Springer

KSME

Journal of Mechanical Science and Technology 24 (2010) 85~88
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-1167-9

Friction and wear properties of rice husk ceramics under dry condition†

Tuvshin Dugarjav*, Takeshi Yamaguchi, Kei Shibata and Kazuo Hokkirigawa

Graduate School of Engineering, Tohoku University, 6-6-01 Aramaki Aza-Aoba, Aoba-ku, Sendai, Miyagi 980-8579, Japan

(Manuscript Received May 1, 2009; Revised October 15, 2009; Accepted October 30, 2009)

Abstract

The friction and wear behaviors of rice husk (RH) ceramics, prepared by carbonizing the mixture of rice husk and phenol resin at 900 °C in N_2 gas environment, sliding against high carbon chromium steel (JIS SUJ2), austenitic stainless steel (JIS SUS304), and Al_2O_3 under dry condition were investigated using a ball-on-disk tribometer. The test results show that the friction coefficient of RH ceramics takes very low values 0.05-0.08 and 0.06-0.11 sliding against SUJ2 and SUS304, respectively, and much higher values around 0.14-0.23 against Al_2O_3. It was also shown that SUJ2 provides the lowest specific wear rate values below 10^{-9} mm^2/N, while, those of SUS304 and Al_2O_3 mostly stayed between 10^{-9} to 10^{-8} mm^2/N range. The worn surfaces of counterparts were observed with optical microscopy and analyzed using cross-sectional transmission electron microscopy with energy dispersive X-ray spectroscopy and electron diffraction. It was suggested that the tribological behaviors of RH ceramics are closely related with the formation of a transferred film, consisted of amorphous silica and carbon particles, on a counterpart surface. The transferred film was formed readily on SUJ2 balls, whereas for SUS304 the presence of the film was subject of the sliding conditions. Moreover, formation of the transferred film could not be detected on Al_2O_3 counterparts.

Keywords: Amorphous silica; Carbon; Counterpart material; Friction; Rice husk ceramics; Transferred film; Wear

---

1. Introduction

Traditionally, rice husk, one of the main by-products of rice milling, has been considered a waste material and generally has been disposed off by dumping or burning. Thus, the ways of an effective utilization of rice husk have been the pressing question, particularly with today's increased global environmental awareness. Consequently, in recent years, rice husk has been recognized as a valuable source of various silicon-containing materials due to the high content of amorphous silica [1].

A new hard porous carbon material, called rice husk (RH) ceramics, has been developed by carbonizing rice husk mixed with phenol resin in N_2 gas environment. RH ceramics are composed of roughly 90 wt.% amorphous carbon and 10 wt.% amorphous silica [2].

It was clarified that the carbonization temperature greatly affects tribological properties of RH ceramics by altering its chemical structure and mechanical properties, and that the carbonization temperature of 900 °C yields a material with lower friction and wear characteristics, than those carbonized at higher temperatures, due to optimal mechanical properties and, most importantly, amorphous structure of the silica [3]. It was suggested that the presence of a transferred film on a counterpart surfaces plays an important role in low friction and wear behavior of RH ceramics. However, as the formation of the transferred film can be affected by a counterpart material, the purpose of the present study was to evaluate the tribological properties of RH ceramics sliding against different counterpart materials under dry condition.

2. Experimental

Friction and wear tests were conducted using a conventional ball-on-disk type tribometer under dry condition in air. The tests were carried out under a wide range of sliding velocities and normal loads, as shown in Table 1. RH ceramics, prepared with a carbonizing temperature of 900 °C by the process shown in Fig. 1, were cut into disk specimens of 35 mm×35 mm×5 mm size and polished to a surface roughness of 0.55~0.75 μm Ra. High carbon chromium steel (JIS SUJ2), austenitic stainless steel (JIS SUS304), and Al_2O_3 (99.9 %) balls with a diameter of 8 mm and a surface roughness of 0.13-0.14 μm Ra were used as the counterpart materials for the sliding tests. After the tribological tests, the worn surfaces of ball specimens were observed by an optical microscope and cross-sectional transmission electron microscopy (TEM) with energy dispersive spectroscopy (EDS)

