Wear 326-327 (2015) 36–43

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Research on the contributions of corrosion, erosion and synergy to the erosion–corrosion degradation of Ti(C,N)–based cermets

Weicai Wan, Ji Xiong*, Zhixing Guo, Limei Tang, Hao Du

School of Manufacturing Science and Engineering, Sichuan University, Chengdu 610065, PR China

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form
23 December 2014
Accepted 27 December 2014
Available online 3 January 2015

Keywords:
Slurry erosion
Corrosion-wear
Cermets
Surface analysis

ABSTRACT

In the paper, the contributions of corrosion, erosion and synergy to the erosion–corrosion degradation of Ti(C,N)–based cermets are investigated in the different slurry conditions, and respect to the synergistic effect, corrosion enhanced erosion and erosion enhanced corrosion are also quantified. The results indicate that the contributions of corrosion, erosion and synergy to the erosion–corrosion degradation of Ti(C,N)–Ni cermets are strongly environment dependent. With increasing the environmental corrosivity, the contributions of corrosion and synergy are enhanced, and the erosion role in erosion–corrosion is strengthened significantly with the increased erosion severity. With the increased time, the erosion role is increased and the corrosion role is decreased in the erosion–corrosion conditions. Corrosion enhanced erosion and erosion enhanced corrosion have both increased with the increased time, however the increment of corrosion enhanced erosion is much more than that of erosion enhanced corrosion. Corrosion enhanced erosion is more significant than erosion enhanced corrosion, and corrosion enhanced erosion plays a dominant role in the synergy.

1. Introduction

In recent years, Ti(C,N)–based cermets are successfully introduced into the erosion–corrosion resistance operations and are considered as an alternative to WC–Co cemented carbides because of the excellent properties and relatively low production cost [1–7]. In common Ti(C,N)–Mo_2C–Ni cermet, Ti(C,N) supply the high hardness of the material, and metal Ni makes the cermet has a moderate toughness, and role of Mo_2C is to improve the wettability between Ni and Ti(C,N) and enhance the mechanical properties. Compared to Co, because of better corrosion resistance, Ni is usually used to be binder in the cermet which is applied in the corrosive conditions.

Erosion–corrosion degradation of materials and machine parts is widely encountered in numerous industries and applications, such as the petroleum production and refinery, chemical engineering, mining, marine pumping and hydropower industries [8–10]. This behavior involves in the corrosion damage, the mechanical erosion failure and the complex interaction of two processes which is commonly referred to as synergy [11]. Because of the important synergistic effect, erosion–corrosion results in the severe equipment failure and produces a total material loss significantly in excess of the sum of pure corrosion and erosion [11].

To date, a lot of work has been carried out to assess the material durability in erosion–corrosion environments as a function of test parameters including velocity, sand loading, temperature or pH value, etc. [12–16]. It has been demonstrated that the erosion–corrosion performance of material is significantly influenced by these factors. There also are some works to investigate the contributions of corrosion, erosion and their interactions to the total wastage of materials in erosion–corrosion conditions [15,17–34]. The contributions of corrosion, erosion and synergy to erosion–corrosion were strongly material dependent [20], so the there are some differences in the conclusions obtained by different test materials. In addition, cermets materials behave in a significantly different erosion–corrosion behavior in comparison with the other materials, due to the differences in microstructure and composition. Hence, the speculations proposed through other materials are not well applicable for cermets materials. However, there are few studies on the erosion–corrosion behavior and the synergistic effect of corrosion and erosion of cermets materials. Shipway and Howell [23] pointed out that the wear behavior of cermet materials occurred predominantly by preferential removal of the binder phase followed by pullout of the carbide, and binder phase removal was accelerated by corrosion, resulting in the accelerated material degradation. In literatures [24–26], the researchers concluded that the corrosion degradation of binder–carbide interface resulted in the accelerated removal of hard phase and binder. However, there is hardly any study in which the components of weight loss is quantified for Ti(C,N)–Ni cermets in the erosion–corrosion conditions. Especially, with the erosion–corrosion

---

* Corresponding author. Tel.: +86 13880085119; fax: +86 28 85196764.
E-mail address: wj927vick@sina.com (J. Xiong).

http://dx.doi.org/10.1016/j.wear.2014.12.041
0043-1648/

process proceeding, the component of materials loss is not well quantified or clearly understood. It is of vital importance for understanding the relationship to assess the practical applications of Ti(C,N)–based cermets in erosion–corrosion operations. The shortage of tungsten and cobalt and the poor corrosion resistance in corrosive mediums restricted the application of traditional WC-based cobalt-bonded cermets [27]. For this reason, the so-called tungsten free hard metals have been developed and adopted in industry, and nickel and their alloys were used as binder in these composites [27,28]. The most widely known among tungsten-free cermets were those based on TiC (TiCN) cemented with Ni and Mo alloys [27]. Compared to the traditional WC–Co materials currently used in the erosion–corrosion applications, Ti(C,N)–Ni cermets have more excellent wear resistance, higher hardness, perfect chemical stability, and more superior thermal deformation resistance. Additionally, Ti(C,N)–Ni cermets possess the lower production cost and better degradation resistance in corrosive conditions, in comparison with WC–Co. Therefore, in the work, Ti(C,N)–based cermets are considered as an alternative to WC–Co materials in the aggressive erosion–corrosion conditions.

