Study on Impact Wear Properties of the Surface Composites Reinforced by Particles

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Abstract. Six kinds of surface composite with different ingredients had been prepared on steel matrix by traditional cast processing. Impact wear properties of the prepared composites had also been studied by dynamic load abrasive wear testing machine with type of MLD-10. Results indicated the following four points. Firstly, composite layers on the casting bonded with matrix metallurgically. Secondly, hardness values of the composites increased firstly and then decreased gradually to the same value of the matrix in the direction perpendicular to the surface. Thirdly, the impact wear rate of the prepared composites decreased firstly and then increased with the increase of the high-carbon chromium iron content in reinforcements, reduced with the increase of the tungsten carbides content in reinforcements, enlarged firstly and then shrunk with the increased of impact energy. Finally, Wear mechanism of the prepared surface composites was mainly composed of plastic deformation and flaking off under the condition of impact wear.

Introduction

Impact wear refers that surface wear caused by dynamical intermittent contact and collision when one solid surface contact with another [1]. In all kinds of wear formats, impact wear damages materials most severely because of the present of impact force while wearing. At present, the researches about impact wear concentrate mainly on the impact wear under the condition of constant impact energy while the reports on impact wear under the condition of random impact energy is rare [2-4]. Many machine parts including vehicle hook for train, jaw plate for crasher, scraper blades for paper manufacturing machinery, and et al, bear impact load while working. Moreover, the magnitude of loads changes randomly due to the effect of many environment factors. Accordingly, impact wear properties of the materials at working condition of random loads are necessary to be researched. Surface composite is a compound material including surface strengthen layer and matrix. Particles and fibers are two common kinds of reinforced phase and particles are usually used as reinforcements for composite with metal matrix. Based on these reasons, six kinds of surface composite with different ingredients were prepared in this paper using tungsten carbide particles and high-carbon chromium iron particles as reinforcements and cast steel with carbon content of about twenty five in mass percent as matrix. Furthermore, impact wear properties of these surface composites were studied under the working condition of vehicle hook for train for the purpose of providing theoretical foundation to prolong its service life.

Experimental Procedure

Preparation for Specimens

Test specimens were prepared by traditional foundry processing. The casting mould was made of sodium silicate bonded sand and solidified by blasting carbon dioxide. Cast steel with grade of ZG230-450 was used as matrix of surface composite. The main constituents of reinforcement included cast tungsten carbide particles which diameter ranged from 0.2mm to 0.256mm and high-carbon chromium iron particles which diameter were about 0.2mm.The rest reinforcements were iron powders. The ingredients of the reinforcements were shown in table 1. In additions, Sodium borate was used as fusion agent in order to improve the penetrating degree of reinforcement. Resin solution was used as a bonder to make all the reinforced particles become a whole integration. All the reinforcement, flux and bonder were bought form the market. At first, all the reinforced particles and fusion agent were mixed uniformly and were tuned into mush by bonder. And then the mushy reinforcement mixture was brushed in the special position of the mould and dried in a box-type furnace before pouring matrix metal into the mould. The coating thickness of the reinforcement mixture was about 3mm. The pouring protocol was shown in figure 1. There were four cavities in a casting mould. Bottom gating system was used in order to ensure that the molten metal filled the mould smoothly. The matrix metal liquid was poured into the mould at the temperature of about 1680 centigrade. The reinforcement coating was melted by the high temperature metal and bonded with the matrix after cooling. Thus, a composite layer was formed on the surface of matrix metal. In order to investigate the effect of ingredients of reinforcement on wear properties of surface composite, six kinds of specimens with different ratios of tungsten carbide to high-carbon chromium iron were prepared (listed in table 2). Finally, the specimens were cut into samples which length, width and height were 10mm, 10mm and 30mm respectively to detect their impact wear properties.

Table 1 Ingredients of the reinforcement particles

Name of materials	Casting tungsten carbide	High-carbon chromium iron	Iron powders
Main ingredients	W:95~96%; C:3.9%	Cr:59.7%; C:7.4%	Fe:98%; Mn:0.35%; Si:0.1%; C:0.05%; S:0.025%; P:0.025%

