Microabrasion of glass – the interrelated effects of load and abrasive slurry viscosity

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Abstract
Microabrasive wear testing of materials has been the subject of a significant amount of research as its potential for examining the wear behaviour of thin coatings and bulk materials in a sensitive manner has become apparent. A microabrasive wear test was first reported by Kassman et al. [1] where a TEM dimple grinder with a crowned wheel was used to create wear scars in materials in the form of a spherical cap. Both the wheel and the sample were rotated (around orthogonal axes) to produce wear; the test relied on the axis of rotation of the sample passing through the centre of the crowned wheel which was difficult to achieve with accuracy [2]. The test was developed by Rutherford and Hutchings [3]; in their apparatus, a ball was rotated (with no translation) whilst in contact with a stationary specimen with a continuously replenished pool of slurry abrasive surrounding and being drawn into the contact zone between the two. The resulting wear was again in the form of a spherical cap with radius the same as that of the ball. The test has been employed to assess the wear resistance of a wide range of materials including metals, ceramics, polymers and hard and soft coatings with both plane and non-plane geometries. Whilst the test is elegant and simple, there are some phenomena which may occur during a test which may render the results of such an abrasive test invalid. Such a phenomenon is ribbon or ridge formation.

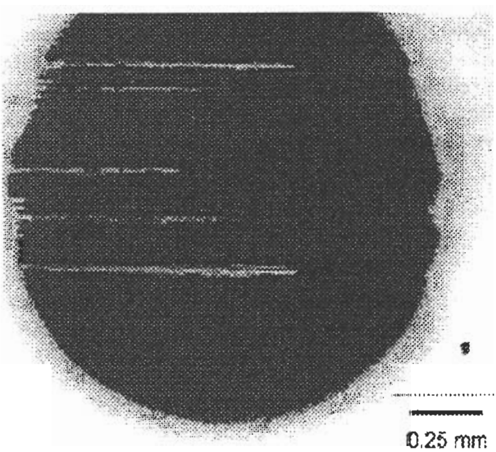

Figure 1 Ribbons in a wear scar in soda-lime glass following abrasion with SiC slurry

This work has examined the role of ribbon formation in soda-lime glass; such ribbons have been reported in previous work [4, 5] and can be seen in Figure 1. Ribbons are thin bands of unabraded material which form in the wear scar which, once developed, are worn down only by a sliding action against the ball. No abrasive slurry is entrained between the ribbon surface and the ball surface. It is proposed that the ribbons form in the wear scar due to inhomogeneous flow of abrasive slurry. A protuberance which forms at the trailing edge of the wear scar may be immediately worn away or may develop in length into a ribbon. Its development is promoted by high loads and low slurry viscosities, both of which hinder entrainment of abrasive particles between the ball and the forming ribbon. The viscosity of a slurry depends not only on the particle volume fraction in the slurry but also upon the abrasive particle type. Alumina slurries were found to have low viscosities due to electrostatic stabilisation of the particles in water due to their largely ionic nature. Silicon carbide slurries, however, had higher viscosities due to the more covalent nature of the bonding in the particles. Moreover, two

different batches of silicon carbide abrasive particles from the same manufacturer were found to exhibit very different slurry viscosities for a given particle volume fraction. Despite these variations in slurry characteristics, a regime where ribbon formation in soda lime glass is suppressed has been identified in terms of applied load and slurry viscosity for a range of abrasive slurries. Ribbon formation results in low wear rates, but when ribbon formation is suppressed, wear of glass has been observed to be broadly independent of slurry viscosity and proportional to applied load as predicted by the Archard wear equation. It is proposed that ribbon formation is a general phenomenon in such tests, and care must be taken to ensure that it is suppressed to allow valid abrasive wear tests to be conducted in such microabrasion apparatus.

