Article ID: 1003－6326(2003)04－0893－05

WC-M coating to improve resistance of hydraulic turbines to cavitation erosion and abrasion ①

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Abstract: WC-M hard-faced ceramic coating was made on the substrate of steel by means of high velocity oxygen-fuel flame (HVOF) thermal spraying. The resistance of this coating to cavitation erosion and abrasion (CEA) is about 2.5 times higher than that of 18－8 stainless steel, and is about 1.5 times higher than that of Stellite alloy (CoCrWC) made in America. When this coating were applied to the hydraulic power stations with more silt content in the flow water, which reaches 50 kg/m^3, the resistance of above-mentioned coating to CEA was about 2 times to that of NiCr alloy coating, and is about 4－5 times to that of OCr13Ni4Mo stainless steel. In addition, the micro-hardness, microstructures and electron probe analyzing of the WC-M coating are all discussed.

Key words: WC-M coating; cavitation erosion; abrasion hydraulic turbines
CLC number: TG 174.44 **Document code:** A

1 INTRODUCTION

Cavitation erosion and abrasion (CEA) occurs in all hydraulic machines, including turbines, pumps and ships, etc. The above-mentioned equipments early failure, caused by CEA, is a difficult problem of science and technology. The problem is more severe in the hydraulic power stations at the center and west part of China, south Asia, Africa and South America. It causes loss of natural water energy of these areas. In recent years, many researches have been concentrated on improving the resistance of materials to CEA. Among them, hard-faced ceramic coating has displayed better results to resist CEA. For example, a Cr_3C_2-Co ceramic coating on the steel substrate has been prepared by means of the plasma thermal spraying, and has been applied to some hydraulic turbines and specific pumps in Japan and America[1－3]. Verdon[4, 5] and Shao[6] carried out an experiment to prepare (WC-Co) coating on steel substrate by means of HVOF thermal spraying in laboratory. However, because Cr_3C_2-Co and WC-Co coatings are very expensive, in China, no any hydraulic power station is willing to use them as the coating of hydraulic turbines. But yet, many Chinese researchers have concentrated on making NiCr coating of alloy to resist CEA by means of thermal spraying, and the NiCr alloy's coating has been applied to some middle or small size hydraulic turbines[7－9]. Although the coating of NiCr alloy can improve resistance to CEA to a certain extent, up to now, this coating has not been widely applied to hydraulic power station because it can not improve resistance to CEA to a large extent, and there is obvious thermal deformation after thermal spraying.

On the basis of summarizing advantages and shortages of NiCr alloy coating and hard-faced ceramic coating of Cr_3C_2-Co and WC-Co, in this paper, the authors propose to prepare WC-M hard-faced ceramic coating with no cobalt, on steel's substrate by means of HVOF thermal spraying for improving resistance to CEA (M= Ni, Cr, Fe, Si, Mn, B, etc).

2 EXPERIMENTAL

On the steel substrate, the following three methods were used for preparing the WC-M type of hard-faced coating not containing cobalt: 1) HVOF thermal spraying WC-M powder (M= Ni, Cr, Mn, Si, Fe, B etc; 30%－50% WC) and scanning melting the coating; 2) Plasma thermal spraying WC powders, wrapped up by nickel (80% WC) and then laser melting the coating; 3) Electric arc deposit welding tungsten carbide ceramic plates on stainless steel substrate, austenitic stainless steel electrodes were used for binder. In order to compare the resistance of different materials to CEA, the above-mentioned three kinds of WC-M hard-faced coating materials and 18－8 stainless steel, Stellite alloy CoCrWC made in America, were tested together. In order to test the materials resistance to CEA, an experiment machine, simulating condition of CEA, was designed. It is a small impeller which rotated in a fluid of 60% water

① **Foundation:** Project(95EO49M) supported by the Natural Science Foundation of Yunnan Province, China
Received date: 2002－06－03; **Accepted date:** 2002－08－28
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and 40% silt (mass fraction). The blades of impeller were made of different materials tested. After the impeller rotated in the fluid for 448 h, the blades were dismantled down and weighed in an analyzing scale. The resistance of material to CEA was described by mass loss of the blade. The material, having the best resistance to CEA in the experiment machine test, would be selected to do hydraulic turbine experiment in hydraulic power station to be compared with the original materials.

3 RESULTS AND DISCUSSION

The surface layer micro-hardness of five kinds of tested materials are shown in Table 1. It can be seen from Table 1 that the WC-M coating, prepared by laser melting, has the highest hardness among the five kinds of tested materials, but its microhardness values are not homogeneous, fluctuant range of hardiness values reaches ±Hv439.

