University of Groningen

Tribological behaviour of laser-clad TiCp composite coating

Ouyang, J.H.; Pei, Y.T.; Lei, T.C.; Zhou, Y.

Published in:
Wear

DOI:
[10.1016/0043-1648\(95\)06604-7](https://doi.org/10.1016/0043-1648(95)06604-7)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1995

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Ouyang, J. H., Pei, Y. T., Lei, T. C., & Zhou, Y. (1995). Tribological behaviour of laser-clad TiCp composite coating. *Wear*, 185(1), 167-172. [https://doi.org/10.1016/0043-1648\(95\)06604-7](https://doi.org/10.1016/0043-1648(95)06604-7)

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Tribological behaviour of laser-clad TiC_p composite coating

J.H. Ouyang *, Y.T. Pei, T.C. Lei, Y. Zhou

Department of Metals and Technology, Harbin Institute of Technology, Harbin 150001, P.R. China

Received 18 May 1994; accepted 26 January 1995

Abstract

The wear behaviour of laser-clad TiC–Ni alloy coatings was studied by X-ray diffraction, scanning electron microscopy, transmission electron microscopy and pin-on-ring friction and wear tests. TiC particles can act as hard barriers to resist the scoring and plastic deformation of the matrix and then delay the occurrence of delamination without distinctly increasing the friction coefficient of the coatings. The degree of wear depends mainly on the extent of debonding and removal of TiC particles. With increasing normal load, mild scratching with fine grooves, oxidative wear with a thin layer of Ni₂O₃ film, delamination wear with serious plastic deformation and regular scale-like features were observed on the worn surfaces of coatings corresponding to various wear conditions. The softening and local melting of worn surface layers caused by friction heat produces a crushed crystalline or amorphous structure.

1. Introduction

Laser cladding of carbide-reinforced coatings on cheap metals or alloys successfully combines the high hardness, wear resistance and good high-temperature stability of ceramic phases with the good ductility of metal materials and has therefore created a new kind of wear-resistant composite coating [1–4]. Ayers [5,6] reported that Ti–6Al–4V (wt.%) alloy injected with 30–50 vol.% TiC has a hardness of 450 HV; its coefficient of friction decreases with increasing TiC content, reaching a minimum at 50 vol.% TiC. The enhanced wear resistance is mainly attributed to the undissolved TiC particles. However, testing of a TiC-reinforced aluminum alloy sample in a sliding wear condition showed less promising results than were found for Ti–TiC composites [7]. In the present paper, the wear mechanism of a TiC–Ni alloy composite coating was studied using a dry sliding friction and wear testing machine.

2. Experimental procedure

Commercial steel 1045 was used as the substrate and a mixture of 30 vol.% TiC particulates and 70 vol.% Ni–alloy powders was used as the coating material. The chemical composition of Ni–alloy powder with an average size of 40 µm

is (wt.%) 15.0 Cr, 4.0 B, 5.8 Si, 0.73 C and 12.3 Fe, and its geometry appears to be spherical, whereas TiC particulates less than 4 µm in size show an irregular shape. The thickness of the preplaced mixture is 0.5 mm. A 2 kW CO₂ laser was employed to produce the coating under the condition of 1000 W laser power, 3 mm beam diameter and 6 mm s^{−1} traverse speed. Argon was used to shroud the molten pool from the outside atmosphere. Wear test was carried out without lubrication at room temperature using a pin-on-ring friction and wear testing machine. The ring of wear couple was made of hard alloy (WC–8%Co) with a hardness of HRA89. The wear conditions were given as 50–110 N normal load, 1.06–2.29 m s^{−1} sliding speed, and 90–330 m sliding distance. The coefficient of friction was calculated using the equation

$$\mu = \frac{2M_f L}{D \sum Q_i L_i}$$

where M_f is the moment of torsion measured using a PY1-type moment–speed gauge, L is the pin arm, D is the diameter of the ring and $\sum Q_i L_i$ is the sum of parallel moment loaded on the lever. A Phillips CM-12 type transmission electron microscope was used to examine the structure of coatings and worn surfaces. And the morphology of worn surface was examined by using a S-570 scanning electron microscope and the phase analysis of these surfaces was performed using a D/MAX-RB type X-ray diffractometer with Cu K α radiation.

* Corresponding author.

3. Results

3.1. Microstructure of the coatings

Microstructural characteristics of TiC–Ni alloy coatings are shown in Fig. 1. The coating consists of fine TiC particles, γ -Ni primary dendrites and a eutectic composed of γ -Ni plus $(\text{Fe,Cr})_{23}(\text{C,B})_6$ in the interdendritic regions. High dislocation density can be seen in the γ -Ni primary dendrites, especially around the TiC particles (Fig. 1(b)). The morphology of eutectics in the interdendritic areas is shown in Fig. 1(c).

