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Analysis of technological characteristics of high-melting metal arc spraying 3Cr13

***Abstract**. The experimental study has been done for high-melting metal arc spraying 3Cr13 technological parameters to research the influence of spraying current, spraying voltage and wire feed voltage on spraying arc and the influence of spraying current on coating temperature. Theoretically, it has been analyzed the distribution rules of spray gun jet speed field and temperature field and their influence factors. The results showed that the arc current increases along with arc voltage increase. The lower the spraying voltage is, the smaller the molten grain size becomes. However, if the arc voltage is lower than the minimum critical arc voltage of the material, the arc could not keep smooth burning. The spraying current has correspondence relationship with wire feed speed. The spraying current could be adjusted through wire feed speed adjustment. The temperature on the coating surface increases along with spraying current increase and the air velocity has almost no influence on grain's temperature.*

***Streszczenie** Przeprowadzono eksperymentalne badania technologicznych parametrów metalizacji łukowej natryskowej metalem o wysokiej temperaturze topnienia, typ 3Cr13. Badano wpływ prądu i napięcia metalizacji oraz przesuwu drutu na łuk metalizacji a także wpływ prądu na temperaturę powłoki. Teoretycznie zbadano wpływ tych parametrów na rozkład szybkości i temperatury w strumieniu pistoletu natryskowego. Prąd metalizacji wzrasta z napięciem. Zmniejszenie napięcia wywołuje zmniejszenie rozmiaru ziarna stopionego metalu. Jednak, zmniejszenie napięcia poniżej minimalnego dla danego materiału może spowodować, że łuk nie będzie gładki. Prąd metalizacji zależy od szybkości przesuwu drutu i musi być do niej dostosowany, Temperatura powierzchni powłoki wzrasta wraz z prądem metalizacji a szybkość strumienia powietrza nie ma wpływu na temperaturę ziarna. **Analiza własności technologicznych metalizacji łukowej metalami o wysokiej temperaturze topnienia, typ 3Cr13**.*

Keywords: high-melting metal arc spraying, spraying current, spraying voltage, coating temperature.
Słowa kluczowe: metalizacja łukowa metalem o wysokiej temperaturze topnienia, prąd metalizacji, napięcie metalizacji, temperatura powłoki.

Introduction

Metal arc spraying rapid moulding technology is a kind of moulding technology based on "duplication" that it takes the physical model (or called prototype) as female die and arc as heat source. The high speed airflow is used to atomize melting metal materials to form spraying grains and jet and deposit on the surface of female die to form compact metal coating to certain thickness, called die shell. The die shell accurately copies the prototypical shape and gets the necessary die cavity. Metal arc spraying rapid moulding technology actually is near net-shape technology of rapid moulding. No additional mechanical processing will be required after accomplishment of arc spraying mould making and be directly used for prototyping and manufacturing. Metal arc spraying moulding technology takes female die as standard that the die cavity size and geometric precision completely depends on female die. Since cavity surface and its fine figure can be generated at the same time[1-4].

The middle and low melting metal arc spraying rapid moulding technology represented with zinc or zincaluminium alloy, has been applied in die development of large automobile panel[5-7]. However, since the hardness of zinc and zinc aluminium alloy is relatively low, the service life and application scope of the die have been restricted to certain extent. It is extremely attractive to manufacture arc spraying die with high melting point and high hardness metal (carbon steel and alloy steel) not only because the material is relatively cheap but also high hardness and strength die shell could greatly improves service life thus to expand application scope of spraying die and better serve manufacturing[5-7]. However, the high melting point metal has bigger coating contractibility rate, thermal stress and porosity in spraying that the coating is easy for cracking, warping or spalling; difficult to manufacture die shell and hard to control technological parameters. Theoretical analysis and experimental research have been done for high melting point metal arc spraying technological parameters in this paper.