In previous work [1–7], the relationships of the composition, microstructure and mechanical properties and the erosion–corrosion and erosive wear behavior of Ti(C,N)–based cermets have been researched. The results indicated that the composition and microstructure significantly affect the erosion/erosion–corrosion behavior of Ti(C,N)–based cermets, but relationships between the composition and microstructure and the performance of materials are depended on the specific test conditions, such as velocity, sand loading, and pH value etc. Furthermore, the erosive wear resistance could not be evaluated by single mechanical property of cermets [28]. Accordingly, there is no consistent conclusion on these relationships.

In the work, the static corrosion, pure erosion and erosion–corrosion experiments are designed to examine the mass loss of Ti(C,N)–Ni cermets in different conditions. In this paper, a typical slurry pot is used to perform the erosion and erosion–corrosion behavior of Ti(C,N)–based cermets, because this device is well suitable to simulate the engineering applications in the erosion/erosion–corrosion conditions [20]. The sulfuric acid solution is usually used to simulate the corrosive surroundings and Al_2O_3 sand is a common and typical erodent in the aggressive industry applications because of its relative hardness [20]. Thus, they are also employed in this study. The main purpose of this paper is to investigate and quantify the contributions of corrosion, erosion and their synergy to the erosion–corrosion degradation of this material. Furthermore, in synergy, corrosion enhanced erosion and erosion enhanced corrosion is also quantified to research their roles in the total material failure.

2. Experimental procedures

2.1. Materials and characterization

$TiC_{0.7}N_{0.3}$–10wt% Mo_2C–15wt%Ni cermet was prepared by a typical powder metallurgical technique. The material is the typical representative of Ti(C,N)-based cermet and shows a good performance in most service conditions. Characteristics of commercially available $TiC_{0.7}N_{0.3}$, Mo_2C and Ni raw powders are listed in Table 1. The powders mixture was ball-milled for 72 h in stainless steel lined mills using WC–8 wt% Co balls with ultra-fine grain size, using alcohol as the milling medium. The ball to powder weight ratio was selected to be 10:1, and the milling speed was 68 rpm. And then the powders were pressed to green bodies under a pressure of 200 MPa. The compact specimens were sintered at 1450 °C for 1 h, with the vacuum degree of 5 Pa.

The microstructure of target material is shown in Fig. 1. The material had the typical core/rim microstructure. The core is the undissolved Ti(C,N) particles, and rim is (Ti,Mo)(C,N) solid solution with relatively higher Mo content and lower Ti content. The typical core/rim microstructure is formed by dissolution–reprecipitation mechanism. In sintering process, the Mo_2C and Ti(C,N) dissolve in metal Ni. When they reach to their solubility in Ni, they precipitate around undissolved Ti(C,N) particles to form (Ti,Mo)(C,N) rim phase. So, most of Mo atom is in the (Ti,Mo)(C,N) solid solution. The brighter part in morphology is Ni-based binder phase which contains Ti, Mo and C atoms.

The density measurement was performed at room temperature (25 °C) by the Archimedes method. Subsequently, Rockwell hardness (HRA), transverse rapture strength (TRS) and fracture toughness (K_{IC}) of cermets were measured, and the results are tabulated in Table 2.

2.2. Experiments

In the work, the separate erosion and corrosion tests were designed to determine the contributions to total erosion–corrosion degradation due to erosion and corrosion. The solid–liquid erosion tests were carried out using two slurries of distilled water and Al_2O_3 sands (150–250 μm, 2000–2300 HV_{30}), and the erodent content was 1 wt% and 5 wt%, respectively. The pure liquid erosion was performed in the distilled water. The potential monitoring of target material indicated that there was no obvious corrosion behavior on the material surface in the static solid–liquid and pure liquid conditions. 0.1 mol/L and 0.5 mol/L sulfuric acid solution was used as the corrosive medium in the static/dynamic corrosion tests. In the erosion–corrosion experiments, four corrosive slurries containing sulfuric acid solution and Al_2O_3 sands were used. In summary, the detailed tests parameters are presented in Table 3.

Furthermore, in order to investigate the interactive effects between corrosion and mechanical erosion, corrosion followed by erosion (corrosion → erosion) and erosion followed by corrosion (erosion → corrosion) were performed: the samples were tested in static corrosion conditions for a certain period of time (0.5 h, 1 h, 1.5 h, …, 3.5 h, 4 h, respectively), and then they were attacked in solid–liquid erosion conditions for the same test time; on the other hand, the samples were eroded firstly in solid–liquid erosion conditions for a certain period of time (0.5 h, 1 h, 1.5 h, …, 3.5 h, 4 h, respectively) and after that, they were subjected to static corrosion for the same test time. In this section of study, 0.5 mol/L sulfuric acid solution and a slurry of 0.5 mol/L sulfuric acid and 5 wt% Al_2O_3 were employed as the media in static corrosion and solid–liquid erosion tests, respectively. The corrosion → erosion and erosion → corrosion process were both termed as 'cycle', and the corrosion time and erosion time were recorded as the test

Table 1
Characteristics of starting powders.

Powders	FSSS (μm)	Total carbon (wt%)	Free carbon (wt%)	Oxygen (wt%)	Manufacturer
$TiC_{0.7}N_{0.3}$	1.85	13.52	0.08	0.30	Changsha Wing Hing High-Tech New Materials Co., Ltd., China
Mo_2C	1.55	6.03	0.20	0.52	Changsha Wing Hing High-Tech New Materials Co., Ltd., China
Ni	2.65	0.10	–	0.10	Chengdu Nuclear 857 New Materials Co., Ltd., China