Table 1 Microhardnesses of five kinds of tested materials

Material	Hv(average)	Hv(range)
(WC-M) by HVOF spraying	1114	1072 - 1197
(WC-M) by laser melting	1303	1145 - 1584
(WC-M) by deposit welding	713	543 - 959
Stellite alloy(CoCrWC)	494	472 - 516
18 - 8 stainless steel	197	182 - 202

The WC-M coating, prepared by HVOF thermally spraying, has the second high micro-hardness values (only smaller than WC-M, made by laser melting), but its micro-hardness values are more homogeneous than those of laser melting, its fluctuant range is only ±Hv149.

The microstructures of WC-M coating, prepared by laser melting, are manifested in Fig. 1(a) (lower magnification) and Fig. 1(b) (higher magnification). It can be seen in Fig. 1(b) that there are many dendritic microstructures, produced by the high speed cooling and freezing. The microstructures of WC-M coating, prepared by HVOF thermal spraying, are shown in Fig. 2 (less magnification). It can be seen in Fig. 2 that the three zones of *A*, *B* and *C* correspond to substrate, WC-M coating, and air, respectively.

Second electron micrograph of WC-M coating, HVOF sprayed, is shown in Fig. 3(a). It is seen in Fig. 3(a) that WC-M coating consists of alloy phase matrix (white) and tungsten carbide particle (black)

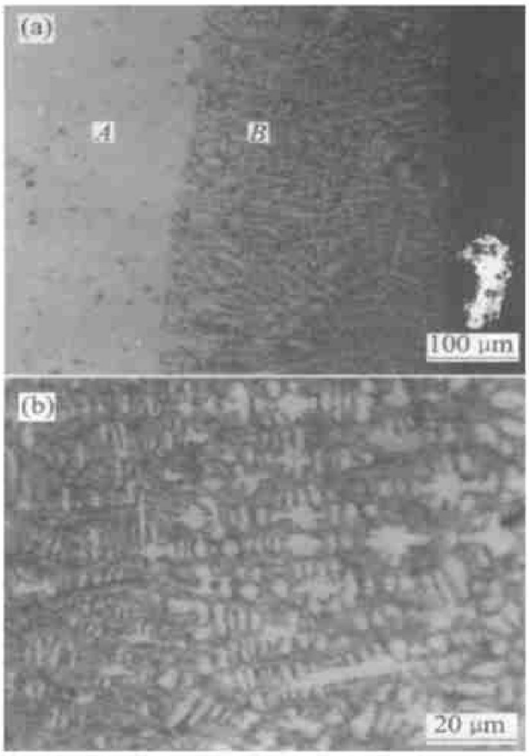

Fig. 1 Micrographs of WC-M coating melted by laser

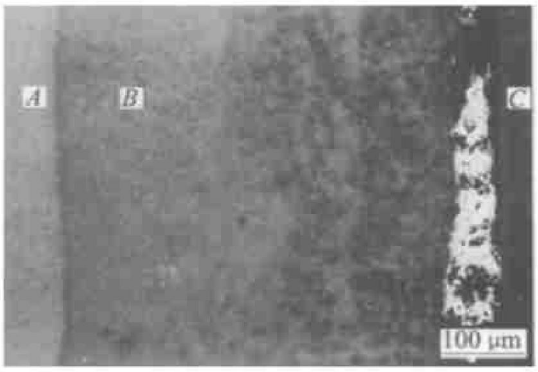

Fig. 2 Micrograph of sprayed WC-M coating

of varying size; In addition, it is seen in Fig. 3(a) that many WC micro-particles tend to concentrate together and form a bigger WC particle whose sizes are about 8 to 28 μm. Because the carbide particles are very brittle, it may be considered that these WC micro-particles got together, resulted from fragmentation of WC particles in original powders because of impacts and partial decomposition of WC particles in original powders in the course of thermally spraying and melting WC-M coating. Other researchers also observed similar fragmentation phenomenon of the carbides particles[4, 6]. In the above-mentioned course, WC particles were decomposed partially by reactions as[4, 5]

