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Effects of Residual Stress on Interfacial Bonding Strength of WC Coating

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Abstract. The residual stresses of WC coating prepared by flame spraying and laser re-melting were measured quantitatively with X-ray diffraction (XRD) stress tester, and its micro-structures were observed with SEM, and the effects of residual stress on bonding strength of coating interface were analyzed. The experimental results are shown that residual stresses of WC coating are all tensile, and the effects of coating thickness on its residual stress is obvious, and residual stress is verse ratio with its thickness; Coating stress influences its cracking, tensile stress speeds its cracking, which causes its bonding strength decrease; The stress state is improved by decreasing its thickness, and its bonding strength can be increased.

Introduction

During the usage of metal-ceramic composite coating at present, resistance wear effect of WC coating is more ideal, WC is mutually wetted with Ni, whose bonding strength is better, and its hardness is too higher, therefore it may receive satisfied effects at rigor situation of resistance wear. WC coating prepared by thermal spraying has many advantages such as wear resistance, heat resistance, corrosion resistance, high hardness and etc., that is applied in petroleum chemical engineering, railroad vehicle, A-energy industry, and etc.. The process of thermal spraying is a dynamic process, it will produce residual stress because spraying materials, coating thickness, spraying crafts, spraying speed and thermal expansion coefficient and elastic module and etc., are different [1]. Residual stress will speed surface cracking, delamination and failure behaviors that has negative influences on its service life and applied capabilities [2]. Residual stress is one of internal characteristics of WC coating by thermal spraying, the reason is that coating-substrate materials have bigger temperature grads and different physical performances [3]. Residual stress has distinct influence on coating quality and applied capabilities, and badly influence on service life of WC coating, therefore it is a very important that the methods of measuring residual stress of coating by thermal spraying [4], therefore, and it is necessary to research the effects of residual stress of WC coating by thermal spraying on its bonding strength [5]. WC coating is prepared by flame spraying and laser remelting in this paper, and its structures, residual stresses, were tested and analyzed with SEM and) and XRD, respectively, and its bonding strength was investigated, and the influenced factors of residual stress of WC coating on its bonding strength were analyzed.

Experimental

Sample Preparation. Substrate material is 45 steel, and its dimension is 60mm×40mm×20mm, the sample surface was milled, and cleaned by acetone, flame spraying crfats were shown as follows: Ni powder and packed WC powder were mixed, flame spraying was finished with SPH-2/h spraying gun, cooling mode was natural air-cooling, and the spraying process was shown:

warm-up→spraying→cooling, WC coating thickness is about 1mm. The technological parameters of laser remelting were shown as follows: laser power 400 W; spot diameter 2mm; scanning speed 1000/mm/min, scanning distance 2/mm.

Measurment of Residual Stress. Residual stress of the sample is analyzed by X-350A type XRD stress tester when tube voltage is 22 kV, tube current is 6mA. As for Co-target K_{α} characteristic radiation, collimating diameter is 2mm, gradient scanning is 0.1°, time constant is 1s, step angle of scanning initial angle and termination angle are 130° and 100°, respectively, list angle Ψ is 0°, 15°, 25° and 45°, respectively. The diffraction peaks in crystal planes is (210), and its stress constant K=-2518.

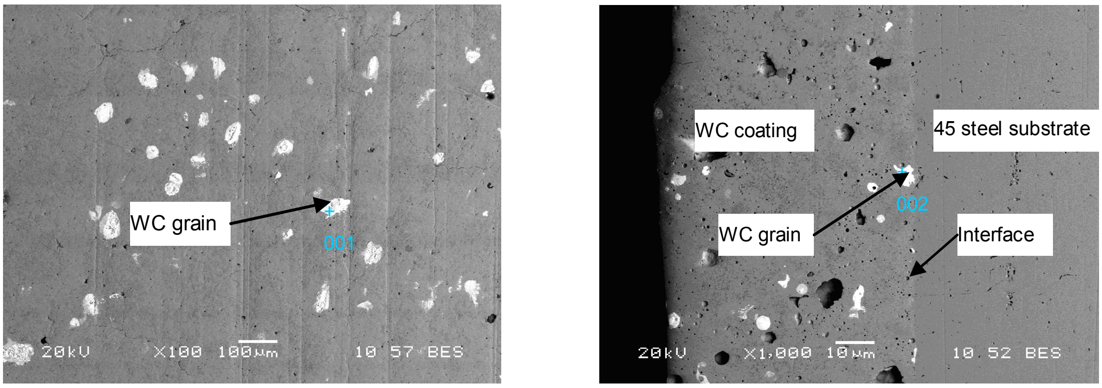
Testing of Bonding Strength. Bonding strength of WC coating was tested with stretching method, according to the standard of ASTMC633-79, it is tested on electronic stretching tester. WC coating surface and sample surface were bonded by E-7 gluewater, and solidified at 100□ for 3h, then after 24h, it was stretched in room temperature. Bonding strength of coating is shown as follows [6].

$$\sigma = \frac{4F}{\pi d^2} \qquad (1)$$

where F is the most stretching force when snaping; d is the sample radius after snaping.