References

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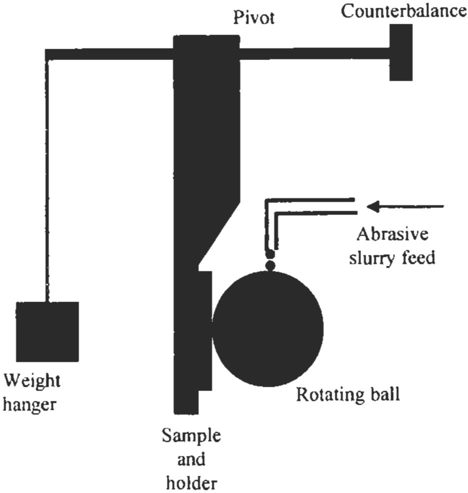
2. R. Gahlin, M. Larsson, P. Hedenqvist, S. Jacobson and S. Hogmark, The crater grinder method as a means for coating wear evaluation - An update, *Surf. and Coatings Tech.*, 90 (1997) 107-114

3. K.L. Rutherford and I.M. Hutchings, A micro-abrasive wear test, with particular application to coated systems, *Surf. and Coatings Tech.*, 79 (1996) 231 - 239.

4. P.H. Shipway, The rôle of test conditions on the micro-abrasive wear behaviour of soda-lime glass , *Wear*, accepted for publication

5. D.N. Allsopp, R.I. Trezona and I.M. Hutchings, The effects of ball surface condition in the micro-scale abrasive wear test, *Tribology Lett.*, 5 (1998) 259 - 264



Test variables

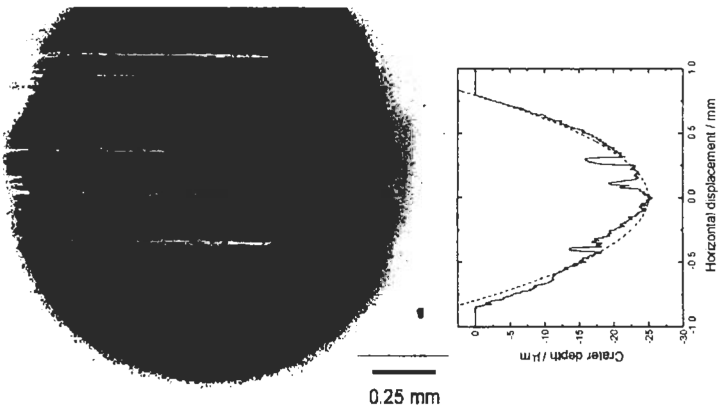
- Sliding distance
- Ball type / condition
- Abrasive type and size
- Slurry suspending medium
- Slurry concentration / viscosity
- Applied load

Aims of this work

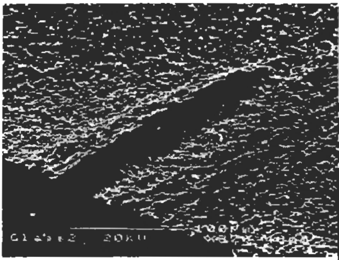
- To investigate
  - the effect of applied load
  - the effect of slurry concentration / viscosity