† This paper was presented at the ICMDT 2009, Jeju, Korea, June 2009. This paper was recommended for publication in revised form by Guest Editors Sung-Lim Ko, Keiichi Watanuki.
*Corresponding author. Tel.: +81 22 795 6897, Fax.: +81 22 795 6897
E-mail address: tuvshin@gdl.mech.tohoku.ac.jp

Table 1. Friction test conditions.

Normal load *W*, N	0.98, 1.96, 4.9, 9.8
Sliding velocity *v*, m/s	0.02, 0.05, 0.1, 0.5, 1.0
Number of repeat passages *N*, cycles	2×10^4
Lubrication condition	Dry

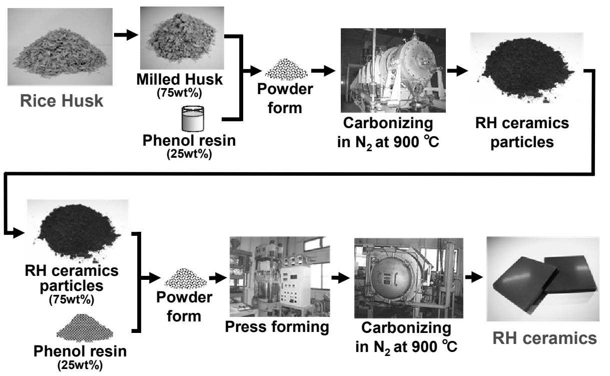


Fig. 1. Schematic diagram of preparation process of RH ceramics.

and electron diffraction analysis. TEM specimens of 20 μm×10 μm× 3 μm size, and consequently thinned in the middle to electron transparency, were prepared with the use of a focused ion beam (FIB).

3. Experimental results and discussion

Fig. 2 shows the typical frictional behavior of RH ceramics sliding against different counterpart materials. As can be seen, the friction coefficients decreased rapidly at the initial stage to values less than 0.1 at steady state for RH ceramics sliding against SUS304 and SUJ2, and relatively higher values over 0.15 when sliding against Al_2O_3.

Fig. 3 displays summarized tribological properties of RH ceramics sliding against different counterparts. As can be seen, RH ceramics displayed low values of friction coefficient of 0.2 and less, and low values of specific wear rate of RH ceramics below 10^{-8} mm^2/N under wide range of sliding velocities and normal loads, regardless of the counterpart material. However, SUJ2 and SUS304 provided much lower friction coefficient values than Al_2O_3, with SUJ2 also promoting the lowest specific wear rate values. Nevertheless, Al_2O_3 seemed to be the worst choice among these three as a mating material for RH ceramics resulting in the highest friction coefficient and specific wear rate values under dry condition.

Fig. 4 compares typical appearances of worn surfaces of ball samples after low and high friction sliding tests. It is evident from the optical microscope images in Fig. 4 that a thick transferred film was observed on the worn surfaces of SUJ2 ball samples, irrespective of the sliding conditions, which resulted in very low friction coefficient, less than 0.1, and low specific wear rate values. In contrast, the presence of such transferred film on SUS304 ball samples was subject of sliding conditions; the existence of such transferred film resulted

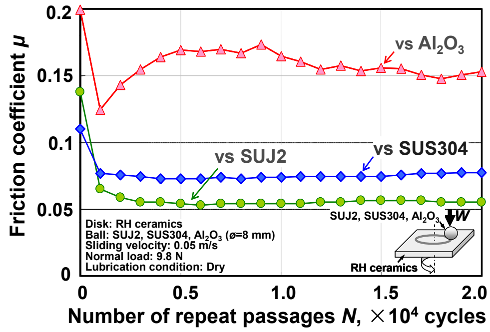


Fig. 2. Variation of friction coefficient with number of repeat passages (test conditions: *W*=9.8 N, *v*=0.05 m/s).