Analysis and Discussion of Experimental Results

Structures of Coating Bonding Interface. The bonding interface of coating-substrate had a obvious interlocking, it is indicated that bonding state was well, such as Fig.1 shown. In Fig.1 (a), WC granules are uniformly dispersed in the coating, the boundary of coating-substrate is relatively obvious, and the bonding layer has some holes. Convection agotateion of molten pool makes the substrate become rough and non-smooth, it is indicated that the boundary of coating-substrate in bonding interface is not obvious, and the coating is more denser in bonding layer and forms metallurgy combination, therefore, it enhances bonding strength of coating-substrate.

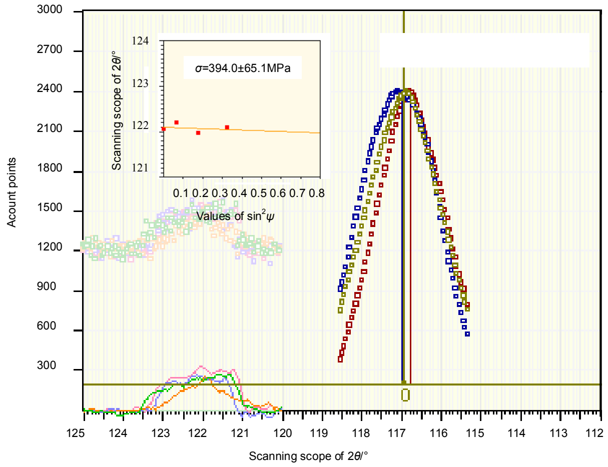


(a) Surface (b) Interface

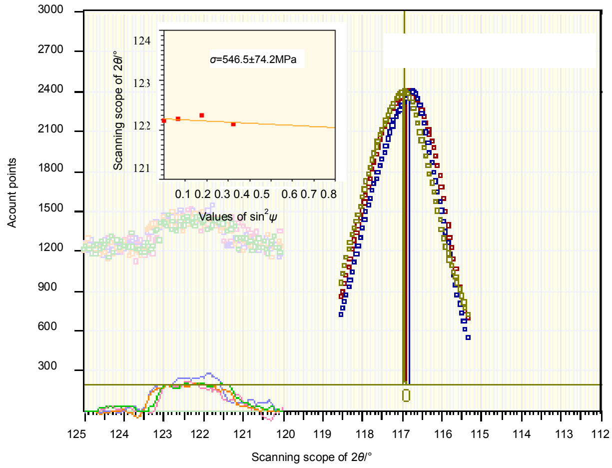
Fig.1 Morphologies of WC coating by flame spraying and laser re-melting

Aanalysis of Residual Stress. The measured results of residual stress were shown as Fig.2. Residual stresses of WC coating by flame spraying and laser re-melting were tensile stress, because expansion coefficient of WC coating is bigger than that of substrate, thermal contract is not matched and asymmetry produce resudial stress. Tensile stress makes WC coating exist forth expansion trend, and results in cracks forming on the substrate surface, moreover expands into the coating , and then produces coating cracks.

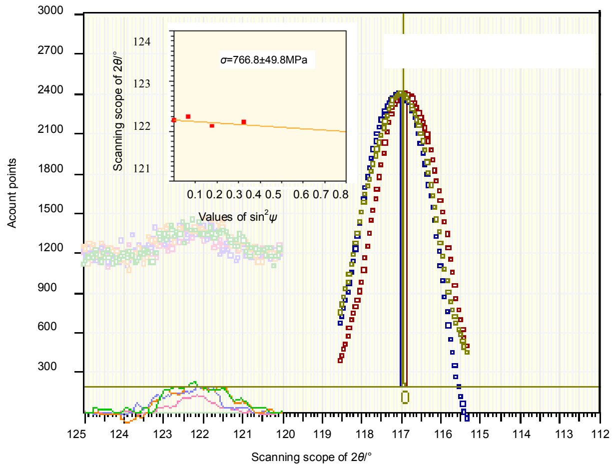
During its preparation, because the thermal expansion or thermal shrinkage of WC coating is misfit with that of the substrate, residual stress is produced, that not only affects its bonding strength, but also cause micro-cracks and the layer debond from the substrate, the changed residual stresses in the thickness direction firstly produce cracks in the interface; and then they produce WC coating cracks, and the interface debonds, which are related with the design, the gradient and the magnitude of residual stress.



