

Abrasive Wear Comparison of Cr₃C₂/Ni₃Al Composite and Stellite 12 Alloy Cladding

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Abstract: The room-temperature abrasive wear resistance of Cr₃C₂/Ni₃Al composite and Stellite12 alloy cladding was investigated. Three kinds of tests, designed for different load and abrasive' size, were utilized to understand the wear behaviour of these materials. Under all three wear conditions, the abrasion resistance of Cr₃C₂/Ni₃Al composite cladding is much higher than Stellite12 alloy. In addition, the wear-resistant advantage of Cr₃C₂/Ni₃Al composite is more obvious when the size of the abrasive is small. The relative wear resistance of Cr₃C₂/Ni₃Al composite increases from 2.44 times to 6 times when the size of the abrasive decreases from 180μm to 50μm. The good wear resistance of Cr₃C₂/Ni₃Al composite cladding can be mainly attributed to the high hardness, large volume fraction of reinforcement, large reinforcement particles, and size distribution of reinforcement.

Key words: Ni₃Al, Stellite12, chromium carbide, composity, abrasive wear

1. Introduction

Nickel aluminide (Ni₃Al) possesses superior oxidation and carburization resistances due to the formation of protective Al₂O₃ films, and interesting mechanical properties due to their ordered crystal structures. Furthermore, the high strength and work hardening ability of these alloys mean that they can perform well in a variety of wear environments. A number of laboratory studies have indicated that Ni₃Al alloys have significant potential in critical wear applications^[1-3]. In addition, Ni₃Al is an excellent candidate for the matrix for intermetallic matrix composites. The slowed diffusion of the ordered lattice may reduce the formation and /or growth of any matrix/reinforcement reaction. Since the useful life of a metal matrix composite is limited by this reaction, the slowed diffusion of the intermetallic matrix may increase the life and/or operating temperature of the composites^[4].

Metal matrix composites containing a high volume fraction of carbide, nitride, boride, or oxide particles are frequently the materials of choice for

applications that require good wear resistance^[5-7]. For high temperature service in air, oxidation resistance and hot hardness of hard particle are the most important factors. Of course hard oxide particles such as Al₂O₃ or Y₂O₃ would not be affected by oxygen, but their bond to metal matrix is inferior to that of metal carbides^[5]. In metal carbides, chromium carbide is the most suitable for adding in metal matrix as hard particles for their very high hot hardness, excellent oxidation resistance and good wetting ability with metal matrix^[8].

Surface modification techniques, which are regarded as effective methods to improve the wear resistance of materials, have been successfully applied to enhance the ability of components to resist the wear damage in recent years^[9-10]. With the characteristics of Ni₃Al and chromium carbide, it is expected that the formation of chromium carbide reinforced Ni₃Al matrix composite cladding would improve the wear resistance of the workpieces. This paper reports the investigations of the room-temperature abrasive wear resistance of this composite cladding. Stellite 12 alloy, the conventional high temperature wear resistant

materials, was chosen to compare with the composite for similar application with the composite.

2. Experimental Procedure

A new producing method has been designed to fabricate chromium carbide reinforced Ni₃Al matrix composite. Firstly, a Ni-Al-Cr₃C₂ welding wire was fabricated by metal-powder-core technique. The advantage of this technique is easy to produce wires in large scale. In this approach, elemental powders and carbide powders of the correct composition are filled in a nickel strip and sealed and compacted by drawing through a set of dies. Before filling powders, Cr₃C₂, Al, and BFe powders were mixed together with appropriate amounts (see table1). The particle diameter of all powders is about 200 μ m. Secondly, the welding wires were welded on a nickel base superalloy DZ125 surface by the manual gas-tungsten arc (GTA) welding. Under the effect of the physical heat of arc, Ni reacted with Al to form Ni₃Al. Cr₃C₂ was dissolved during welding. Most of [Cr] and [C] reacted to form chromium-riched M₃C₂ or M₇C₃ phases except that a few dissolved into Ni₃Al matrix. As a result, chromium carbide particles reinforced Ni₃Al matrix composite was formed at welding layers^[11-12]. Stellite 12 alloy wires were also welded on DZ125 alloy surface by GTA welding for abrasive wear test comparison with Ni₃Al matrix composite.