The relationship among spraying voltage, wire feed voltage and spraying current

The speed and temperature of molten drop are two important factors to influence on internal stress of arc coating. To analyze for spray gun's jet speed field and temperature field, master spraying mechanism and the deposition process of spraying grain have significant effect to reduce coating internal stress, control spraying coating quality and improve spray moulding technological level. Spraying current and spraying voltage control output power, known as arc combustion power; wire feed voltage determines wire feed speed; that means wire quantity needed to be melted by arc in unit time; the compressed air has cooling effect while atomizing metal molten drop, so spraying current, spraying voltage, wire feed voltage, air pressure and flow will affect temperature of metal grain. Air jet flow speed determines flying speed of grains. In flying, grain have severe change along with different temperatures and speeds of spraying distance under the effect of compressed airflow. When reaching at matrix surface, the grain speed and temperature determine coating stress and coating quality. Grain flying speed should be as fast as possible to increase grain's pressure stress generated in hitting to balance part coating tensile stress, which is beneficial to increase coating critical thickness. If the temperature is too low, the solid phase proportion in the grains is high that grain is easy to rebound thus to reduce deposit efficiency; if the temperature is too high, liquid phase proportion is increased that the grain is easy to splash and the coating has poor quality. This table 1 shows melting values of commonly used spraying materials. Seen from this table 1, the melting point of 3Cr13 is higher than 1000□ and it is belonged to martensite stainless steel high-melting metal that the coating has features of high bond strength, low contractibility rate, low residual stress and good abradability, etc.

Table.1 Melting values of commonly used spraying materials

Materials	Melting values (℃)
Zn	419.5
Al	660.4
ZnAl15	677
Cu	1083
3Cr13	1482

The metal liquid drop and diameter distribution are related to technological parameters such as fuse voltage, wire feed speed and atomization air pressure, etc. The average temperature of metal jet flow is related to spraying distance. The combined method of experiment analysis and numerical calculation is used to build the relationship between spraying technological parameter and coating quality.

Table 2 spraying current values

voltage(V) current (A) voltage (V)	9	10	12	14	15
27	100	120	150	190	200
30	100	120	150	190	210
33	110	130	160	190	210
35	110	120	180	210	220
40	110	140	190	230	240

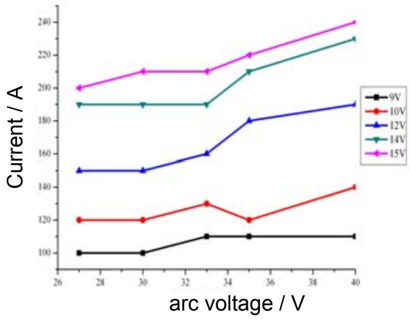

Fig.1 The influence of arc voltage on arc current

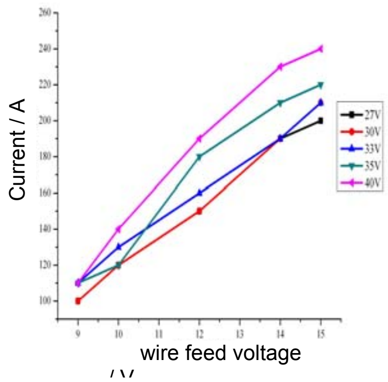

Fig.2 The influence of wire weed voltage on arc current

QD8-LA arc spraying system and 3Cr13 martensite stainless wire with spraying diameter of 2mm are used to research in the experiment for the influence of spraying voltage and wire feed voltage on spraying current. The experimental result is shown in the table 2. In the precondition of unchanged wire feed speed, when the arc voltage is increased from 27V to 40V, the arc current has the increasing tendency. When the arc electric intensity E is unchanged, arc column length d=U/E, increase arc voltage U, the arc column is elongated and the arc section will proportionally magnify along with current increase thus to speed up heat loss of the arc column. In order to balance the loss, the power must provide more heat energy (IE). When E is unchanged, the current (I) becomes bigger.

The influences of arc voltage and wire weed voltage on arc current are shown in the Figs.1-2. From the Fig.2 can be seen that in the magnifying process of the wire feed voltage from 9V to 15V, the arc current gradually increases. It is found that the influence of wire feed speed is more obvious on arc current than spraying voltage by comparing Fig.1 and Fig.2.