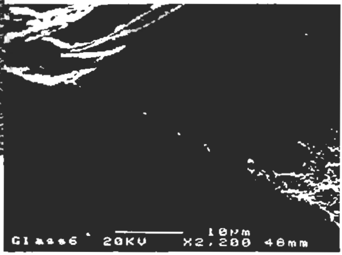
on wear rate and ribbon formation

- μ-abrasion of glass: 3 N, SiC slurry @ 39.5 g l^{-1}

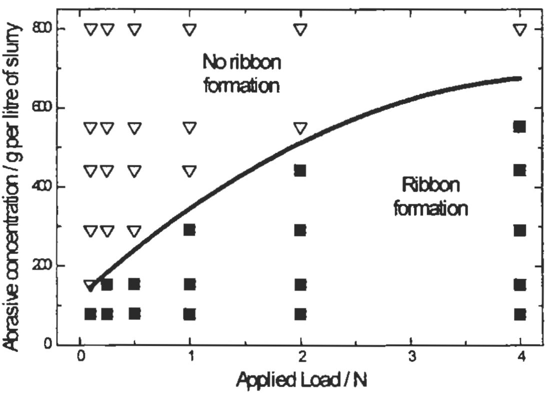


Ribbons

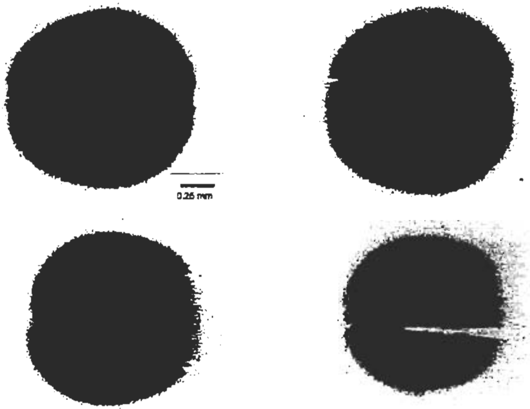




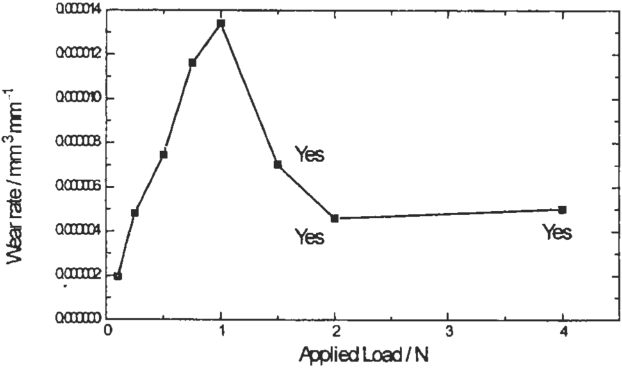
- μ-abrasion of glass with SiC slurry



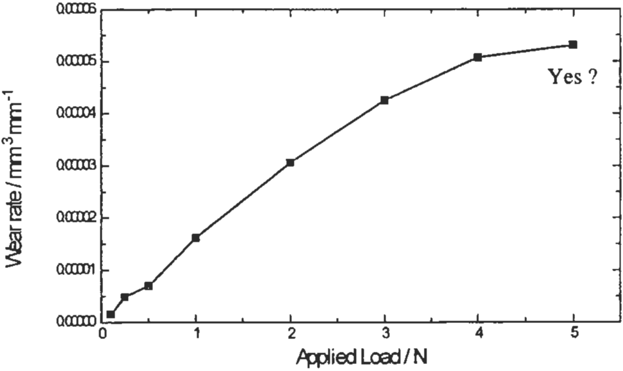
- μ-abrasion of glass: Al_2O_3 slurry @ 981 g l^{-1}



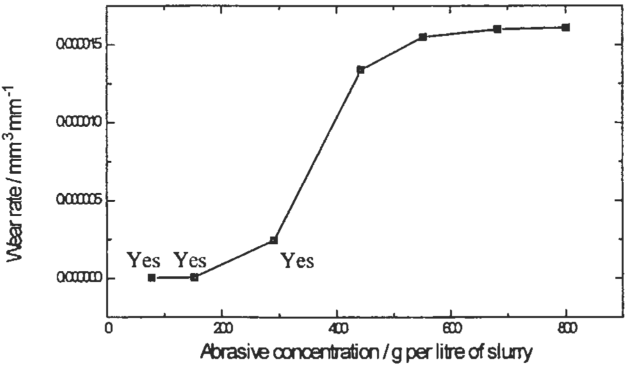
- μ-abrasion of glass: SiC slurry @ 443 g l^{-1}



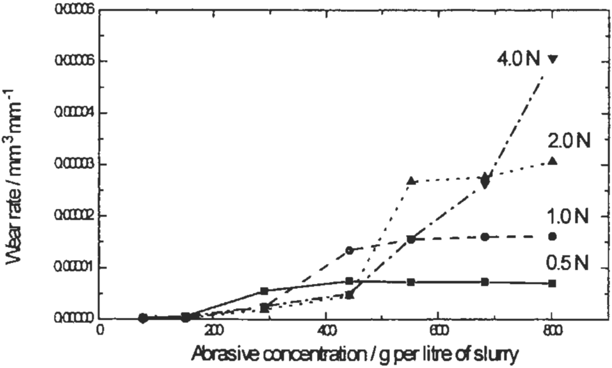
- μ-abrasion of glass: SiC slurry @ 801 g l^{-1}