The pin-on-disk test was employed to determine the abrasion resistance of the composite and stellite12 alloy. The pins with 6mm diameter machined from welded layers were abraded on Al₂O₃ paper under a certain load. The thickness of the clad layers was 6mm. The rotational speed of disk is 60rpm. The run track of pins is spirality and linear speed is unconstant. Each test was run for distance of 16.4m. The present experiment was designed as three tests to evaluate the effect of load and abrasive' size on the wear resistance of two materials cladding, as shown in Table 2. After each test, the weight loss of the sample was measured

Table1 Chemical composition of Ni-Al-Cr₃C₂ welding wire

	Cr ₃ C ₂	Al	BFe	Ni
wt%	25	10	0.1	74.5

Table 2 Wear conditions designed in this experiment

Number of test	I	II	III
Load/kg	3.7	3.7	4.8
Abrasive' size / μ m	50	180	180

then the results of the wear tests, averaged from three data points obtained, were calculated as a relative wear resistance with follow equation:

$$\varepsilon_w = \Delta W_s / \Delta W_t$$

ΔW_s: Weight loss of Stellite 12 alloy

ΔW_t: Weight loss of testing samples

The microstructure and worn surfaces of clad layers were observed by scanning electron microscopy (SEM).

3. Results and Discussion

The surface microstructure of Ni₃Al matrix composite cladding (see Fig.1a) shows that Cr₃C₂ particles with various sizes are dispersed in Ni₃Al matrix uniformly. The size of larger ones is about 30μm and the size of smaller ones is about 2μm. The microstructure of the stellite 12 cladding (see Fig.1b) shows a typical uniform equaxed to columnar dendritic microstructure. The dark area between the dendrite arm spacing consists mainly of eutectoid with higher Cr, W and Si content and chromium-riched M₇C₃ carbide precipitates. The average size of M₇C₃ particle is smaller than 5 μ m. Fig.2 illustrates abrasive wear comparison of the Cr₃C₂/Ni₃Al composite and Stellite12. The results demonstrated that

1) Under all three testing conditions, the wear resistance of Cr₃C₂/Ni₃Al composite is much better than that of stellite12. The relative wear resistance of Cr₃C₂/Ni₃Al composite is 2.44~6 times higher than that of stellite 12 alloy.

2) Larger abrasive particles and higher load resulted in more wear for both two materials. Especially, the size of the abrasive affected wear resistance of two materials more seriously. In addition, the wear-resistant advantage of Cr₃C₂/Ni₃Al composite is more obvious when the size of the abrasive is small. The relative wear resistance of Cr₃C₂/Ni₃Al composite increases from 2.44 times to 6 times when the size of

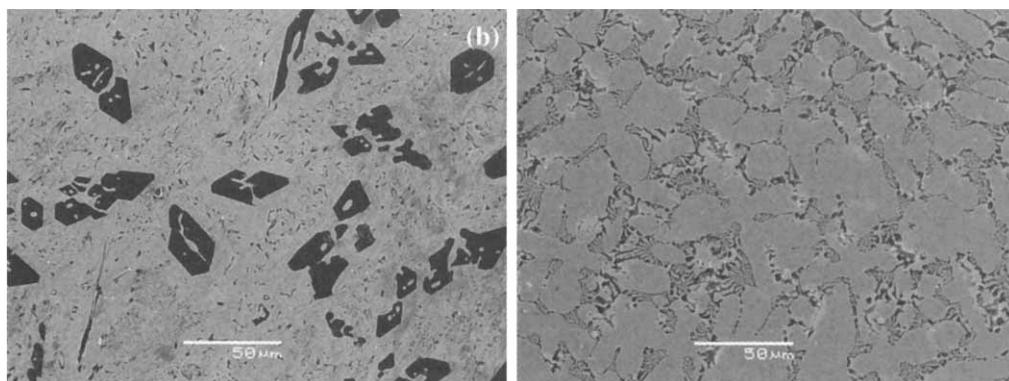


Fig.1 Surface microstructure of two clad layers (a) $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite, (b) Stellite 12

