Study on Spraying Technology of Super-hard Ceramic Corrugated Roll

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Abstract: with the rapid development of the carton packaging industry in China, intense marketing competitions urge the companies to give more consideration on the qualities and costs of carton products. The core part, corrugated roll, plays an important role in carton products quality and economic benefits, but the traditional corrugated roll can't meet the requirements any more. In order to improve the working life of corrugated roll and meet the requirements of the wider and wider web and the faster and faster speed of carton producing line, the study on the spraying technology of super-hard ceramic corrugated roll was performed. In this paper, the corrugated roll was respectively treated with three techniques including ceramic rod flame spray, high velocity oxygen flame WC/TiO_2 and electroplated diamond, dimension variances of flute shape were observed, the surface performances were tested and the good processing technology was determined.

Keywords: Ceramic Corrugated Roll; Flame Spray; HVOF; Electoplated Diamond

1. Introduction

Corrugated roll is a core component in the production line of corrugated carton. Because hardness of chromium is proximate HV 950, the traditional chromium-plated metal roll can be used to produce only 4.5 million meters paperboard, its service life is limited [1,2]. Furthermore, due to low wear resistance of chromium, traditional corrugated roll with chromium layer surface usually cause some quality problems including flute injuries, crushed flute, flute cracks, uneven flutes and surface wrinkles, another troublesome is the purification of electrical plating solution from Chromium Electroplating.

With the rapid development of carton packaging industry in China, the carton companies are facing intense competition and pay more and more attention to the product qualities and cost. As one of core components in carton production line, corrugating roll plays an important role in carton qualities and economic benefits, traditional corrugated roll can't meet the production requirement anymore.

Corrugated roll should have higher surface hardness to improve its wear resistance and mechanical strength. Comparing with chromium plating coating, thermal spray coatings has higher smoothness, hardness and wear resistance [3]. Ceramic material has advantages such as the stability at high temperature, higher hardness and higher melting point, it is the common materials for thermal spray technology [4]. This paper discussed about three coating technologies including Cr_2O_3 Ceramic Rod Flame Spray (CRFS), High Velocity Oxygen Flame (HVOF) WC/TiO_2, and Electroplated Diamond (ED).

The most common method to improve the hardness of the metal surface is coating treatment of metal surface. According to the different coating materials and coating methods, surface coating treatments could be divided into plating coating (electroplating, plasma spray, evaporation and deposition and gas phase, etc.), organic coating (finishing) and the spray coating (ceramic). This paper focuses on three technologies including CRFS, HVOF WC/TiO_2 and ED.

1.1 Thermal Spray Technology

Coating materials are heated to melted or half melted state, and injected and deposited onto a pretreated matrix surface with a certain speed, and then the coating layer is generated [2]. Thermal spray create a special surface to common material, which have several functions such as anticorrosion, wear resistance, anti-friction, high temperature resistance, anti-oxidation, heat insulation, insulation, conductivity and microwave radiation proofing, so materials saving and energy saving could be achieved [5,6]

According to heating resource, thermal spraying technology can be divided into:

- Flame categories including powder flame spray (welding), wire flame spray, CRFS, high velocity flame spray (HVOF) or high velocity oxygen fuel spray, and D-gun spray;
- Electrical arc categories including electrical arc spray and plasma spray;
- Electrothermal categories including wire exploding spray, induction heating spray and capacitive discharge spray;
- Laser categories such as laser spray.

(1) Ceramic Rod Flame Spray Technology (CRFS)

The end of ceramic rod is melted into ceramic droplets by high-temperature oxyacetylene flame, and injected

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onto the surface of workpiece to form a uniform, compact, high performance ceramic coating.

Ceramic rod coating requires an appropriate CRFS gun, which is composed of front part and back part. Oxygen and acetylene combust in the front part to melt the end of ceramic rod, the melted ceramic is atomized into a small droplet by compressed air and sprayed onto the matrix to form coating. Back part is a pushing mechanism, which moves the ceramic rod to the flames evenly with a certain speed. Spray gun is fixed by clamping tools to maintain uniformity of the coating.

(2) High Velocity Oxygen Flame (HVOF)

Arc discharge (non transfer plasma arc) generates plasma (thermal ionization gas, argon) as heat resource to melt spraying powder, the melted powders are blown to the workpieces with supersonic speed under the acceleration of plasma flame, and then the coating is generated. the primary gas (small flow argon gas) is introduced from the back part of gun, a large number of secondary gas (nitrogen or the mixed gas of nitrogen and hydrogen) pass through the gas vortex rings and is injected from the second Laval-shape nozzle with the main gas (tungsten electrode connects to cathode, when arc igniting, the first nozzle connects to anode), when the primary gas ignite arc with high-frequency, anode connects to the secondary nozzle, that is to say the electrical arc is generated between tungsten and the inner wall of secondary nozzle. With the impact of revolving secondary gas, the electrical arc is compressed at the center of nozzle, and stretched to the edge of the nozzle, a high-pressure extended plasma arc is produced. High-power extended plasma arc efficiently heated the main gas and secondary gas, stable supersonic plasma flow inject from nozzle. Powder join in the supersonic plasma flow through nozzle, it is heated to very high temperature with greater kinetic energy, and then hit onto the workpiece surface to form coating.

