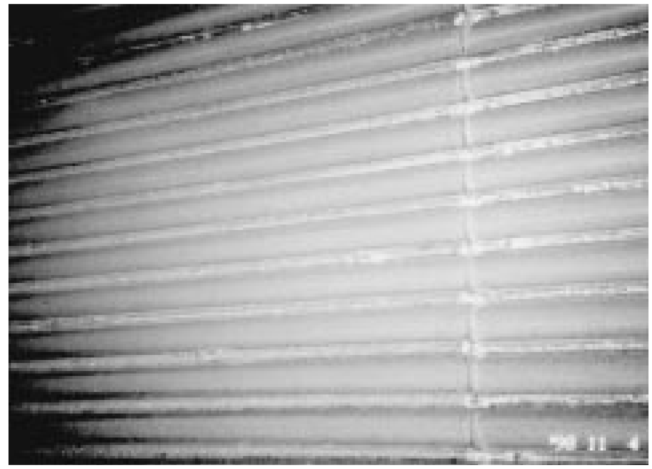

Fig. 3 Arc-sprayed high-temperature corrosion protection coatings for boiler waterwall

Fig. 4 Arc-sprayed Al coatings were applied on the bolting surface of Wuhu Yangtse River bridge

sprayed coatings have been made. The results show that the original antisliding coefficient of arc-sprayed Al coating is 0.673, and arc-sprayed Al coatings have excellent properties. Arc-sprayed Al coatings exhibit low porosity rate and behave well against corrosion. They are an ideal coating for anticorrosion and antisliding of the railway steel bridge bolting surface (Fig. 4).[18]

4. Summary

With the advances and developments in arc spray equipment and spray materials and the simplicity of operation, arc spray technology is used for sophisticated, high-quality coating applications, which are nearly equivalent to those previously available from plasma technology but at significantly reduced capital and operating costs.

With new technological advances, arc spraying is becoming a serious economic alternative to other thermal spraying processes while maintaining, and in many cases improving, the quality of the finished product. In conclusion, arc spraying technology will find boundless prospects in China.

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