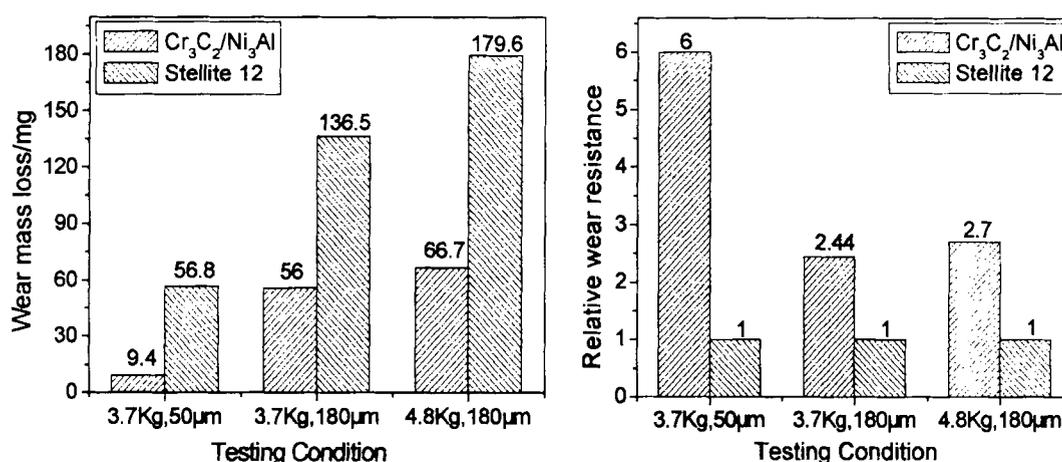


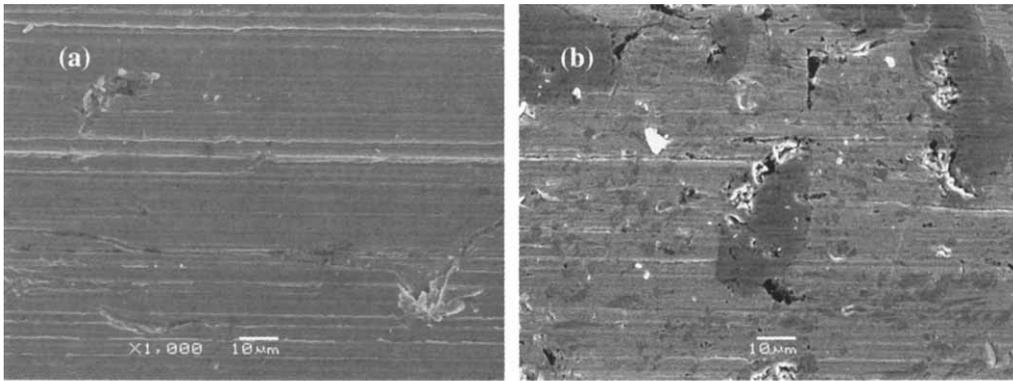
Fig.2 Abrasive wear comparison of $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite and Stellite 12 under different testing conditions (a) wear mass loss (b) relative wear resistance

the abrasive decreases from 180 μm to 50 μm .

The room-temperature hardness of abrasive particle Al_2O_3 is HV2070 that is higher than that of both $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite (HRC52) and Stellite 12 alloy (HRC47). So, this wear test belongs to hard two-body abrasive wear. Damage and material removal occur as a result of plowing and cutting of the material surface. The worn surface of the two materials under different testing conditions, as shown in Fig.3 and Fig.4, is different apparently. The wear scars of Stellite 12 alloy cladding are very deep, more defined and continuous. The chromium-riched M_7C_3 particles were all ploughed out. Otherwise, the wear scars of $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite cladding are much shallower and discontinuous. The major portion of the Cr_3C_2 particles was not extracted from the matrix even if suffers large abrasive abrading. The good wear resistance of $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite cladding can be

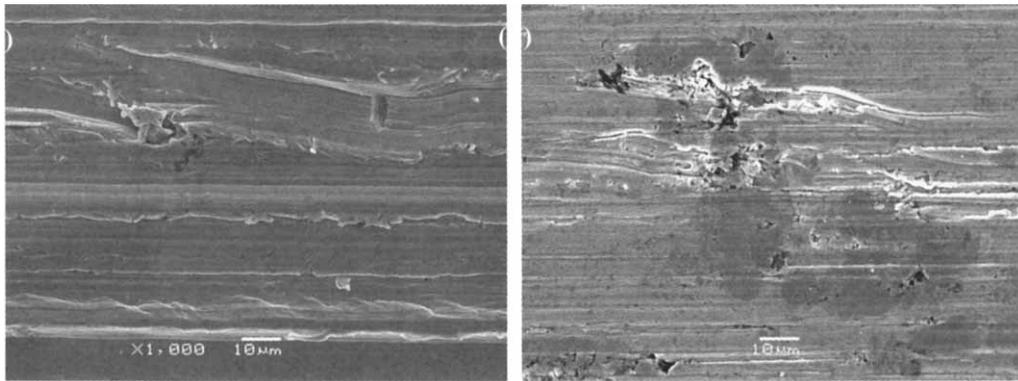
mainly attributed to the high hardness, large volume fraction of reinforcement, large reinforcement particles, and size distribution of reinforcement.

