초청강연

Friction and Wear Behavior of Structure Ceramic

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Friction and Wear Behaviors of Engineering Ceramic

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1 Research importance for friction and wear

2. Many research works related to tribology

1. Mechanical Properties of Engineering Ceramic

1 Properties of engineering ceramics

Engineering ceramics have a series of excellent properties,for example,high strength,high hardness,wear-,corrosion-,oxidation- and shock-resistance etc,and is a kind of high temperature structural material with enormous potentialities for future development

2. Normal engineering ceramic

Al_2O_3 `$Si_3N_4$ `Sialon `SiC `ZrO_2 etc

2. Mechanical behavior of ceramic under contact

2.1 Elastic contact of ceramic

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2.1 Elastic contact of ceramic

- When two solids contact with each other under load, the real contact area is at tops of the asperities on the surface roughness. The contact situation may be divided into elastic,elastic-plastic and plastic state.

2. For the friction counter of ceramic/ceramic, the ratio between elastic modulus (E) and hardness (H) is in the range of 10 to 20. However, The values of E/H for most metals are in the range of 200 to 300. Thus, the friction counter of ceramic is inclined to elastic contact .

2.2 *Crack formed in ceramic under contact with lower load*

1.Cracks are formed on the surface or sub-surface as high hardness indenter presses on the ceramic surface.

2.For ball indenter, the critical contact radius a_c is expressed as:

$$a_c = \frac{\alpha}{\pi^2}\frac{E\gamma}{H^2} \infty \frac{E\gamma}{Y^2}$$

Where γ is fracture surface energy.H is hardness of ceramic. Y is yield strength. $\alpha$is coefficient.

Table.1 Properties of Materials

Materials	E (GPa)	(J/m^2)	$E\gamma/Y2$
Diamond	103	5.4	5×10^{-9}
Glass	70	~ 4	8×10^{-8}
HP- Si_3N_4	265	8.1	1.3×10^{-7}
ZrO_2	120	~ 2	2×10^{-7}
High Carbon Steel	200	300	2.6×10^{-5}
Alloyed steel	200	1.1×10^4	3.5×10^{-3}
Low carbon steel	190	1.2×10^4	1.6×10^{-1}

3. As seen in Table.1, the values of E?/Y^2 for Si_3N_4 and ZrO_2 are lower than those of quenched steels. This indicated that micro-crack is nucleated in ceramic at lower load.

2.2 *Crack formed in ceramic under contact with lower load*

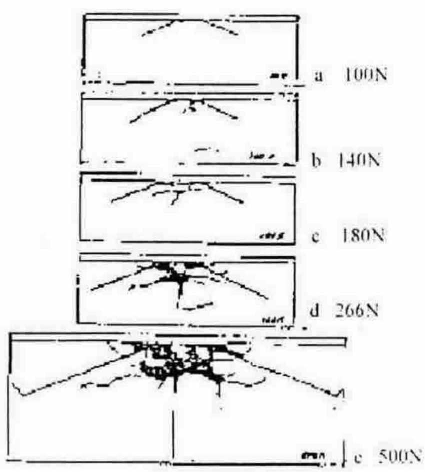


Fig.1 Effect of loads on the crack shapes in Na-Ca-glass under harden alloy ball with radius of 0.5mm

2.2 Crack formed in ceramic under contact with lower load

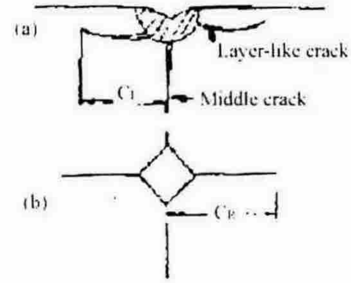


Fig.2 Schematic illustration of crack forming in brittle materials under cone indenter

With an increase in load, the crack shape under blunt indenter will transform into the crack characteristic under sharp diamond indenter (as seen in Fig.1 and Fig.2) . Micro-crack is formed in ceramic as the harden asperities slid against ceramic. Especially , the propagation of subsurface lateral cracks will cause the materials spallation and wear is occurred.

3.Mechanical behavior of ceramic under sliding contact

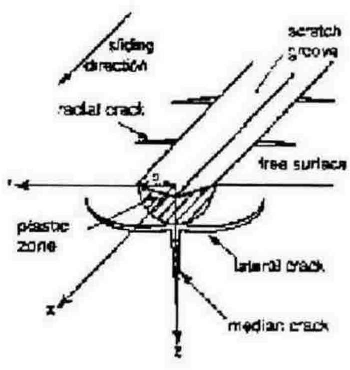


Fig.3 Schematic illustration of crack and scratch

The lateral crack in ceramic propagated to surface after the sharp indenter slid against ceramic. The size of lateral crack increased with an increase in load.