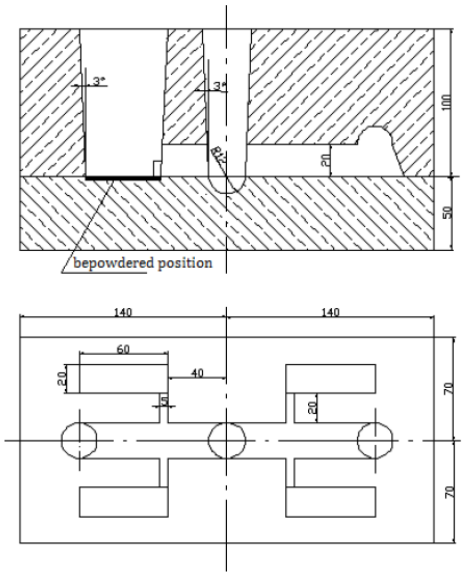

Figure 1 Sketch of cast processing

Table 2 Samples with different composition

Main reinforcement particles		numbers
Tungsten carbide content (%)	High-carbon chromium iron content (%)	
10	20	1#
	40	2#
	60	3#
20	20	4#
	40	5#
	60	6#

Impact Wear Experiment

It was supposed that the relationship between impact numbers and impact energy was accord with normal distribution curve and impact energy ranged from 1J to 4J. Two experiment stages, from 1J to 3J and from 2J to 4J, were taken out of the impact energy. In each stage, five experiment points which increased by degrees of 0.5J were extracted. That is, the extracted impact energy in the first stage were 1J, 1.5J, 2J, 2.5J and 3J while the same values in the second stage were 2J, 2.5J, 3J, 3.5J and 4J. The impact numbers corresponding to the extracted impact energy were calculated according to the normal distribution law and then impact time were calculated considering impact frequency and impact number. The calculated impact time were shown in Table 3. The impact wear experiments were conducted by a pin on ring dynamic load abrasive wear testing machine with type of MLD-10. The pin specimen installed in upper sample holder was a cubic cylinder made of prepared surface composite which size of length, width and height were 10mm, 10mm and 30mm respectively. While the ring specimen installed in lower axis was a circular ring made of cast steel ZG230-450 which inner and external diameters were 30mm and 50mm respectively. And the thickness of ring specimen was 20mm. Parameters for experimental machine were that the mass of impact hammer was 10kg and its drop height was 40mm and the spindle speed was 200r/min. Pre-wearing need to be carried to ensure the good conduct between pin and ring. Before and after each experiment, the specimen must be cleaned by alcohol and dried in the air firstly, and then weighted by an electronic balance with type of BS210 and accuracy of 0.0001g. Finally, the wear rates (wear loss in every minute) were calculated.

Table 3 Impact time corresponding to the impact energy

Impact energy(J)	1	1.5	2	2.5	3	2	2.5	3	3.5	4
Impact numbers	812	3639	6000	3639	812	812	3639	6000	3639	812
Impact time(min)	4	18	30	18	4	4	18	30	18	4

Results and Discussion

Microstructure of Surface Composite

The microstructures at different positions of surface composite were shown in figure 2. Figure 2(a) showed the interface between surface layer and matrix and it could be seen from this figure that the surface reinforced layer combined with matrix interlockingly at the interface. The reason for this phenomenon was that the reinforced particles were molten by matrix metal with high temperature and diffused in matrix. It was the mutual diffusion that formed transition region at the area around the interface. It was also indicated that the combination between surface layer and matrix belonged to metallurgical bonding. This combination could afford high interface strength. Figure 2(b) showed the microstructure of composite layer. In the figure, the white fish-bone structures were tungsten carbide in M_6C type while the black massive structures were chromium carbides in $M_{23}C_6$ type. X-ray diffraction result shown in figure 3 indicated that there also had some un-molten tungsten carbide particles in MC type in the surface layer. The matrix metal melted the reinforced particles when it was pouring into the mould. And then in the following cool stage the tungsten carbide in M_6C type and chromium carbides in $M_{23}C_6$ type were formed.