Under the precondition of unchanged arc voltage, to increase wire feed voltage speeds up spraying wire feed speed and to melt mental wire consumes more arc heat. In order to balance with the loss, the power must provide more heat energy and the current I is bigger. Under the effect of arc and atomization airflow, the tips of two metal wires undergo the process of metal melting-molten metal breaks away-molten drop atomized into particles. In each process, distance between two poles has frequent change. When the power and voltage keep constant, for current's self-adjusting feature, the arc current has frequent fluctuation along with it. When the arc length is smaller, the current could rapidly magnify to speed up wire's melting and recover the arc length. When the arc length becomes bigger, the current also rapidly decrease to reduce wire's melting speed and recover the arc length, so that the current could self-maintain wire's melting speed.

The effect of spraying current to coating temperature

Firstly prepare 100×100×20mm cast iron matrix. The infrared radiation thermometer is used to real-time monitor temperature change of single points on the coating surface in the spraying process. QD8-LA arc spraying system is adopted to spray 3Cr13 martensite stainless wire with spraying diameter of 2 mm. For matrix with different initial temperature, the coating temperature is also different. The coating temperature will increase along with increase of the initial temperature. Therefore, the coating needs to be cooled to 20□ before each spraying in the experiment to achieve comparability. The spraying current sprays the coating every 20A among 100-180A. Since the temperature fluctuation is big, choose five repeated samples for each current value to detect the coating temperature in each spraying process and take the average value as the final result.

Tab.3 The effect of spraying current on coating temperature

spraying current (A)	100	120	140	160	180
Maximal temperature (℃)	82.24	88.73	101.02	112.92	120.65
Minimal temperature (℃)	19.95	20.03	19.87	20.26	20.85
temperature fluctuation (℃)	62.28	68.7	79.43	92.66	101.63

The experiment result is shown in the table 3. When the current increases from 100A to 180A, the highest temperature on the coating surface has increase tendency. In this experimental condition, taking 20℃ as the initial temperature, the highest temperature increases from 82.24℃ to 120.65℃ with 38.41℃ of change amplitude. In order to reduce spraying coating temperature, under the precondition to guarantee smooth jet flow, the wire feed speed should be as low as possible thus to reduce spraying current. In the deposition process for each layer, temperature fluctuation occurs at any point on the coating surface along with shift of jet flow light spot, equally to bear thermal shock cyclic loading effect. The temperature change each time accompanies with change of coating internal stress. According to result of this experiment, it is primarily to choose the spraying current of 100A, the initial temperature of 20℃, the temperature fluctuation range of 62.3℃ in the spraying process and the highest temperature of 82.24℃.

Analysis of melted metal airflow field

Since the spray gun and its jet flow are axial symmetry structure, in order to simplify the calculation, the current contact nozzle in the spray gun is ignored. The triangle gridding is adopted for division, the boundary condition is: inlet pressure 0.5MPa, outlet pressure 0MPa and the initial pressure of up and down wall surface in jet flow are a 0MPa.

The sprayer nozzle increases air velocity by changing section's geometric dimension within short route. In the sprayer nozzle firstly contracted and then extend, the subsonic velocity airflow speeds up in the reducing pipe; appears sound velocity at the minimum section and accelerates to be supersonic speed after entering into increasing coupling. It is assumed the air is the ideal gas, meaning without considering gas viscosity. The airflow is isentropic, zero friction and heat insulation. The airflow is flow in straight line from the inlet to the outlet. The air has compressibility.

According to air jet dynamics principle, the speed of compressed jet flow at the outlet could be calculated with the following formula:

(1) $$V_e = \sqrt{\frac{TR}{M} \cdot \frac{2k}{k-1} \cdot \left[1-\left(P_e/P\right)^{(k-1)/k}\right]}$$

Where, V_e=exhaust velocity at outlet of sprayer nozzle, m/s;T=thermodynamics temperature of the air at inlet, K;R=common air constant, (8314.5 J/(kmol•K); M=air molecule quality, kg/kmol; k=cp/cv=adiabatic index, ;cp=air specific heat at constant voltage; cv=air specific heat at constant volume;P_e=air absolute pressure at outlet, Pa; P= air absolute pressure at inlet, Pa.