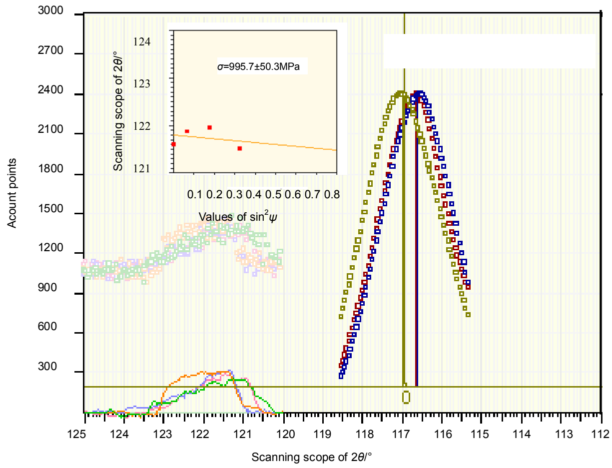
(a) Thickness 200μm



(b) Thickness 400μm



(c) Thickness 600μm



(d) Thickness 800μm

Fig.2 Residual stress vs coating thickness

Interface Invalidation Behaviors. Bonding strength of coating-substrate is important precondition to evaluate coating quality and service life, and its interfacial bonding strength is separateed into two parts: bonding strength of the interface oneself (rupture toughness, elastic modulus and hardness or strength) and interface connection (thickness, shape, bonding strength). Coating resudial stress weaken combination strength of coating and ground material,and makes coating easily crack and fall off, shorten using life .It will produce shearing strength in interface ether tensile stress or pressure stress.coating will crack, warp or fall off when shearing strength bigger than accrete stress ofinterfance between coating and ground material .

Residual stress leading to coating invalidation has four kinds [6]: (1) delamination desquamation, it may happen under tensile stress or pressure stress. (2) tiny crack of surface or linking crack. it takes place expansion from its surface to interface, and leads to desquamate betwen coating and ground material. (3) spalling occurs in coating-substrate interface where exists tiny cracks or partial abruption when pressure stress of coating exceeds critical spalling stress, spalling will happen. (4) Interaction of spalling and delamination.When the interface takes place palling, because compressive residual stress is acted, the fringe zone may cause abruption of coating-substrate.

Effects of Resudial Stress on Bonding Strength. Coating resudial stess in one important factor to influnce on bonding strength of coating-substrate. When resudial sress of coating is bigger than its bonding strength, coating can not accrete substrate material. Bonding strength of coating-substrate is synthetical embodiment of resudial stess and bonding strength. Tensile stress of coating is shown, rupture surface are all combination interface of coating-substrate, and it does not appear inside of coating. It is indicated that bonding strength of coating inside (cohesion) is bigger than bonding strength of coating-substrate.

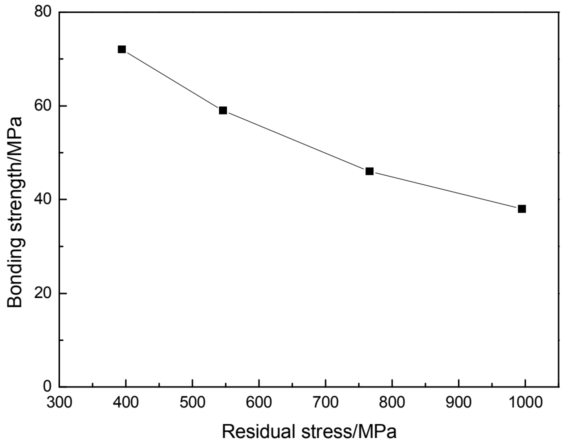


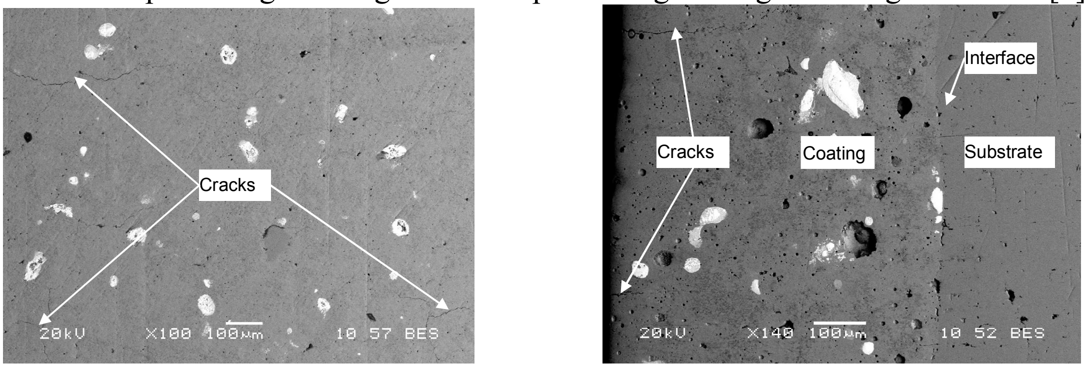
Fig.3 Coating thickness vs its bonding strength