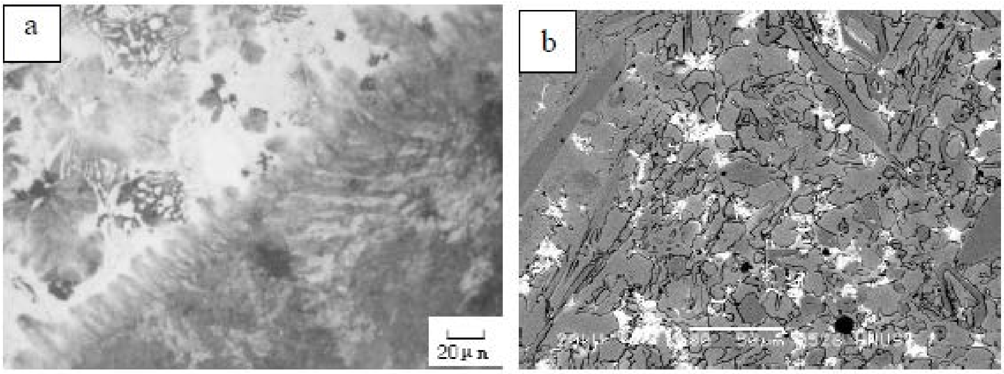

Figure2 Microstructures of the composite

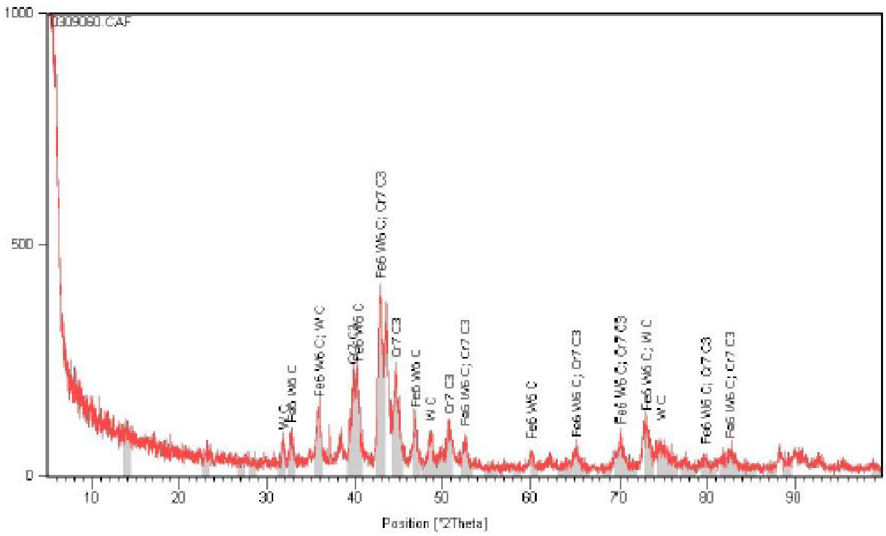

Figure 3 X-ray diffraction result of the composite

Hardness Distribution of Surface Composite

Figure 4 showed the microhardness of composite in the direction perpendicular to the surface detected by microhardness tester with type of MH-3. In the figure, the hardness values increased gradually in the distance from the surface to about 0.3mm depth. And then the hardness values kept its mean value of 1100 approximately in the distance between 0.3mm depth and about 32mm depth. After that the hardness values decreased gradually in the distance between 3.2mm depth and about 3.9mm depth. Finally, the hardness remained its value at about 150 which was the hardness value of matrix material. This phenomenon indicated that a harden layer which thickness was about 3mm had formed on the surface of the matrix. The reason for the low hardness values near the surface was that the metal at this position cooled quickly and so the reinforced particles were molten insufficiently. Foundry defects occurred easily at the surface was another reason for this phenomenon. The high hardness for middle region was due to the formation of tungsten carbides in type of M_6C and chromium carbides as well as the undissolved tungsten carbides in type of MC. These hard phases made the surface composite have high hardness through insetting in the matrix. The transition region in which hardness values decreased gradually reduced the hardness gradient from surface layer to matrix. This was benefit for improving the wear resistance of surface composite.