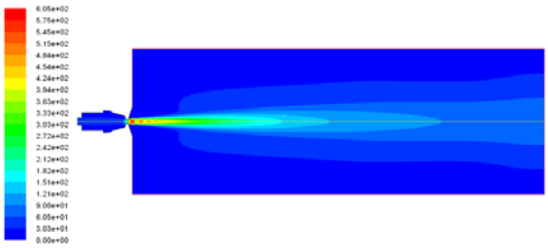

Fig.3 Velocity field nephogram of melted metal airflow

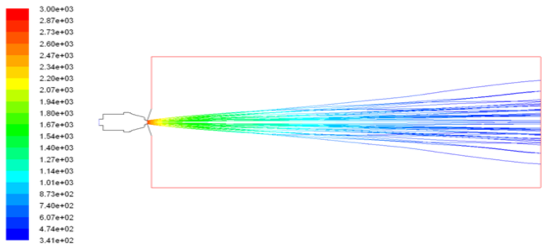

Fig.4 Temperature distribution nephogram of melted metal airflow

The Fig.3 is the velocity change of airflow axial along with axial distance. Seen the Fig.3 from simulation result, at the spray gun outlet, the highest air speed reaches 600m/s with violent disturbance wave. After ejection, air velocity rapidly reduces to subsonic velocity (about 200m/s) within 0-250mm of spraying distance. The air velocity continuously decreases along with increase of spraying distance. The high speed air atomizes metal molten drop to drive metal drop to accelerate flying towards the matrix and meanwhile quickly cool the high temperature molten drop.

On the basis of continuous phase analysis, the loading dispersed phase conducts secondary calculation. The boundary condition: initial temperature 3000K, initial speed 0m/s, particle diameter 25μm and flow 0.00139kg/s. the load result of dispersed phase is shown in the Fig.4.

According to aerodymanics principle, the change of air axial velocity along with axial distance x is represented as:

(2) $$V_g = V_{gi} \exp\left(-\frac{x}{\lambda}\right)$$

where, V_{gi} is air speed at the outlet and λ is the attenuation coefficient (0.1～0.3).

The total acting force F received by spherical metal drop with diameter of d is represented with the following formula:

(3) $$F = m\left(dV_d/dt\right) = C_D \rho_g \left(V_g\text{-}V_d\right)^2 \cdot A/2$$

A is sectional area of metal drop.The accelerated speed of metal drop:

(4) $$dV_d \big/ dt = 3C_D \rho_g \left(V_g - V_d\right) \left|V_g - V_d\right| \big/ 4d\rho_d$$

The drag coefficient C_D is related to Reynolds number.

(5) $$C_D = 0.28 + \left[6/\text{Re}\right]^{1/2} + \left[21/\text{Re}\right]$$

Taking grain with diameter of 25 μm as the research object, the influence of different air pressures on grain's flying speed has been analyzed that the grain's flying speed increases along with air pressure increase, can be seen in the Fig.5. The maximum speed is distributed in 200-250m/s. When the spray gun structure is unchanged, the airflow velocity increases along with air pressure increase and the grain's accelerated speed increases accordingly.

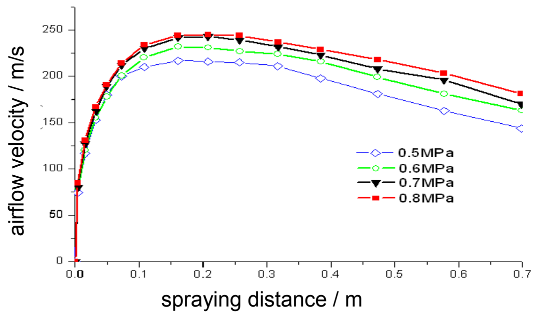

Fig.5 The effect of different air pressures on airflow velocity

The temperature distribution of grains under different air pressures along with jet flow axis is shown in the Fig.6. In the flying stage, the grain's cooling speed continuously decreases along with grain's temperature decrease and the air velocity has almost no influence on grain's temperature. However, under the same air pressure spraying condition, grains in different diameters have obvious change for the temperature, just as shown in the Fig.7. The melting point of 3Cr13 stainless steel materials is 1482℃. When the grains in small diameter is lower than the melting point temperature, since flying speed could not reach cold spraying condition (500m/s), the grain is likely not to deposit for rebound reason.

