Erosion Resistance of Ceramic Particle Reinforced MMC Coating

Jianjun Fang¹, Yanping Li*¹

¹ State Grid of China Technology college, No. 500, South Erhuan Road, Jinan City, Shandong Province, 250002, China

Abstract: There are relevant reports on preparing TiB₂ particle reinforced metal matrix composite (MMC) anti-wearing coating by plasma spraying and HVOF spraying methods successfully. The research uses high velocity electric arc spraying with low cost and convenient operation to prepare four TiB₂ particle reinforced composite coatings (MMC) with high bonding strength and uniform tissue. The results indicate the coating has excellent erosion wearing resistance.

1. Preface
Using TiB₂ to produce wear and erosion resistant ceramic particle reinforced metallic matrix composite (MMC) coatings has gained great attention in recent years etc.[1] Wear resistance TiB₂ particle reinforced MMC coatings can be deposited using the plasma spray, high velocity oxygen fuel and high velocity arc spray procedure. Technology of preparing MMC coatings by using high velocity electric arc spraying process with low cost and convenient operation is one of effectively reducing pipe failure methods. 304L and NiCr are selected as cored wire alloy sheath, and alloy powders such as Ni, Al and a certain number of TiB₂ ceramics hard are chosen as arc spraying cored wire powders. Previous studies have shown that metal matrix ceramic composite coating is superior erosion resistance of the metal, such as metal coating this research of MMC coating containing. Using prepared cored wire and high velocity arc spraying four coatings are prepared. In this study metal matrix composite coating that contains TiB₂ is to solve pipe erosion problem of coal fired boiler, so the chapter analyzed erosion resistance test results on developed series by different metal and ceramic containing (304L-TiB₂, 304L-TiB₂/Al₂O₃, NiCr-TiB₂/Al₂O₃ and NiCr-TiB₂) with good comprehensive properties, compares them with 45CT coating, and studies erosion resisting mechanism of coating.

2. Test process
Elevated temperature erosion wearing test is made on GW/CS-MS and obey to ASTM G76-95 standard. In order to simulate boiler and primary over-heater of coal power plant pipes, using the equipment is vertical gas-sand jetting type elevated temperature erosion wearing test device to under factories and mines that bear fuel gas fly ash abrasive grain erosion, and its working schematic diagram is shown in Fig. 1. Factories and mines where coal fired boiler pipes are located mainly have low angle erosion of fly ash, and erosive speed of fly ash is about 40-60 m/s. Test conditions are shown in Table 1.

| Temperature (°C) | 25 | 500 | 650 |
|------------------|----|-----|-----|

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
| Erosion angle (°) | 30  | 90  | 30  | 90  | 30  | 90  |
|-------------------|-----|-----|-----|-----|-----|-----|
| Erosion particle mass (g) | 120 | 120 | 120 | 120 | 120 | 120 |
| Erosion time (s) | 360-480 |     |     |     |     |     |
| Erosion particle speed (m/s) |     |     |     |     |     |     |
| Erosion particle | fly ash from power plant |     |     |     |     |     |

Four kinds of MMC coating on 20G matrix erosion samples are prepared. Use JZY-250 type electric arc spraying equipment to prepare coating. Select 20 steel as matrix, clean matrix surface by acetone, use brown alumina sand blasting roughening treatment, and then make electric arc spraying immediately. Electric arc spraying technological parameters: Electric arc voltage is 30-34V, working current is 180-220A, compressed air pressure is 0.6-0.7 MPa, and spraying distance is 100-180 mm. Sample size is 25 mm×16 mm×5 mm, coating thickness is 0.6-0.9 mm, and coating is ground and thickness of about 0.5 mm. Solid aluminizing is made on non-spraying surface of erosion sample before spraying so as to avoid matrix material oxidation weight gain, which influences test results. Aluminizing agent formula \[^1\] is (15% Al powder + 85% Al₂O₃ + 0.5% NH₄Cl + 0.5% KHF₂), aluminizing technology is 900°C×2h, and aluminizing layer thickness is about 100 μm. Morphology of fly ash abrasive grain is shown in Fig. 2, fly ash shows irregular ball shape and has corner with sharp angle, and fly ash abrasive grains mainly consist of SiO₂, Al₂O₃ and few quantity of Fe, Ca oxides and alkali metal salt.

Fig. 1 Structure schematic diagram of GW/CS-MS erosion wear device under elevated temperature \[^2-3\]

3. Test results
Erosion test results of four kind TiB$_2$ ceramic particle reinforced MMC coatings and commercial coating 45CT prepared by electric arc spraying are shown in following figurantes. NiCr-TiB$_2$ coating under different attack angles and temperatures erosion rate is shown in Fig 3, and morphology of coating surface eroded by 30° and 90° incidence at 650°C is shown in Fig.4.