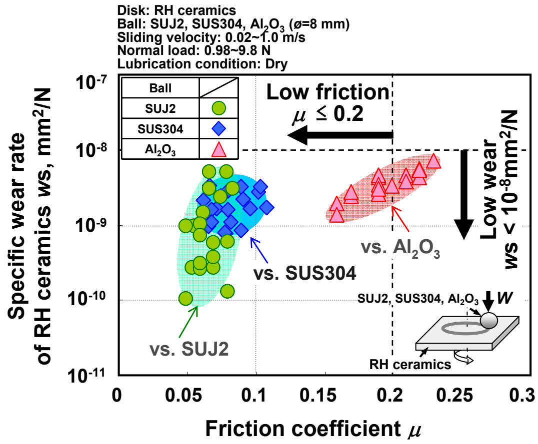
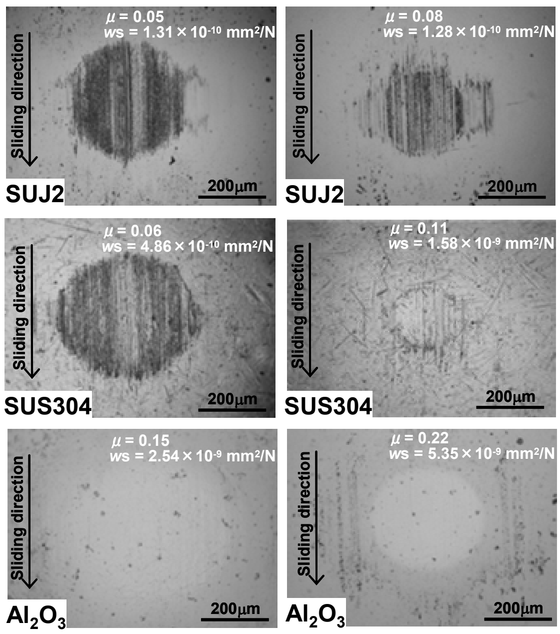


Fig. 3. Comprehensive tribological properties of RH ceramics sliding against SUJ2, SUS304, and Al_2O_3 balls under dry condition.



(a) *W*=9.8 N, *v*=0.02 m/s (b) *W*=0.98 N, *v*=1.0 m/s

Fig. 4. Typical appearance of worn surfaces of counterparts displaying: (a) low friction and wear rate (friction condition: *W*=9.8 N, *v*=0.02 m/s); and (b) relatively high friction and wear rate (friction condition: *W*=0.98 N, *v*=1.0 m/s).

in low friction coefficient and wear rate values, and comparatively lesser amounts of transferred film corresponded to increased friction and wear. Moreover, no visible transferred film could be detected on the worn surfaces of Al_2O_3 ball samples, regardless of the sliding conditions, which resulted in much higher values of friction coefficient and the specific wear rate of RH ceramics than the steel counterparts.

To clarify the mechanisms involved in tribological behavior of RH ceramics sliding against different counterparts, the structural characteristics of the worn surfaces of ball specimens were examined by TEM with EDS and electron diffraction analysis. Figs. 5 and 6 illustrate results of the cross-sectional TEM analysis of the worn surfaces of SUJ2 and SUS304 balls, showing very low friction coefficients around 0.05 and 0.06, respectively. The TEM image in Fig. 5(a) shows formation of 500-750 nm thick transferred film on SUJ2 substrate. Based on EDS and selected area electron diffraction (SAED) pattern analyses in Figs. 5(b)-(d), it was concluded that the film consists of mainly amorphous silica mixed with some carbon debris. In addition, the SAED-1 pattern indicates that an interlayer, consisting of amorphous silica and Fe_2O_3 iron oxide, corresponding to wear debris of SUJ2 ball, was formed.