The influence of air pressure on grain's speed has been gradually decreased when the pressure is over 0.5MPa. The speed almost has no change in 0.7~0.8MPa. The particle acceleration area is within 0.1 m of the spraying distance. When the spraying distance is between 0.1~0.3m, through fully accelerated, the spraying particle has high flying speed.

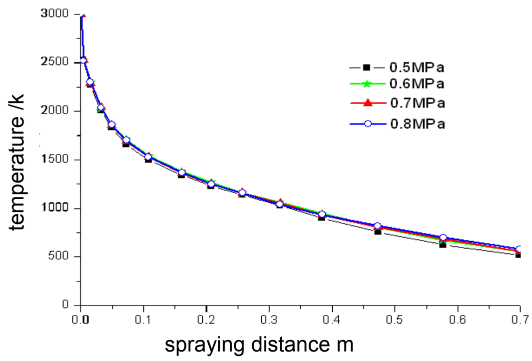

Fig.6 The temperature distribution of grains under different pressures along with jet flow axis

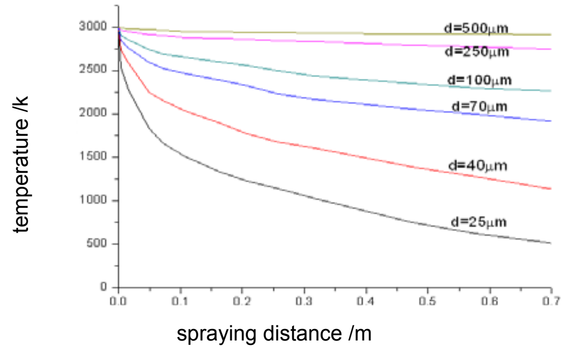

Fig.7 The temperature distribution of grains under different diameter along with jet flow axis

The jet flow grain speed is 60-70m/s and the jet flow grain temperature is 2700-2800K within 100-300mm scope of spraying distance. What is out of expectation: the grain speed and temperature has little change within 200mm flying distance. Seen from Figs.8-9, the error between simulation value of jet flow grain and the experimental value is only 5.5% and the error between simulation value of jet flow grain speed and the experimental value is only 14.1%. The match of speed and temperature testifies the reliability for research result of grain's temperature and speed.

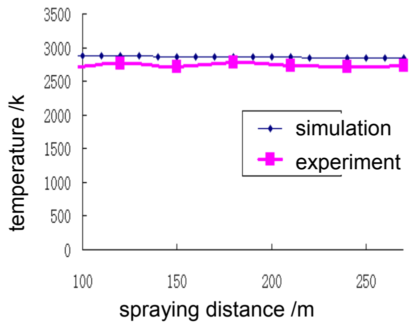

Fig.8 The temperature compare simulation with experimental value

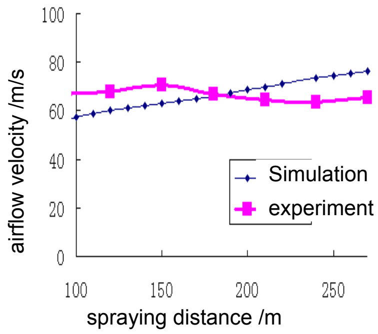

Fig.9 The airflow velocity compare with experimental value

Conclusions

When the spraying voltage is kept unchanged, the spraying current has correspondence relationship with wire feed speed. In the experiment, the spraying current could be adjusted through wire feed speed adjustment. The temperature on the coating surface increases along with spraying current increase and the spraying current is confirmed as 100A in the experiment. The combined method of numerical simulation and experimental analysis is used to quantitatively analyze the change process of grain speed and temperature in high speed flying and the distribution cloud chart of jet flow speed and temperature. The result is proven that, the highest speed of jet flow at the outlet of the spray gun reaches 600m/s; the air velocity quickly reduces to subsonic velocity (about 200m/s) after ejection within 0-250mm of spraying distance. The air velocity continuously reduces along with spraying distance increase. Taking grain with diameter of 25μm as the research object, the influence of different air pressures on grain's flying speed is analyzed and it is found that the grain's flying speed increases along with air pressure increase with the biggest speed distributed within 200-250m/s. The air velocity has almost no influence on grain's temperature. However, under the same air pressure spraying condition, the grains in different diameters have obvious changes for the temperature.

Acknowledgments

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