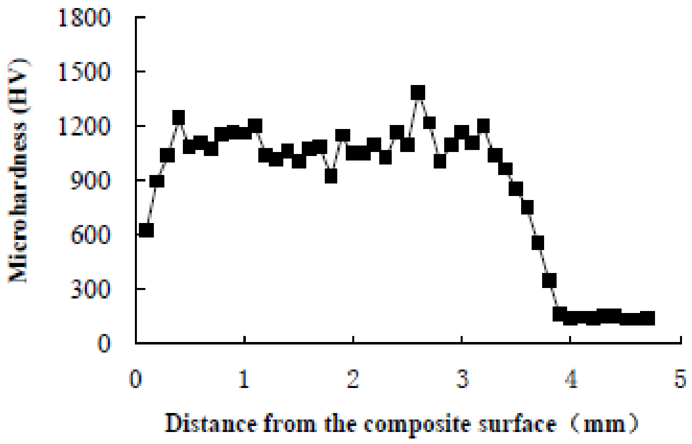

Figure 4 Microhardness distribution of the composite

Effect of high-carbon Chromium Iron Content on Impact Wear Properties

Figure 5 showed the mean wear rate of surface composite. It could be shown from the figure that the wear rate decreased firstly and then increased with the increase of high-carbon chromium iron content in reinforcement. And the wear rate of samples with 40% high-carbon chromium iron content was highest when the tungsten carbide content was both 10% and 20%. This was due to that chromium was a strong carbide-forming element and so the number of chromium carbide increased with the increase of high chromium content when the content of tungsten carbide was constant. All the carbides were hard and brittle phases in the metal materials. A reasonable quantity of this phase could improve the strength and wear resistance of materials and so made the wear rate decrease. But an excess quantity of the carbide could make the brittleness of materials increased significantly and so the carbides was easy to split into fragments or flake off from the surface of the samples when the samples were applied impact loads[5].

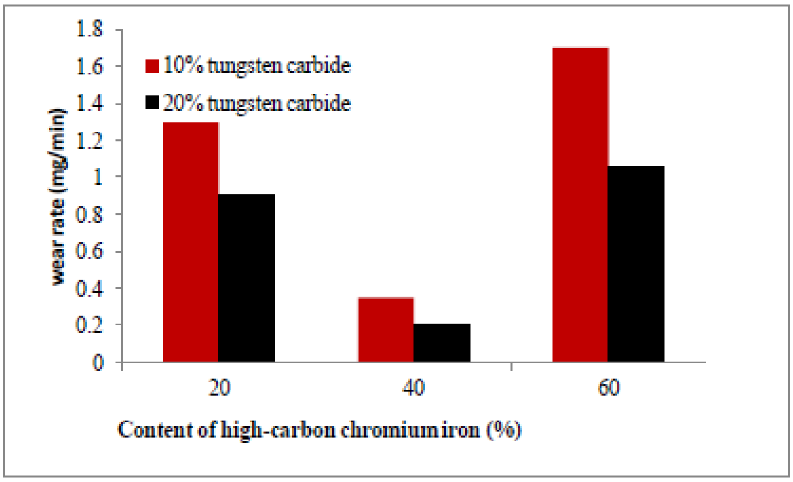

Figure 5 Mean wear rate of surface composites

Effect of Tungsten Carbide Content on Impact Wear Properties

In figure 5, the mean wear rate of the samples with 20% tungsten carbide was obviously lower than that of the samples with 10% tungsten carbide when the high-carbon chromium iron content in reinforcements was constant. That is to say that the wear resistance increased with the increase of tungsten carbide content. This was due to that tungsten carbide was an ultrahigh hard material. New microstructures might be formed when this material was added into steels. If the new microstructures distributed in the steel matrix evenly and dispersedly, the hardness of matrix would be highly improved. Therefore, the hardness of the surface composite prepared in the experiment was improved substantially by both the newly formed carbides ($M_{23}C_6$) and the dissolved carbide (MC) added into steel primarily. The high hardness made the wear rate of the composite decreased. In other words, the wear resistance of the composite had been improved.

Effect of Impact Energy on Impact Wear Properties

Figure 6 showed the relationship between impact energy and wear rate of the specimens. In the figure, wear rate of the surface composite decreased firstly and then increased. This was due to that the shadowing effect was a dominant factor in early stage while the flake off of carbides was a leading factor in later stage. When the impact energy applied to specimen was low, matrix produced plastic deformation prior to carbides and so the projecting carbides endured the load and protected the matrix from wearing [6]. But when the impact energy applied to specimen was high, the brittle carbide split into fragments and then flake off from the matrix. Thus the wear rate increased with the increase of the impact energy.