The $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite and stellite 12 alloy are multiphase materials formed of a metallic matrix reinforced by a dispersion of hard particles. For these materials, it is known that the hard reinforcement mainly bears the wearing force, while the matrix binds the reinforcement, accommodates deformation and absorbs impact energy, thus reducing the probability of reinforcement fracture. A proper combination of hardness and ductility/toughness should result in higher resistance to wear. Many experimental studies have showed that there must be an optimal volume fraction of the reinforcement, which provides the optimal balance between hardness and ductility^[13-14]. When the volume fraction of reinforcement exceeds the critical value, the material becomes brittle and



(a)Stellite12,(b) $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$

Fig.3 Worn surface of two materials under No. I testing conditions



(a)Stellite12,(b) $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$

Fig.4 Worn surface of two materials under No. II testing conditions

fracture more easily, leading to a decrease in the wear resistance. However, if the volume fraction of reinforcement is smaller than the critical value, there are not enough hard particles in the matrix to withstand the wearing force. As a result, the wear resistance would also be low. For different multiphase materials, the critical volume fraction may vary. 30%~35% was considered as the critical volume fraction for most of multiphase materials^[15]. Previous work has reported that the volume fraction of carbides of stellite 12 is about 18%^[16]. Compared with stellite 12 alloy, $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$ composite has a larger volume fraction of carbides (about 22%). The volume fraction of these materials should be lower than their critical volume fraction. So, the larger volume fraction of carbides results in higher hardness and better wear resistance.

The room-temperature hardness of $\text{Cr}_3\text{C}_2/\text{Ni}_3\text{Al}$

composite cladding is HRC52, which is higher than that of Stellite 12 alloy (HRC47). Hardness of a multiphase material determines the penetration depth of abrasive particles, and therefore an increase in hardness of composite could reduce abrasive wear^[15].

The size of reinforcement particles can influence the wear behaviour of a composite. As suggested, larger reinforcing particles are more effective in protecting the matrix and the corresponding total interfacial area is smaller, which may help to reduce the probability of interfacial failure between the matrix and the reinforcement. A composite reinforced by larger particles may require a higher load to develop cracks and delaminate a substrate layer^[17]. For a composite reinforced by homogeneously dispersed small reinforcement particles, the small particles are easier to plough out, which might act as abrasive to further

increase the abrasion rate^[18]. In addition, small reinforcement particles have relatively larger total interfacial area, which could lead to a higher probability of interfacial failure. Compared with Stellite 12 alloy cladding, the wear scars of Cr₃C₂/Ni₃Al composite cladding are much shallower and discontinuous, which can be mainly attributed to larger size of the reinforcement particles. The coarse carbides particles can lower the volume wear rate by dislodging the abrasive particles from the paper.

In addition to those factors, the size distribution of reinforcement particles in Cr₃C₂/Ni₃Al composite may also largely influence wear. The larger particles mainly withstand the wearing force and the small dispersed particles preferentially strengthen the matrix so that it would be more difficult for the abrasive to abrade the relatively softer matrix. Since the average mechanical properties of the matrix can be adjusted by adding small dispersed particles, an optimal balance between the overall hardness and ductility could be achieved, thus resulting in superior tribological properties^[15].

4. Conclusions

(1) The pin-abrasion wear test showed that the abrasion resistance of Cr₃C₂/Ni₃Al composite cladding is much higher than Stellite12 alloy at room temperature. In addition, the wear-resistant advantage of Cr₃C₂/Ni₃Al composite is more obvious when the size of the abrasive is small. The relative wear resistance of Cr₃C₂/Ni₃Al composite increases from 2.44 times to 6 times when the size of the abrasive decreases from 180μm to 50μm.

