Scratching of glass by metals: The hardness question revisited

Gary L Smay and Peter DeHaan present the results of investigations that show soft as well as hard metals can create damage on glass surfaces.

There is widespread belief that damage can be created on glass surfaces only if the hardness of the contacting material is greater than glass. This issue was previously investigated by Ghering and Turnbull[1], who studied the contact of blunt metal styluses of various materials in sliding contact with clean glass surfaces.

The damage observed in their studies was in the form of crescent cracks that were aligned normal to the direction of the sliding motion.
They found that the hardness of the sliding metals was of some importance, since the load that was required to generate damage increased as the hardness of the metals decreased. For example, the minimum load required to create damage for a hard metal such as chromium was only 200g, while the minimum load required to create damage for a soft metal such as aluminium was 1kg-2kg. However, they observed that many metals softer than glass produced damage on the glass surface, which led to the conclusion that factors other than simply hardness were critical in the creation of damage.

During sliding contact of a blunt object, crescent cracks are formed when the stresses developed in the glass exceed the micro-strength of the glass surface. The equation governing the stresses that are created in glass during sliding contact is:

$$\sigma_f = \left[\frac{3(4+\upsilon)}{16}\right]\left(\frac{4}{3\,k\,\pi}\right)^{2/3}\left(\frac{L}{R^2}\right)^{1/3}\mu$$

$$k = \left(\frac{1-\upsilon^2}{\pi E}\right)$$

where L is the force normal to the glass surface, R is the radius of curvature of the contacting object, E is the modulus of elasticity of the glass, ú is Poisson's ratio of the glass and μ is the coefficient of friction between the glass and the sliding material. Thus, for a constant radius and normal load, the stresses generated during sliding contact will be determined solely by the coefficient of friction. If the friction is sufficiently high, the generated stresses will be relatively high and damage will be created.

Experimental procedure

The substrates used in this study consisted of soda-lime-silica glass plates that measured 2in x 3in x 0.065in. Prior to testing, these plates were immersed in a dilute aqueous solution of hydrofluoric acid to remove any surface contaminants and to create a clean, high strength surface.

Styluses consisting of glass, titanium, aluminium, copper, brass, carbon steel and stainless steel, the tips of which were rounded to 0.25in, were used in this study. The normal load during sliding was maintained constant at 1kgf. Sliding contact was made on the air side of the glass plates and the glass surfaces were wetted with deionised water to eliminate any potential lubricating effects of contaminants that might be inadvertently present on the glass surfaces.

The friction force was recorded during sliding contact and the coefficient of friction was determined by calculating the ratio of the friction force to the normal force. Following these tests, the glass slides were dried by impinging a stream of nitrogen onto the surface and the glass strengths were immediately determined by a ball-on-ring device using an Instron Universal Tester, operating at a crosshead speed of 5mm/min. During the strength tests, a stream of dry ▸

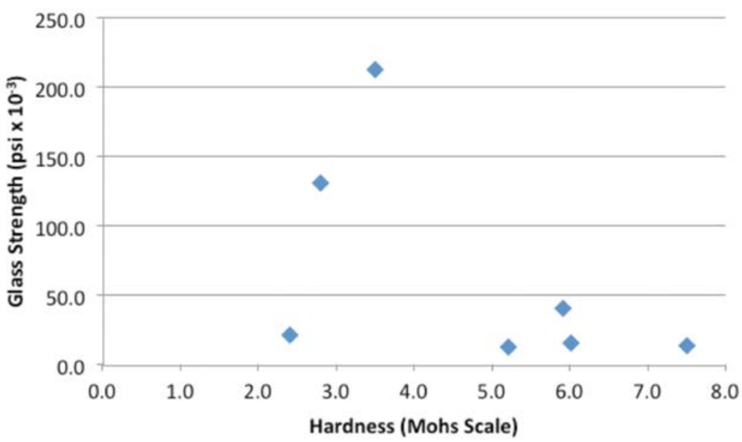

Figure 1: Resultant glass strength as a function of metal hardness.