![Fig. 3 Erosion results of NiCr-TiB$_2$ coating](image)

![Fig. 4 Morphology of NiCr-TiB$_2$ coating surface eroded by 30° and 90° incidence at 650°C](image)

The results of erosion resistance of TiB$_2$ ceramic particle reinforced metal matrix composite coating prepared by electric arc spraying is better than 45CT coating in general. Erosion resistance of 304L-TiB$_2$ and NiCr-TiB$_2$ is better.

Mass loss of electric arc spraying TiB$_2$ reinforced coatings under room temperature erosion is within range 12-19 mg/100 g. And during large angle erosion, material with good toughness can resist repeated deformation and avoid brittle fracture caused by deformation. Under elevated temperature, tenacity of coating increases, and erosion resistance of coating improves. The test results of the research that under elevated temperature coating with TiB$_2$ (304L-TiB$_2$ and NiCr-TiB$_2$) has less mass loss that foreign normal 45CT coating, and is one elevated temperature resisting erosion coating material with good development prospect.

4. Analysis and discussion

Included angle between movement direction of impact particle and tangent direction of impacted material is defined as impact angle, which is also called as attack angle $\alpha$. When particle front face rushes at target surface, its attack angle is 90°. Many research results indicate, erosion loss of material has close relation with attack angle of particle. According to erosion rate, with change of attack angle,
block material is divided into two types, i.e., erosion damage of plastic material and crisp material (Fig. 4).

Fig. 5 Relation between erosion rate and erosion angle of both ductile and brittle materials under ideal status

For whichever alloy composition, erosion of ductile material shows similar erosion mechanism: surface plastic deformation, lip or corrugation is generated, further particle impact is made, plastic stress exceeds critical value, and surface material is removed. When serious erosion of ductile material occurs at small angle, shown in Fig. 5. Crisp erosion: Under particle impact, plastic deformation absorbing impact power doesn’t occur, and failure is caused by expansion of crisp crack of sub-surface during impact. Erosion mass loss of electric arc spraying coating has close relation with erosion angle, and erosion is often shown as combination of ductile and crisp erosions. Due to specialty of electric arc spraying metallic ceramic composite coating, forms of erosion damage are complex, influence of erosion angle on coating is also different from block material.

Influence of erosion angle on TiB$_2$ particle reinforced composite coating prepared by electric arc spraying is different from block material, and the coating has obvious rules, and this is mainly related with damage mechanism of coating. Fig. 4 shows erosion test results of coating under different conditions, and Fig. 6 shows coating surface before erosion. It can be seen from Fig. 4, erosion loss of NiCr-TiB$_2$ composite coating under room temperature and both 30° and 90° is more than that under elevated temperature. Coating under room temperature erosion shows crisp feature (Fig. 6), and surface under 30° erosion shows large quantity of slight crisp cracks. Many plastic rolled protruding crescent lips occur along erosion direction of fly ash particle, after erosion continues, such rolled crescent lips will have crisp collapse. Main damage mechanism of coating is chipping and soyabean residue shaped crisp collapse. Surface of NiCr-TiB$_2$ composite coating under room temperature and 90° erosion is full of erosion pits, and these damages don’t have direction under 30° erosion. According to Suh’s [5] delamination wearing theory, under continuous impact load function of abrasive grain, erosion wear process of material can be regarded as generation, growth, expansion, breakage of material sub-surface slight crack, which form stripe abrasive dust and removes from the matrix.

NiCr-TiB$_2$ composite coating under room temperature erosion shows typical crisp material feature, and 90° erosion loss is higher than 30° erosion loss. Different from room temperature, loss caused by 30° erosion under elevated temperature is more than 90° erosion, and this is mainly caused by surface and mechanic property change of NiCr-TiB$_2$ composite coating after temperature increases.
5. Conclusion
1) Erosion resistance of electric arc spraying TiB$_2$ particle reinforced composite coating is better than that of 45CT coating, under various erosion conditions, erosion resistance of TiB$_2$ coating is better.
2) TiB$_2$ particle reinforced composite coating with metal adhesion phase matrix with higher hardness and low porosity of coating, distribution of TiB$_2$ matrix ceramic phase and combination property with metal adhesion phase increased erosion property of MMC coating.

References
[1] J.J.Fang, Z.X.Li, M. Qian, et al. Effects of Powder size in Cored Wire on Arc-sprayed Metal-ceramic Coatings. ITSC. Beijing, 2007
[2] Deng Shijun. Hot spraying High Performance Ceramic Coating. Material Protection. 1999, 32 (1): 31
[3] D. W. McKee. The Oxidation of Dispersed Refractory Metal Compounds and Their Behavior As Carbon Oxidation Catalysts. Carbon. 1986, 245 (3): 331-336
[4] Qu Jingxin, Wang Honghong. Surface Engineering Manual. Beijing: Chemical Industrial Press. 1998: 589
[5] A. V. Levy. Solid Particles Erosion and Erosion-Corrosion of Materials. Ohio: ASM International. 1995: 73-170