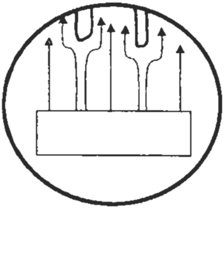
- μ-abrasion of glass: 1 N, SiC slurry



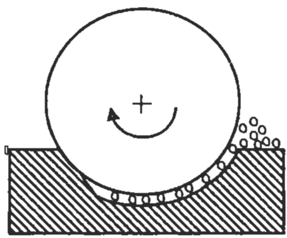
- μ-abrasion of glass: SiC slurry



Formation of ribbons



Plan view of wear scar

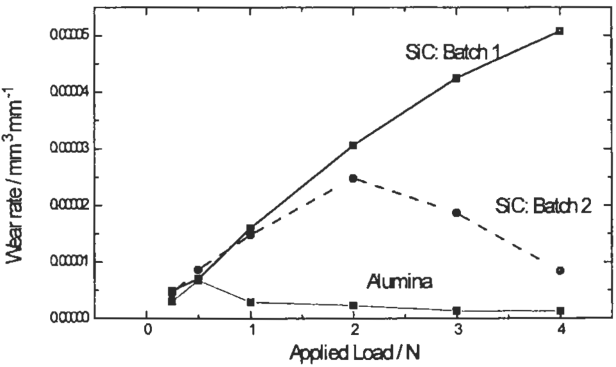


Section through wear scar

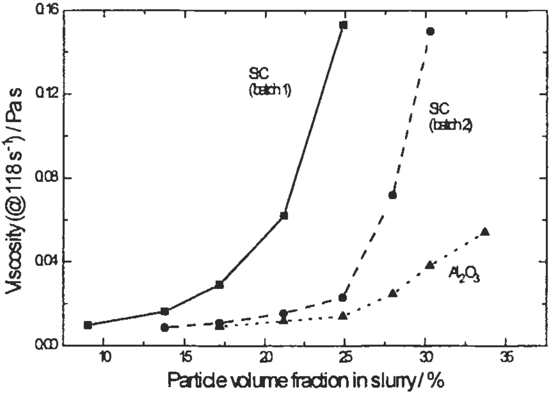
Ribbon formation

- Promoted by thin slurry film
  - high loads
  - low concentrations
- Results in low wear rate
  - ball supported by ribbon
  - wear controlled by ribbon-ball sliding wear

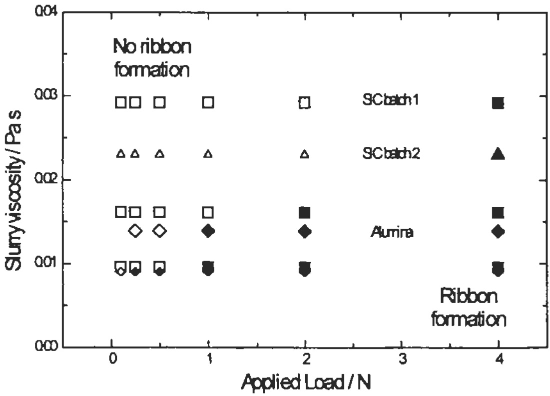
- μ-abrasion of glass: abrasives at 24.9 vol%



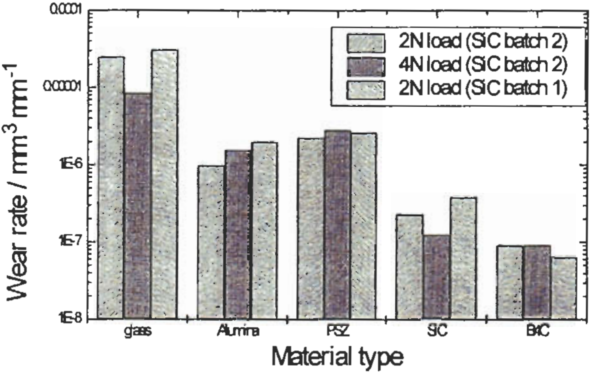
- Viscosity of abrasive slurries



- μ-abrasion of glass with various slurries



- μ-abrasion of various ceramics: SiC @801 g l^{-1}



Conclusions

- High loads / low abrasive viscosities promote ribbon formation
- If ribbons form, wear rate governed by ribbon wear (i.e. abrasive test invalid)
- Ribbon formation also dependent on material type
- When well behaved, wear rate independent of abrasive concentration and proportional to applied load