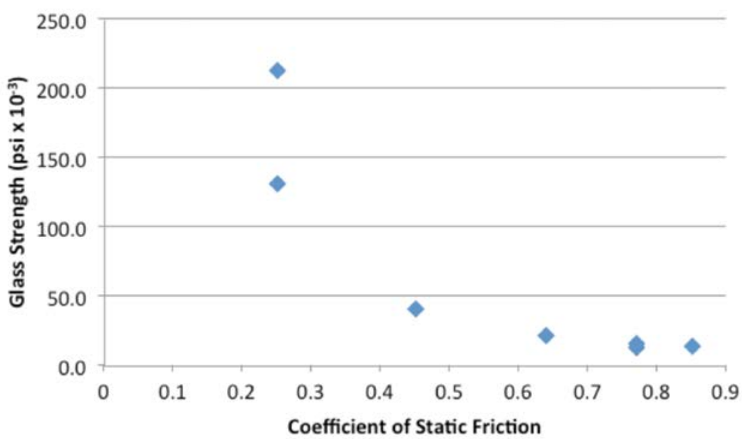

Figure 2: Resultant glass strength as a function of friction.

Metal	Hardness (Mohs scale)	Coefficient of static friction	Glass strength (psi x 10-3)
Aluminium	2.0-2.9	0.64	17.7
Copper	2.5 – 3.0	0.24	96.1
Brass 260	3.0 – 4.0	0.25	149.6
Carbon steel	5.0 – 5.5	0.77	9.4
Stainless steel 304	5.5 – 6.3	0.45	25.5
Titanium grade 5	6.0	0.77	11.0
Soda-lime-silica glass	5.5	0.85	10.6
Control (no damage)			561.7

Table 1: Hardness, friction and strength values.

To download content and subscribe, visit www.glassworldwide.co.uk

nitrogen gas was impinged onto the tensile surface of the glass slide to minimise the effect of static fatigue. A total of 10 slides were prepared and tested for each of the seven contacting metals.

The broken slides were examined visually and it was found that all of the fracture origins were located in the damage produced during sliding contact. The average breaking strength was calculated for each metal and plotted as a function of metal hardness and static coefficient of friction. Finally, the breaking strength of undamaged slides was determined and used as the baseline for comparison of the severity of the damage that was created by sliding contact of the various metals.

Summary of results

The hardness of the contacting metals were obtained from the literature and are summarised in table 1, along with the measured static coefficients of friction and the resultant average strength of the damaged surfaces. As shown by these data, the resultant glass strengths after sliding contact with the various metals ranged from 9400 psi to 149,600 psi. These values were significantly less than the strength of the undamaged control surface (561,700 psi).

A plot of the resultant glass strength as a function of metal hardness is shown in figure 1. As shown by these data, there is no strong correlation between strength and hardness. Conversely, a plot of the resultant glass strength as a function of the coefficient of static friction, as shown in figure 2, shows a very strong correlation. As the coefficient of static friction increased, more severe damage was created on the glass surface during sliding contact and the resultant strength decreased. These data indicated that when the normal load was held constant, the damage generated on a glass surface by the sliding contact of a blunt metal object was a function of the static friction and not of the metal hardness.

Based on the data derived from the current study, soft metals can cause damage to glass surfaces and that damage can significantly weaken the strength of a pristine surface. These data are in agreement with those of Ghering and Turnbull and refute the assertion that only hard metals can create damage on glass surfaces. ●

Reference:

1. L G Ghering and J C Turnbull, Scratching of Glass by Metals, *Bulletin of the American Ceramic Society,* Vol 19, No 8, August, 1940, Page 290.

About the authors:
Gary L Smay and Peter DeHaan are Senior Scientists at AGR International

Further information:
AGR International Inc, Butler, PA, USA
tel: +1 724 482 2163
email: gsmay@agrintl.com, pdehaan@agrintl.com
web: www.americanglassresearch.com