3.2. Wear volume and wear rate of the coatings

The wear volume and wear rate of Ni and TiC–Ni alloy coatings, shown in Fig. 2, indicate a significantly enhanced wear resistance caused by the addition of TiC particles. Within the normal load range used in this study, the TiC–Ni alloy coating gives much less increase in wear volume and wear rate with increasing sliding speed compared with the single Ni–alloy coating. It can also be seen that sliding speed

has a more distinct effect on the wear rate of pin samples than the normal load.

The friction coefficient of the clads is given in Fig. 3. The two coatings have a much lower friction coefficient (0.25–0.3) than that of the steel substrate (0.75). With increasing sliding distance, the friction coefficient of the substrate undergoes a slight increase while that of the coatings undergoes a slight decrease. These two friction coefficients decrease with increasing normal load and become very close when the normal load is higher than 90 N (Fig. 4). When increasing the sliding speed, no distinct change in friction coefficient is produced (Fig. 5). This reduction in friction coefficient with increase in load, rather than with increase in speed, is probably dependent on the degree of contact between the Ni–alloy matrix and wear couple ring, and on the self-lubrication ability of the coatings.

Morphology of the worn surface for the two kinds of coating is shown in Fig. 6. It indicates only a mild wear with fine scratchings for the TiC–Ni alloy coating and a severe adhesive wear with a scale-like feature for the Ni–alloy coating caused by extensive shear. This indicates that the TiC–Ni alloy coating possesses a much higher resistance against plas-

Fig. 1. Microstructure of TiC-reinforced coating. (a) Clad layer (SEM); (b) TiCp in γ -Ni primary dendrite (TEM); (c) eutectic in interdendritic area (TEM).

Fig. 2. Wear volume of (a) Ni-alloy coating and (b) TiC-reinforced coating pin specimens ($L=90$ m). Wear rate of (c) Ni-alloy coating and (d) TiC-reinforced coating pin specimens ($L=90$ m).

Fig. 3. Friction coefficient of the clads ($P = 70$ N, $V = 1.47$ m s⁻¹, $L = 90$ m).

Fig. 4. Friction coefficient vs normal load ($V = 1.47$ m s⁻¹, $L = 90$ m).

Fig. 5. Friction coefficient vs sliding speed ($P = 70$ N, $L = 90$ m).

tic deformation and scoring. As a result, an enhanced resistance against plastic erasing and removal of the edges of grooves during subsequent passes is observed. Fig. 7(a) shows the function of TiC particles at earlier stages of the wear process ($L = 90$ m). The TiC particles can serve as hard barriers which interrupt the scratching or convert the path of scoring. When the sliding distance is increased to $L = 270$ m (Fig. 7(b)), the delamination mechanism of wear appears and microcracks originate next to the existing defects or to

the drastic plastic deformation zones in the sub-surface layers. As shown in Fig. 7(b), a TiC particle restrains the deformation of the ductile matrix and causes a pile up of the latter near the particles in the wearing direction and thus decreases the wear rate of the coating.

The worn surfaces of TiC-reinforced coatings subjected to various wear conditions are shown in Fig. 8. For a given sliding speed $V = 1.88$ m s⁻¹, when normal load is low, a smoother worn surface with mild scratchings is found (Fig. 8(a)). With increasing normal load above 70 N, oxidative wear with a thin film of Ni₂O₃ examined by X-ray diffractometer occurs on the worn surface (Fig. 9). Discontinuous fine oxide debris can be found on the worn surface (Fig. 8(b)). With further increase of normal load to 110 N, adhesive wear with a scale-like morphology gives a major contribution to the removal of the clads (Fig. 8(c)). Longitudinal cross-sections of the sub-surface layers are shown in Fig. 10. A clear plastic deformation zone and a recrystallized zone caused by the friction heat are observed. TEM observation (Fig. 11) of worn surface layers of pin specimens indicates the presence of a crushed microstructure and/or amorphous phase in the surface layers as a result of local severe wear.

4. Discussion

The higher wear resistance of TiC–Ni alloy coating with respect to that of Ni alloy coating is attributed to high hardness ($HV_{0.2}1300$) and uniformly distributed TiC particles in the ductile matrix. Under mild wear condition, TiC particles can act as hard barriers to resist the plastic deformation of matrix and thus delay the nucleation and propagation of microcracks in the matrix. Only mild scratchings appear on the worn surface. When the normal load is increased to 70 N, the friction heat causes the appearance of the Ni₂O₃ film on the worn surface. The formation and thickening of oxides are in close relationship with the wear conditions. Oxidation can reduce the adhesion of the material, but can possibly introduce a certain abrasion component. In the later stages of wear, this may lead to the pulling out of reinforcing particles as an additional abrasives.