$$2WC+ 1/2O_2+ Q \rightarrow W_2C+ CO;$$

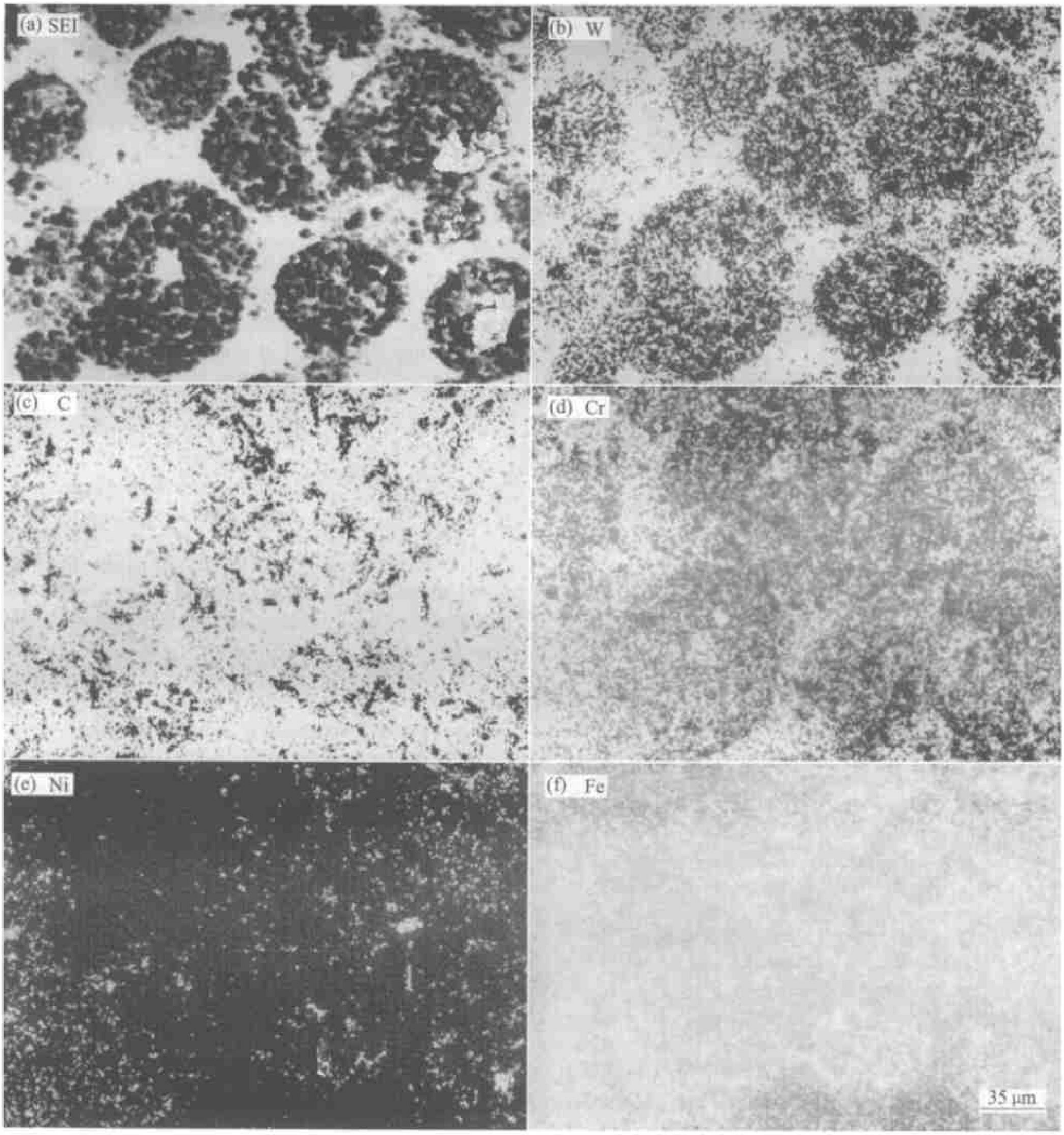

Fig. 3 Microstructure of WC-M coating (a) and elemental distributims of W(b), C(c), Cr(d), Ni(e) and Fe(f)

$$W_2C + 1/2O_2 + Q \rightarrow 2W + CO$$

Consequently, not only partial carbon loss occurred but also a WC particle of original powder became a group of W_2C+ WC+ W+ alloy phase+ others after the coating formed[4].

The elemental distributions of HVOF spraying WC-M coating, gained from electron probe, is shown in Fig. 3(b)–Fig. 3(f). It can be seen in Fig. 3(b), 3(c) and 3(d) that after WC-M coating is molten, the locations of tungsten atoms hold in original particle basically, but the locations of partial atoms of carbon and chromium are already moved. Because the affinity between carbon and chromium atoms is stronger, carbon atoms had in part diffused out of WC particles to form chromium carbide, and partial chromium atoms had contrarily diffused into original WC particles to form new complex carbide of tungsten and chromium[10]. It can be seen from Fig. 2 and Fig. 3 that during the melting of WC-M coating, liquid-phase sintering occurred on the WC-M coating at the melting temperature range of 1 000 – 1 050 ℃[11, 12]. Consequently, alloy phase M had not only joined up dispersive WC particles, but also had joined up WC-M coating with the substrate.