4. Friction and wear of ceramic

4.1 Effect of ceramic fracture toughness K_{IC} on friction and wear of ceramic

4.2 Wear test machine for ceramic friction and wear

4.3 Friction coefficient and wear rate for different ceramic tribo-counter

4.4 Chemical wear of engineering ceramic

4.5 Friction and wear of engineering ceramic under lubrication

4.6 Heat wear of engineering ceramic

4.1 Effect of ceramic fracture toughness K_{IC} on friction and wear of ceramic

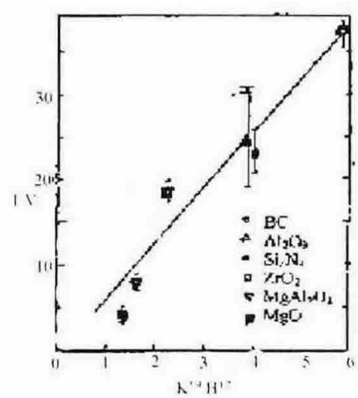


Fig.4 Relationship between $K^{3/4}.H^{1/2}$ and wear-resistance 1/V for ceramic

4.1 Effect of ceramic fracture toughness K_{IC} on friction and wear of ceramic

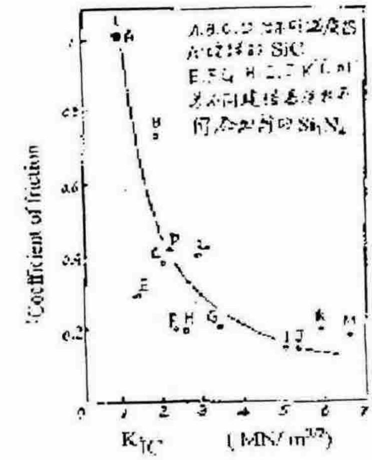


Fig.5 Effect of fracture toughness K_{IC} on friction coefficient for ceramic

4.1 Effect of ceramic fracture toughness K_{IC} on friction and wear of ceramic

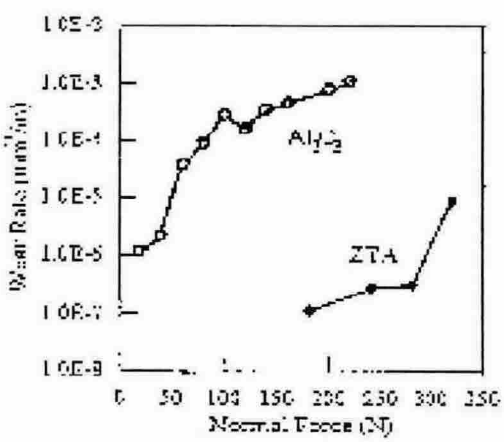


Fig.6 Variation of wear rate at various loads for ceramic

4.1 Effect of ceramic fracture toughness K_{IC} on friction and wear of ceramic

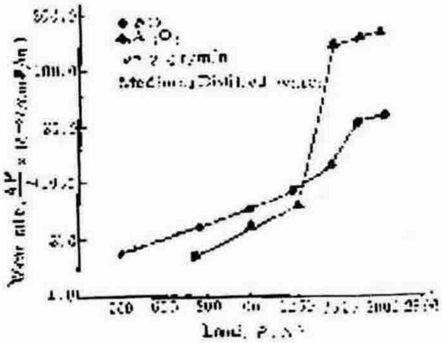


Fig.7 Effect of load on wear transition for ceramic

4.2 Wear test machine for ceramic friction and wear

- Wear test machine

  Pin-on-disk, ball-on-disk, ring-on-disk and ring-on-block etc.

2. Type of tribo-counter

   Ceramic to itself, different ceramic, ceramic/metal, ceramic/DLC etc.