With further increasing, the normal load and sliding speed, a delamination mechanism of wear appears as shown in Fig. 12. During wear of pure Ni-alloy coating, plastic deformation causes dislocation piles-up in the sub-surface layers leading to the formation of microcracks and then delamination [8] (Fig. 12(a)). The incorporation of TiC particles enhances the resistance to plastic deformation and delays the occurrence of delamination. The microcracks within the composite coating nucleate around the TiC particles and propagate in the sub-surface layer (Fig. 12(b)) under the condition of 110 N normal load and 2.29 m s⁻¹ sliding speed. This is very similar to that observed in SiC_p-reinforced Al–Si alloy (A356) [9].

Under severe wear condition, the drastic friction produces a large amount of heat. Temperatures in the wear surface

Fig. 6. Morphology of worn surface ($P=70$ N, $V=1.47$ m s⁻¹): (a) TiC-reinforced coating; (b) Ni-alloy coating.

Fig. 7. SEM pictures showing the functions of TiC particles in the wear process ($P=70$ N, $V=1.88$ m s⁻¹): (a) $L=90$ m; (b) $L=270$ m.

Fig. 8. Morphology of worn surface of TiC-reinforced coating vs normal load ($V=1.88$ m s⁻¹, $L=90$ m): (a) $P=50$ N; (b) $P=90$ N; (c) $P=110$ N.

Fig. 9. XRD pattern on the worn surface of TiC-reinforced coating ($V = 1.88 \text{ m s}^{-1}$, $L = 90 \text{ m}$): (a) $P = 70 \text{ N}$; (b) $P = 90 \text{ N}$.

Fig. 10. Longitudinal cross-sections of worn surface layer of TiC-reinforced coating ($P = 90 \text{ N}$, $V = 1.88 \text{ m s}^{-1}$, $L = 90 \text{ m}$): (a) plastic deformation layer; (b) crushed crystalline layer.

Fig. 11. TEM observation of worn surface layer of TiC-reinforced coating subjected to various wear conditions ($V = 2.29 \text{ m s}^{-1}$, $L = 300 \text{ m}$): (a) $P = 50 \text{ N}$; (b) $P = 90 \text{ N}$; (c) $P = 110 \text{ N}$; (d) selected area electron diffraction patterns of (b); (e) selected area electron diffraction patterns of (c).

Fig. 12. Longitudinal cross-sections of worn surface layer of the coatings showing the propagation of micro-cracks and delamination (a) Ni-coating ($P = 70$ N, $V = 1.47$ m s⁻¹); (b) TiC-reinforced coating ($P = 90$ N, $V = 1.88$ m s⁻¹).

layer and near-surface layer will be also increased. Plastic deformation zone and recrystallized zone can also be found corresponding to the severe wear conditions (Figs. 10 and 11). Therefore, the processes of softening of surface layers and local melting of micro-areas can be expected. This local melting of the coating and its rapid cooling will lead to the formation of an amorphous structure on some worn surfaces. The indicated location E in TEM bright field image (Fig. 11(c)) shows a piece of material pulled up from the worn surface. Selected area diffraction patterns show clearly broad and diffuse rings concentrated around the centre.

5. Conclusions

- (1) TiC reinforced coating possesses a much higher wear resistance than a single Ni-alloy coating. The degree of wear for composite coating depends primarily on the extent of debonding and removal of TiC particles.
- (2) With increasing the normal load, mild scratching with fine grooves, oxidative wear with a thin Ni₂O₃ film and delamination mechanism of material with a scale-like feature are observed on the worn surface corresponding to the increase of severity of wearing conditions.
- (3) A crushed crystalline and an amorphous structure of materials caused by the softening and local melting of worn surface layers is observed in the surface layers under severe wear condition.

References

- [1] J.H. Abboud and D.R.F. West, *Mater. Sci. Tech.*, 5 (1989) 725–728.
- [2] K.P. Cooper, *J. Vac. Sci. Technol. A*, 4 (1986) 2857–2861.
- [3] P.A. Molian and L. Hualun, *Wear*, 130 (1989) 337–352.
- [4] W. Cerri and R. Martinella, *Surf. Coat. Technol.*, 49 (1991), 40–45.
- [5] J.D. Ayers, R.J. Schacfer and W.P. Robey, *J. Met.*, August (1981) 19–23.
- [6] J.D. Ayers and R.N. Bolster, *Wear*, 93 (1984), 193–205.
- [7] J.D. Ayers, *Wear*, 97 (1984) 249–266.
- [8] N.P. Shue, *Wear*, 44 (1977) 1–16.
- [9] A.T. Alpas and J. Zhang, *Wear*, 155 (1992) 83–104.