In CEA experiment machine, the tested results of resistance of different materials to CEA, are given in Fig. 4. It can be seen in Fig. 4 that among 5 kinds of tested materials, their orders to resist CEA are listed as:

WC-M by HVOF thermally spraying > WC-M by laser melting > Stellite alloy> WC-M by deposit welding > 18-8 stainless steel.

In addition, it has also been seen in Fig. 4 that the resistance of WC-M coating, HVOF thermally sprayed, to CEA is about 2.5 times higher than that of 18-8 stainless steel, and is about 1.6 times higher than that of Stellite alloy made in America. Although WC-M by laser melting, has the highest hardness among the tested materials, but its resistance to CEA is not the strongest because its hardness distribution on surface layer is not homogeneous as mentioned above.

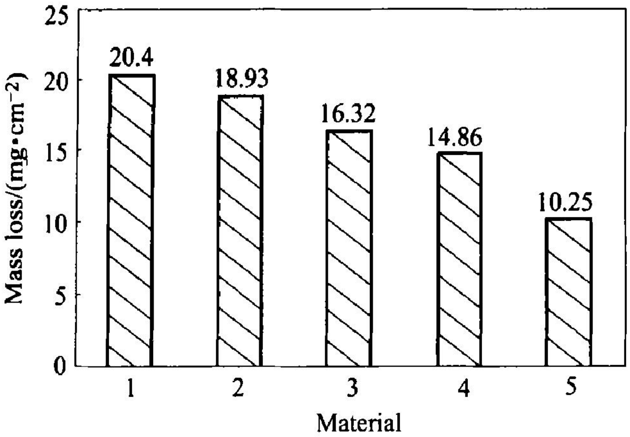

Fig. 4 Mass losses of different material caused by CEA
1—18-8 steel; 2—WC-M by deposit welding; 3—Stellite alloy; 4—WC-M by laser melting; 5—WC-M HVOF thermally sprayed

In Sanmenshia zone of Yellow River, China, average silt content in a year is 45 kg/m^3, maximal silt content reaches 330 kg/m^3 in flood peak period. Therefore Sanmenshia water power station is the most severe one of CEA. The statistical results gained from the impeller blades or guide vanes of hydraulic turbines, made of different materials applied to water power productions, are shown in Table 2.

It is seen from Table 2 that the WC-M coating, HVOF sprayed, has the best resistance to CEA among the several materials applied, both in Sanmenshia and in Shiaoguangzi. When the continuous service period amounted to 3 a, the WC-M coating kept intact yet. When the continuous service period amounted to 5 a, renewing components were required just. However, with regard to those components of original material, $OCr_{13}Ni_5Mo$ stainless steel, when continuous service period amounted to a year only, renewing was required.

4 CONCLUSIONS

1) In test of CEA experiment machine, WC-M coating without cobalt, HVOF sprayed, displays the best resistance to CEA among several tested materials. The components of above-mentioned coating manifest better resistance to CEA in hydraulic power production than any other applied materials.

2) The WC-M coating without cobalt, sprayed by HVOF, has wide prospect application to hydraulic turbines because of its lower cost and excellent resistance to CEA.

3) On the basis of the information EP analyzing, the brittleness of carbides particles and the reports of other researchers, it may be considered that in the courses of thermal spraying and melting of WC-M coating, WC particles of original powders are fragmentized by impact and partial decomposition, and the carbon atoms of WC particles and chromium atoms of alloy matrix have contrarily diffused partially, to form new complex carbide of tungsten and chromium both in alloy matrix and original WC particles.

Table 2 Results applied to some water power installations

Service period/a	Sanmenshia of Yellow River			Shiaoguanzi of Sichuan	
	Blades of (WC-M) HVOF sprayed	Blades of NiCr coating	Blades of OCr_{13}-Ni_5Mo	Guide vanes of (WC-M) sprayed	Guide vanes of $OCr_{13}Ni_4Mo$
1	Intact	Intact	Severe CEA, renewed	Intact	Severe CEA, renewed
2	Intact	20% coating lost		Intact	
3	Intact	Severe CEA, renewed		Intact	

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(Edited by LONG Huai-zhong)