As it can be seen in Fig. 6, the composition of the transferred film formed on SUS304 substrate was similar as in the case of SUJ2. However, the thickness of the film was notably smaller, approximately 140-360 nm. The film also consisted of mostly amorphous silica mixed with some carbon particles.

Based on the above results, the mechanisms of low friction and wear rates of RH ceramics sliding against steel counterparts such as SUJ2 and SUS304, and relatively higher friction and wear rates sliding against Al_2O_3 are suggested as follows. In case of RH ceramics sliding against steel counterparts, the readily formed transferred film of RH ceramics, consisting mainly from amorphous silica mixed with carbon debris particles, on the counterpart surface results in very low friction coefficient and wear rates. However, for SUS304, the formation of the transferred film depends on sliding conditions, with

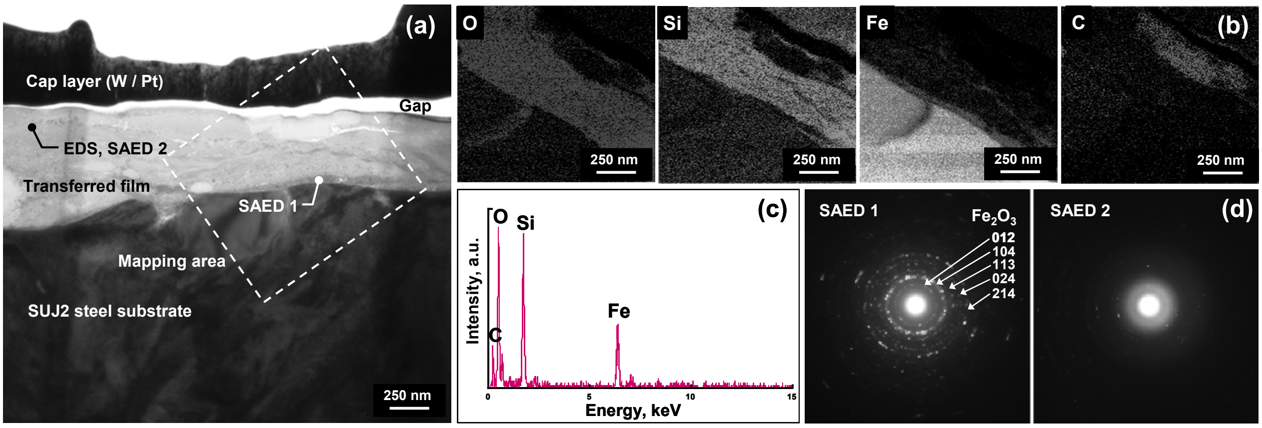


Fig. 5. Cross-sectional TEM analysis of SUJ2 ball worn surface slid under dry condition: (a) TEM image; (b) EDS mappings of O, Si, Fe, and C; (c) EDS spectra; and (d) selected area electron diffraction patterns (friction condition: W=9.8 N, v=0.02 m/s, μ= 0.05, w_s = 1.31×10^{-10} mm^2/N).