The relations bewteen coating thickness and its bonding strengths are shown in Fig.3, bonding strength of the coating decreases with its thickness increase, bonding strength can be enhanced by minishing coating thickness. Resudial stress in coating is produced due to difference material physical characters of sprayinging material and substrate after spraying, resudial stress will increase with coating thickness, and the disfigurement probability will increase, which leads to debase its bonding strength. Thermal stress is main reason of coating cracks, and it has relationships with thermal performances of coating-substrate. Coating thermal stress is [7].

$$\sigma_T = \frac{E_c(\alpha_m - \alpha_c)\Delta T}{1 - v_c} \tag{2}$$

where E_c, v_c is elastic modulus and Poisson ration, respectively; α_m, α_c is thermal expansion coefficient of coating and substrate material, respectively; ΔT is the difference in temperature between the melting temperature of coating and room temperature.

In Fig.4, when the difference of temperature is same, thermal stress produced by heat has mainly relation with thermal expansion coefficient difference of coating-subatrate materials. When thermal expansion coefficient of coating is bigger, thermal wallop is bigger. Under thermal stress, coating surface easily produces micro-cracks (Fig.4 (a)). the melting layer produces bigger thermal stress, when thermal stress excesses rupture strength of WC coating, the cracks will produce on the coating surface. Micro-cracks will expand downwards under thermal stress action repeatly, finally form vertical tortoise cracks (Fig.4 (b)). Tortoise cracks fast expand easily, and forms cracks through the coating. When original cracks are formed, it would extend in the crossing direction, i.e. residual tensile stress is driving force of crossing-crack expansion. Therefore, the crease of tensile residual stress would avoid producing crossing-crack and preventing coating from original failure [9].



(a) Surface (b) Interface

Fig.4 Crack forms of WC coating by flame spraying and laser re-melting

The rupture mechanism of WC coating is correlated with its performances on substrate. Because the strain of coating rupture is smaller than that of substrate, crack is firstly occurred in the coating surface during flame spraying and laser remelting [9]. Under the situation of coating isotropy, crack is generally expanded perpendicular to flame spraying and laser remelting direction, the observed results are exactly like that (Fig.4 (a)). When crack expands to coating-substrate interface, such as Fig.4 (b) shown. There are two kinds of rupture forms as follows: (1) crack cuts across substrate expansion, which results in coating cuting off, its rupture is even slicing; (2) under horizontal stress σ_x or the interface shearing stress τ_{xy}, coating-substrate interface is cut, and results in coating rupture, and its rupture is stir type.

Conclusions

(1) Residual stresses of WC coating prepared by flame spraying and laser re-melting are expressed with tensile stress that increase with its thickness.

(2) Bonding strength of WC coating is inverse ratio with its residual stress, and reduces with its thickness increase.

(3) Residual stress of WC coating influences its cracking, tensile stress speeds its cracking that leads coating to peel off, expand and fail.

Acknowledgments

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References

[1] W.Y. Hu, H.R. Guan, X.F. Sun and et al.: Journal of Materials Engineering, Vol. 43 (1999), pp.3.

[2] B.S. Ying, Q.J. Gao and B.B. Dan: Surface Technology, Vol. 33 (2004), pp.15.

[3] H.Y. Li, H.L. Sun, N.S. Hu and et al.: Journal of Mechanical Strength, Vol. 21 (1999), pp.218.

[4] H. Zhao and B. Sun: Journal of Sichuan University, Vol. 39 (2007), pp.14.

[5] Q.B. Liu, J. Chen, C.S. Wang and et al.: Journal of Guizhou University of Technology, Vol. 30 (2001), pp.27.

[6] X.C. Zhang, B.S. Xu, H.D. Wang and et al.: Chinese Journal of Mechanical Engineering, Vol. 42 (2006), pp.18.

[7] L.P. Zhou, S.L. Li, D.Y. Li and et al.: Materials for Mechanical Engineering, Vol. 27 (2003), pp.48.

[8] S.J. Chu: Journal of Applied Sciences, Vol. 13 (1995), pp.74.

[9] C.Y. Tang, R.F. Chen, Z.X. Shen and et al.: Journal of Yangzhou University, Vol. 11 (2008), pp.52.