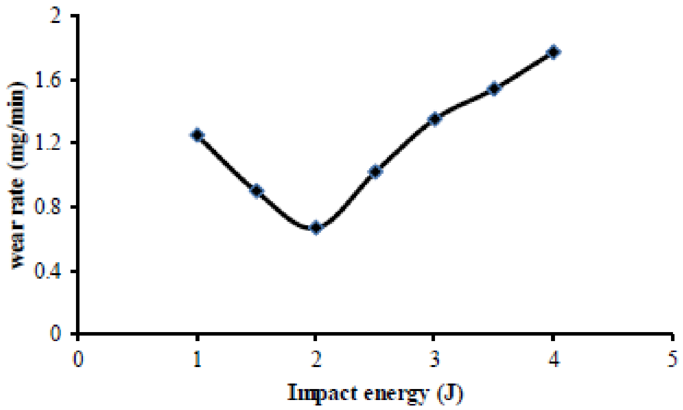

Figure 6 Relationship between wear rate and impact energy

Analysis for Impact Wear Mechanism of Surface Composite

The scan electron microscope photographs of composites with different reinforcement content were shown in figure 7. It could be seen from this figure that the wear mechanism of composite consisted mainly of plastic deformation shown in 7(a), flaking off shown in 7(b) and massive spalling shown in 7(c). In early stage of the experiment, specimen yielded plastic deformation under the action of impact loads. Microcracks would be formed in the subsurface of the specimen when the plastic deformation accumulated to a certain extent. These microcracks would expand automatically after their formation and connected with other microcracks. Macroscopic crack parallel to the surface of the specimen would be formed if a number of microcracks connected each other. Abrasive grains would occur and flake off from the surface of the specimen when the size of microcracks extent to a critical value [7]. Holes would present in the surface due do the exfoliation deviating from the surface. As illustrated above, wear mechanism of the surface composites used in the experiment were mainly composite of plastic deformation and flaking off.

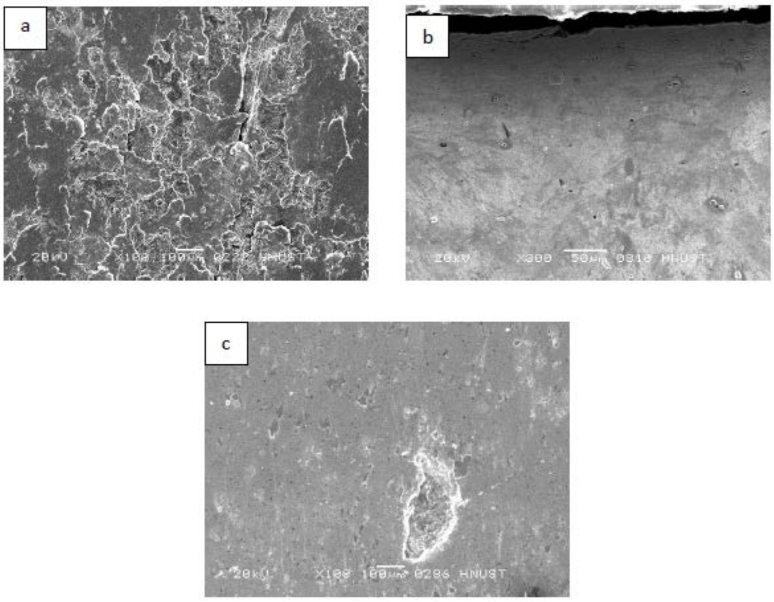

Figure 7 Surface appearances of wear surfaces

Conclusions

Four conclusions can be drawn from the study as follows:

(1) Steel matrix surface composites with different constituents had been prepared by traditional cast processing and the composite layer bonded with matrix metallurgically.

(2) Hardness values of the composites increased firstly and then decreased gradually to the same values of the matrix in the direction perpendicular to the surface.

(3) the impact wear rate of the prepared composites decreased firstly and then increased with the increase of the high-chromium cast iron content in reinforcements, reduced with the increase of the tungsten carbides content in reinforcements, enlarged firstly and then shrunk with the increased of impact energy.

(4) Wear mechanism of the prepared surface composites was mainly composed of plastic deformation and flaking off under the condition of impact wear.

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References

[1]Rabinowicz, E. K., ‘Impact wear of ductile metals’, Proc. Int. conf. on ‘Tribology Conference’, Tokyo, Japan, pp. 263-268, 1985.

[2]Cheng, J. Q., Research on carburized characteristic and impact wear properties of Meta bainite steel, Mater. Mech. Eng., 3, pp. 22-24, 1998.

[3]Ootani, T., Yahata, N., and Fujiki, A., Impact Wear Characteristics of Engine Valve and Valve Seat Materials at High Temperature, Wear, 188, pp. 175-184, 1995.

[4]Li, X. M., and Li, J. Q., Hardening behaviors analysis for brush-plating coating under the action of impact loads, J. Gansu Univ. Tech., 2, pp. 20-24, 1998.

[5]Li, J. M., Wear-resistant and anti-friction materials, China Machine Press, Beijing, 1987.

[6]Jia L. X., Effect of Compositions of Penetrating Agents on the Microstructure of Tungsten-Chromium Surface Composite, Adv. Mater. Res., 634-648, pp1906-1909, 2013.

[7]He, J. A., and Wang, Y. W., Wear of materials and wear-resistant materials, Shenyang, NEU Univ. Press, 2001.