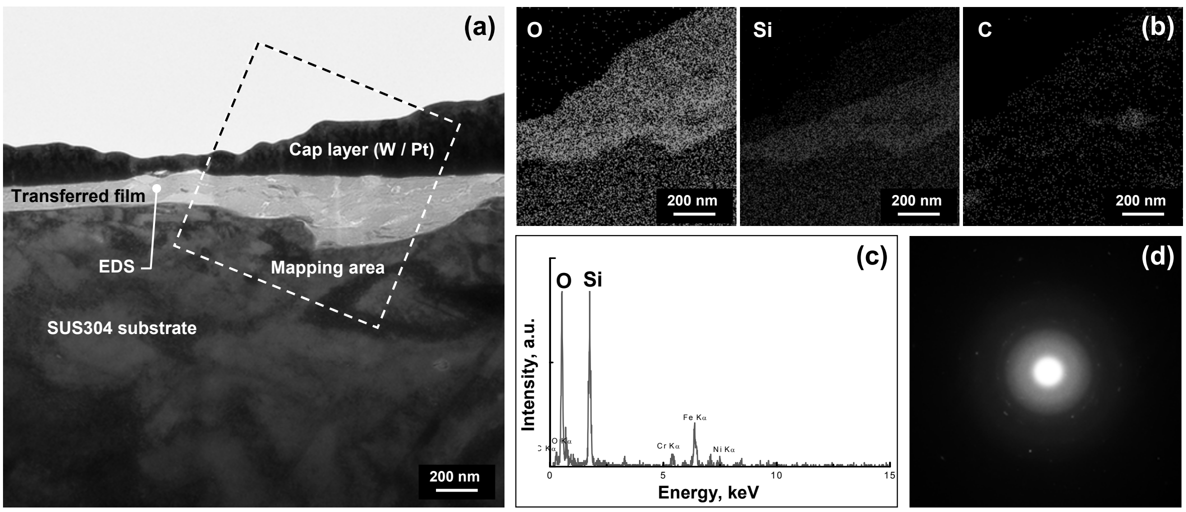


Fig. 6. Cross-sectional TEM analysis of SUS304 ball worn surface slid under dry condition: (a) TEM image; (b) EDS mappings of O, Si, and C; (c) EDS spectra; and (d) selected area electron diffraction pattern (friction condition: W=9.8 N, v=0.02 m/s, μ= 0.06, w_s = 4.86×10^{-10} mm^2/N).

less transferred film corresponding to higher friction and wear rates than those for SUJ2. It was suggested that RH ceramics exhibit such low friction and wear behavior under dry condition due to amorphous silica reaction with water vapor in air to form low shear surface layer of Si-OH, analogous to Si-DLC coatings [4]. In contrast, in the case of Al_2O_3, the non-existence of the transferred film of amorphous silica, forming on the worn surface of the Al_2O_3 surface, inevitably leads to much higher friction and wear rates than those against steel counterparts. Thus, both SUJ2 and SUS304 should be preferred over Al_2O_3 as a counterpart material for RH ceramics for use as low friction and low wear tribo-elements in dry sliding applications.

4. Conclusion

RH ceramics sliding against SUJ2 and SUS304 displayed superior properties, such as very low friction coefficients less than 0.1 and low specific wear rates below 10^{-9} mm^2/N, under dry condition compared to Al_2O_3 counterpart, due to the formation of the transferred film, consisting mainly from amorphous silica, on the counterpart surfaces.

Acknowledgment

The authors are grateful to Dr. Takamichi Miyazaki and Dr. Kazuhiko Sakaguchi for help with the FIB-TEM measurements and valuable suggestions.

References

[1] W. Shigetaka, M. Weerasak and H. Zhemchai, Survey of the research on the utilization of rice husk and rice husk silica, *Proc. 1st Workshop on the Utilization of Rice Husk and Rice Husk Silica*, Bangkok, Thailand (2005) 6-14.

[2] T. Yamaguchi, T. Sekiguchi, H. Toyoshima, E. Kohira, Sh. Shikano and K. Hokkirigawa, Friction and wear properties of new hard porous carbon materials made from rice chaff, *Proc. 3rd Asia Int. Conf. Trib*., (2006) 379-380.

[3] X. Wu, M. Suzuki, T. Ohana and A. Tanaka, Characteristics and tribological properties in water of Si-DLC coatings, *Diamond & Related Materials*, 17 (2008) 7-12.

[4] H. Mori, N. Takahashi, H. Tachikawa and T. Ohmori, Low friction property and its mechanism of DLC-Si film under dry sliding conditions, *SAE 2007 Transactions*, 5 (116) (2007) 408-413.

Tuvshin Dugarjav received his M.S. in Mechanical Engineering from CU Denver, USA, in 2003. His is currently a Ph. D candidate at the Graduate School of Engineering, Tohoku University, Japan. His research area is development of plant-based tribomaterials.