(2) The worn surface of the two materials under different testing conditions was different apparently. The wear scars of Stellite12 alloy are very deep, more defined and continuous. The chromium-riched M₇C₃ particles were all ploughed out. Otherwise, the wear scars of Cr₃C₂/Ni₃Al composite cladding are much shallower and discontinuous. The major portion of the Cr₃C₂ particles is not extracted from the matrix even if suffers large abrasive abrading.

(3) The good wear resistance of Cr₃C₂/Ni₃Al composite cladding can be mainly attributed to the high hardness, large volume fraction of reinforcement, large

reinforcement particles, and size distribution of reinforcement.

References:

- [1] V.K.Sikka, S.C.Deevi, S.Viswanathan, et al. Advances in Processing of Ni3Al-Matrix Intermetallics and Applications[J]. Intermetallics, 2000, 8:1329-1337.
- [2] P.J.Blau, C.E.Devore. Sliding behavior of alumina/nickel and alumina/nickel aluminide couples at room and elevated temperature [J]. Journal of Tribology, 1988, 110: 646-652.
- [3] Peter J. Blau, Charles E. Devore. Sliding Friction and Wear Behavior of Several Nickel Aluminide Alloys Under Dry and Lubricated Conditions[J]. Tribology International, 1990, 23(4): 226-234.
- [4] G.E.Fuchs. Development of Ni-Aluminide based composites for elevated temperature applications[C]. Metal & ceramic matrix composites: Processing ,Modeling & Mechanical Behavior. Edited by R.B.Bhagat, A.H.Clauer, P.Kumar and A.M.Ritter, The Minerals, Metals & Materials Society, 1990:391-400.
- [5] Hans Berns, Stefan Koach. High temperature sliding abrasion of a nickel-base alloy and composite [J]. Wear, 1999, 225-229: 154-162.
- [6] Ö.N. Dogan, J.A.Hawk, J.H.Tylczak, et al. Wear of titanium carbide reinforced metal matrix composite[J]. Wear, 1999, 225-229: 758-769
- [7] R.Colaco, R.Vilar. Abrasive wear of metallic matrix reinforced materials [J]. Wear, 2003, 255: 643-650.
- [8] Compilatory group of machine-producing technology and material(Ed.). Handbook of machine-producing technology and material (second part)[M], Machine Industry Press, 1993: 674.
- [9] Da-Wei Zhang, T.C.Lei. The microstructure and erosive-corrosive wear performance of laser-clad Ni-Cr3C2 composite coating [J]. Wear, 2003, 255: 129-133.
- [10] W. Pang, H.C.Man, T.M.Yue. Laser surface coating of Mo-WC metal matrix composite on Ti6Al4V alloy[J]. Matter.Sci.Eng.A, 2005, 390:144-153.
- [11] Li Shangping, Feng Di, Luo Heli et al. Solution and Precipitation of Chromium Carbide During the Fabricated Process of Cr7C3/Ni3Al Composite[J]. Acta Materiae Compositae Sinica, 2005, 22(4): 53-57.

- [12] Shangping Li, Di Feng, Heli Luo. Microstructure and abrasive wear performance of chromium carbide reinforced Ni3Al matrix composite coating[J]. *Surface & Coating Technology*, 2007, 201:4542-4546.
- [13] A.P.Sannino, H.J.Rack. Dry sliding wear of discontinuously reinforced aluminum composites:review and discussion[J]. *Wear*,1995, 189:1-19.
- [14] K.H.Zum Gahr. How microstructure affects abrasive wear-resistance. *Matal.Prog.*[J],1979,116(4):46-52.
- [15] J.Hu,D. Y.Li ,R.Llewellyn. Computational Investigation of Microstructural Effects on Abrasive Wear of Composite Materials[J]. *Wear*, 2005, 259: 6-17.
- [16] K.C.Antony. Wear-resistant cobalt-base alloys[J]. *Journal of Metals*, 1983, 2:52-60.
- [17] Z.F. Zhang, L.C. Zhang, Y.W. Mai, Wear of ceramic particlereinforced metal–matrix composites[J]. *J. Mater. Sci.*, 1995, 30:1961–1966.
- [18] O. Yilmaz, S. Buytoz, Abrasive wear of Al2O3-reinforced aluminium-based MMCs[J]. *Compos. Sci. Technol.*, 2001, 61: 2381–2392.