4.3 Friction coefficient and wear rate for different ceramic tribo-counter

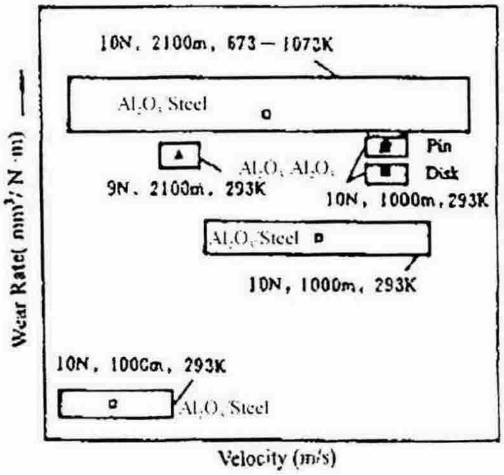


Fig.8 Effect of load and speed on the wear rate for Al_2O_3 ceramic under dry tribology

4.3 Friction coefficient and wear rate for different ceramic tribo-counter

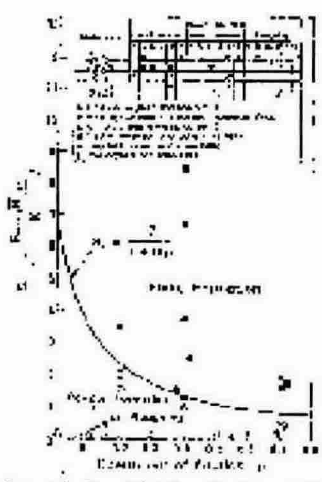


Fig.9 Wear map for Al_2O_3 ,Si_3N_4, Sialon, SiC,ZrO_2 ceramic

4.4 Chemical wear of engineering ceramic

- For non-oxide ceramic such as Si_3N_4 and SiC, water can decrease their friction coefficient and wear rate, which is related to the oxide layer. The reaction can be expressed as:

  $Si_3N_4+6H_2O \rightarrow 3SiO_2+4NH_3$

  $SiC+O_{2+}H_2 \rightarrow SiO_2+CO+H_2$

  $SiO_2+2H_2O \rightarrow Si(OH)_4$

  When the wear test of Si_3N_4 and SiC is carried out at room and elevated temperature, Si_3N_4 and SiC ceramic may react with oxygen. Thus, Si-O compounds form and lead to ceramic wear .

- For oxide ceramic, the effect of water on its friction and wear may depend on the experimental conditions.

  When wear mechanism is governed by tribo-chemistry, water decreases the wear rate of Al_2O_3 owing to the formation of $Al(OH)_3$

  When wear mechanism is governed by stress-corrosion fracture, water increase the wear rate of ceramic due to absorption of water on ceramic surface.

4.5 Friction and wear of engineering ceramic under lubrication

Friction and wear may be reduced markedly by introducing lubricant to tribo- interface between ceramic and ceramic (metal). The research works about the ceramic lubrication are:

(1) Development of new water-based lubricant;

(2) Friction and wear of engineering ceramic in corrosion mediums;

(3) Effects and wear-resistance mechanism of lubricant under various conditions.

4.6 *Heat wear of engineering ceramic*

Temperature has strong influence on the friction coefficient and wear volume of ceramic.