1.2 Electroplated Diamond (ED)

Diamond is deposited on metal coating by electroplating; diamond doesn't participate in chemical reaction. The combination of composite coating includes diamond / Ni, diamond / Ni_2Co, diamond / Ni_2Co_2Mn and so on [7,8]. When the metal ions precipitate onto the cathode surface, the micro particles of diamond gradually enter into the cathode surface, and are buried by deposited metals, after sanding and thickening, the diamonds are finally fixed into matrix and become a component of ED surface.

2. Experiment

2.1 Raw Materials and Equipments

Raw material: three 48CrMo workpieces of corrugated roll (surface hardness 56HRA after heat treatment, Φ40mm × 120mm), Cr_2O_3 ceramic rod (Φ6.35mm × 610mm, HV1000 ~ 1200), WC/TiO_2 powder, diamond (diamond particle 10-15 um).

Equipments and Instruments included FWS-20 Flame gun (FST Company of Holland), HV80 type JP-5000 HVOF system (Chuyue Machinery Equipment Co., Ltd. Shanghai), HV-50 type microhardness tester (Guangzhou Junda Instrument Co. Ltd.), WE-10A universal testing machine (Changchun Material Testing Factory), SRV high temperature friction and wear tester (Germany OPTIMOL Company)

2.2 Methods

(1) Experiment Condition

The surface of mentioned workepieces of corrugated rolls were processed with 3 technologies including Cr_2O_3 CRFS, HVOF WC/TiO_2 and ED, the dimension variation of flute shape was observed and surface performance was tested in order to determine the best processing technology

- Cr_2O_3 CRFS

Ethyne pressure was 0.3MPa, Oxygen pressure 0.4MPa, spraying distance 10~15mm, Jet speed 150~250m/s, the preheating temperature was 200^0C, sample was cooled at room temperature after the spraying.

- HVOF WC/TiO_2

Aviation kerosene was used as fuel, oxygen as combustion supporting gas, fuel pressure 1.2MPa, flow 21L/h, Oxygen pressure 1.5MPa, flow $57m^3/h$, powder flow 5kg/min, spraying distance 380mm.

- ED

Nickel salt diamond solution was used to electroplated solution (diameter of diamond particles was 10~15um), pH4~5, electroplated temperature 40-50^0C, electrical density 2~$3A/dm^3$, power supply was provided with WYJ-3B transistor DC, 100mA DC meter was used to monitor the current density from the cathode, the solution was stirred mechanically with 300r/min.

(2) Performance Test

The sprayed workpieces of corrugated roll were performed the tests including microhardness, bonding strength and wear rate

3 Results and discussion

3.1 Microhardness

HV-50 microhardness tester was used to test microhardness of surface coating with 1kg load and 15s loading time. Each coating was performed 10 tests, and the microhardness was the average of the 10 testing data.

Table 1. Microhardness of Coating

No.	Spray Technology	Microhardness (MPa)
1	Cr_2O_3 CRFS	994
2	HVOF WC/TiO_2	1272
3	ED	7400

Generally, the greater the hardness of the coating, the higher wear resistance it has [9]. However, higher hardness of coating is always accompanied with higher

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brittleness, which results in the higher chance for the coating appearing micro-cracks [10]. Comparing with CRFS and HVOF technologies, the microhardness of workpieces treated with ED technology was highest.

3.2 Bonding Strength

Bonding strength test was performed according to GB9796-88 standard, coating sample and sandblasted 48CrMo counterpart was bonded together with E-7 glue. After solidification, the bonding strength of coating was determined with WE-10A Universal Materials Testing Machine.

Bonding strength of coating was calculated according formula (1)

$$F=P/A \quad (1)$$

F: bonding strength (N/mm^2)

P: tensile load (N)

A: coating area (mm^2)

The bonding strength of each coating was the average of 5 testing data.

Table 2. Bonding Strength of Coating

No	Spraying Technology	Bonding Strength (MPa)
1	Cr_2O_3 CRFS	31
2	HVOF WC/TiO_2	68
3	ED	55

Because the energy of CRFS was lower, bonding strength between coating and matrix was much lower than HVOF. Bonding strength of ED was depended on the bond between plating Nickel layer and matrix and ranged between CRFS and HVOF.

3.3 Wearing rate

In order to characterize the service life of the coating, wearing rate of coating was performed with SRV high temperature friction and wear tester, high precision Si_3N_4 balls were selected and the test was conducted with 30N load, 20Hz frequency and 1.00mm stroke.

Table 3. Wear Rate of Coating

No.	Spraying Technology	Wear Rate (mm^2)
1	Cr_2O_3 CRFS	1.65
2	HVOF WC/TiO2	1.18
3	ED	0.42

During the damage process of the coatings, Cr_2O_3 ceramic coating was completely peeled off, its wear resistance was very poor. WC/TiO_2 composite coating was peeled off locally and the remaining part was intact. The strength of diamond coating was strongest, there were no obvious damage signs, only local shallow grooves were left onto the diamond coating surface.

4. Conclusion

Performance test showed that ED technology has a better result, HVOF WC/TiO_2 was not as good as ED technology, however, the cost of ED was high, its estimated cost was more that 150 thousands, so HVOF WC/TiO_2 was the best choice for surface spraying technology of corrugated roll.

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