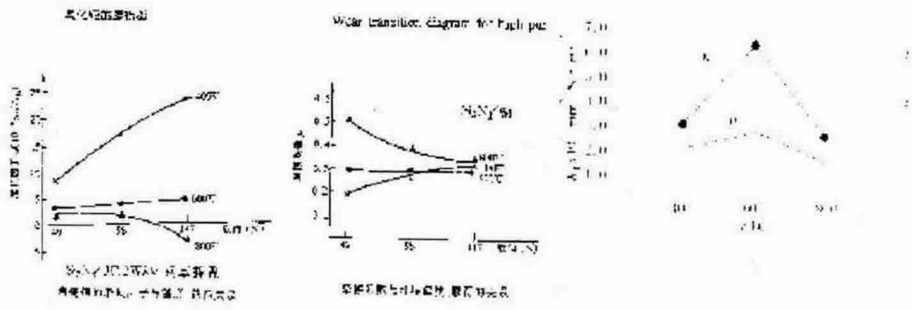


Fig.10 Wear behavior of ceramic/steel tribo-counter at elevated temperature

4.6 *Heat wear of engineering ceramic*

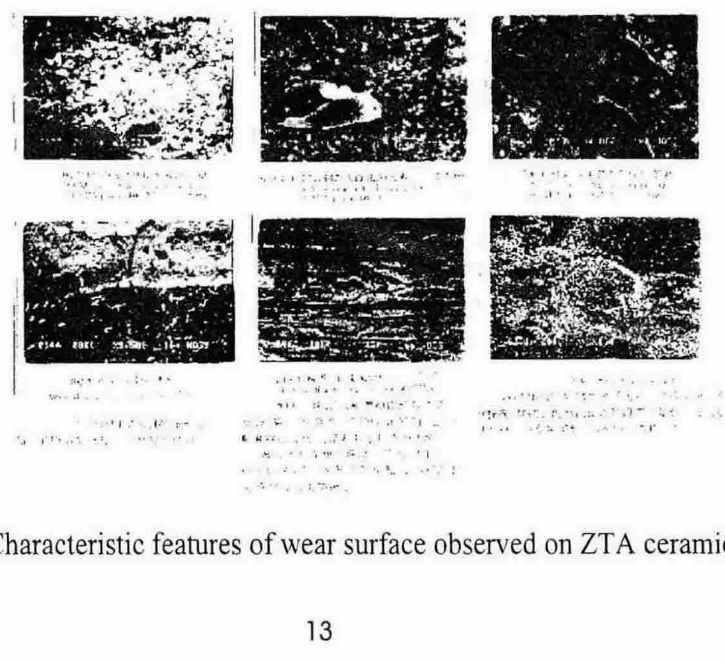
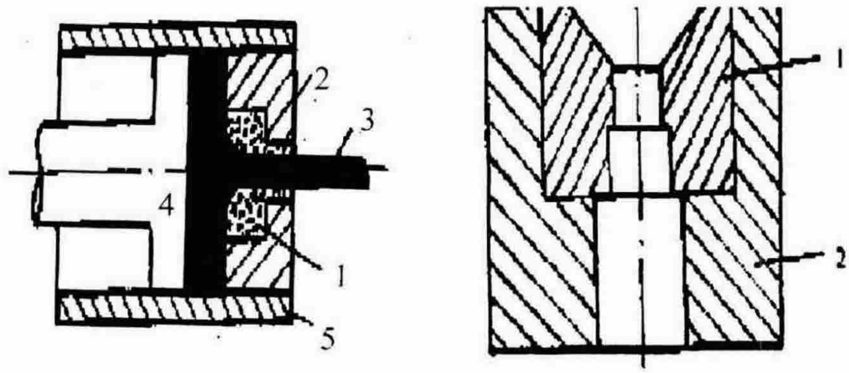


Fig.11 Characteristic features of wear surface observed on ZTA ceramic pin

4.6 *Heat wear of engineering ceramic*

Among many ceramics, Sialon ceramic has highest wear-resistance.



1陶瓷模具 2模块 3被挤金属 4顶杆 5套筒　　1 陶瓷模具 2 模块

Fig.12 Hot extrusion model of Sialon ceramic

4.6 *Heat wear of engineering ceramic*

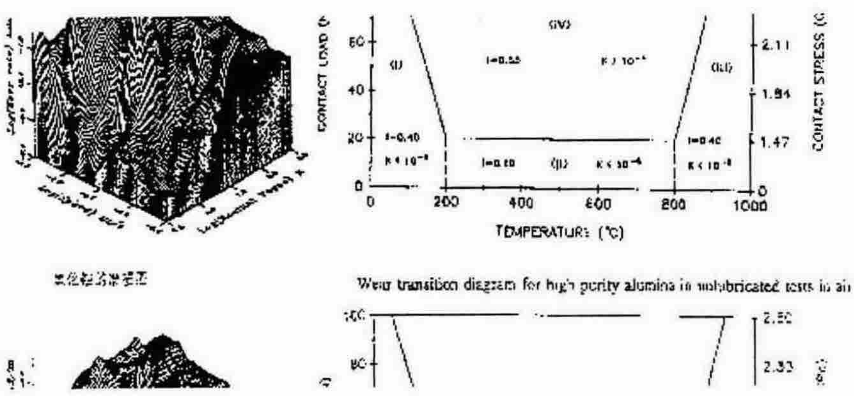


Fig.13 Wear map of Al_2O_3 ceramic

5. Conclusions

1. The E/H value of ceramic is lower than metals'. The ceramic tribo-counter is inclined to elastic contact. Micro-cracks are formed at low load.
2. The critical load of ceramic surface fracture under sliding indenter is lower than that of static indenter. With an increase in load, the brittle fracture tendency of ceramic wear surface increases.
3. With an increase in ceramic fracture toughness, the ceramic wear-resistance increases.
4. Tribo-chemistry has main influence on the friction and wear of ceramic. There are key research works about ceramic friction and wear under lubrication.
5. Engineering ceramics are excellent candidate materials under hot-wear condition.
6. Based on the failure analysis of ceramic tribo-system, we must indicate the effects of ceramic composition, structure and properties and select ceramic materials suitably.