[Reprinted from the Bulletin of The American Ceramic Society, Vol. 19, No. 8. August, 1940.]

SCRATCHING OF GLASS BY METALS*

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Letter of Transmittal†

This investigation calls attention to that type of scratch on glass which some twenty years ago the present writer called "chatter sleeks." At that time interest centered on the nature of the process of polishing glass by abrasives. More recently the action of metal parts rubbing over clean glass surfaces has come up for consideration and has been found to be important. The scratches there produced are nearly always of the chatter-sleek type.

The behavior of different metals, the effect of detergents, and other practical matters are touched on in the present communication. The paper shows that glass, a fairly hard substance, may be scratched and seriously weakened by metals vastly softer than itself.

— F. W. Preston

I. Introduction

Glass may be scratched by a variety of minerals, metals, and abrasives, and in general the harder the scratching substance, the more easily is the glass scratched. It is therefore convenient to assign glass a number on Mohs' hardness scale, and the materials which scratch glass evidently ought to have higher hardness numbers on this scale.

Mohs' scale of hardness is an arrangement of minerals, beginning with talc and ending with diamond, such that any mineral may be scratched by all the minerals above it but by none below it. This scale is commonly used for rating the hardness of minerals, as well as that of metals, alloys, and many other commercial materials.

Soda-lime-silica glass will scratch minerals 1 to 4 and therefore should have a hardness rating of 5. Many substances, however, with a rating of less than 5 as well as those greater than 5 will scratch glass. According to Auerbach,[1] any kind of glass will scratch any other kind of glass, and it will be shown that many of

* Received January 5, 1940.

† The "letter of transmittal" over my signature replaces the ordinary abstract. It serves two other purposes. Together with the last paragraph of the paper it indicates that it represents part of a continuing program, other parts of which may be reported by other investigators, but in the same group; and it indicates also a sort of sponsorship or responsibility in case certain commercial interests, outside the glass industry, consider themselves aggrieved.—F. W. Preston, Preston Laboratories, Butler, Pa.

[1] (a) F. Auerbach, "Über die Härte- und Elasticitätsverhältnisse des Glasses," *Ann. d. Phys. u. Chem.*, 53, 1000 (1894).

(b) H. Hovestadt, Jena Glass, p. 176. Macmillan Co., London, 1902.

the softer metals, such as aluminum, copper, and soft iron, will scratch ordinary glass. This ambiguity concerning the position of glass on the hardness scale has been overcome by the use of the indentation method of determining hardness developed by Knoop, Peters, and Emerson,[2] which indicates that the hardness of soda-lime-silica glass on Mohs' scale is approximately 5. Evidently the ability of a substance to scratch glass is not uniquely given by its rating on Mohs' scale.

II. What Is a Scratch?

The apparent discrepancy that substances softer than glass will scratch glass raises the question as to what precisely is meant by a scratch. Bailey[3] describes two kinds of scratches, viz., (1) surface abrasions and (2) scratches produced by crushing the surface.

(1) Surface Abrasions

Three types of surface abrasions can be produced, depending on the speed of rubbing and the applied pressure, when a sharp corner of one piece of glass is dragged across the smooth surface of another. Under light pressure, the abrasion is confined to the surface layers. Under considerable pressure, a series of embryo conchoidal fractures or cracks, usually at right angles to the path, are formed and the mechanical strength is affected. Under considerable pressure with rapid rubbing, the heat which is formed causes the loose particles of glass to melt together into flakes; a groove unaccompanied by visible cracks is formed, but the mechanical strength is not affected.

(2) Scratches Produced by Crushing the Surface

This second type of scratch is produced by any hard pointed object. Light pressures are sufficient to form a series of very small conchoidal fractures; the central portion of such a scratch is usually crushed and sometimes pulverized, and many chips of glass fly out. Scratches of this type, formed by specially designed cutting wheels, differ slightly in that the glass ahead and behind the wheel is put into high tension so that a deep vertical crack is formed under the wheel with a minimum of chipping. A diamond cutter crushes the surface, wedges it apart, sometimes with chipping, and forms a vertical crack. All scratches of this type cause a great reduction in mechanical strength.

If scratches of type (2) only are considered in the formation of which a groove is made and material is removed from the glass surface, there is no ambiguity in assigning glass a place on Mohs' scale of hardness. On the other hand, softer materials do not remove material from the glass surface and there is no crushing or abrading of the surface. The scratch produced by softer materials, such as soft metals, is therefore in a different category from those listed by Bailey.

[2] E. Knoop, C. G. Peters, and W. B. Emerson, "Sensitive Pyramidal-Diamond Tool for Indentation Measurements," *Jour. Research Nat. Bur. Stand.*, **23**, [1] 39–62 (1939); R.P. 1220; *Ceram. Abs.*, **18** [11] 307 (1939).

[3] James Bailey, "Scratch-Resisting Power of Glass and Its Measurement," *Jour. Amer. Ceram. Soc.*, **20** [2] 42–52 (1937).

III. "Chatter-Sleek" Scratch

A study of commercial problems relating to the use of glassware during the past two years has brought this type of scratch to the attention of the writers. Figure 1 shows a scratch made by dragging a blunt copper point over a clean piece of window glass. It is made of a series of percussion crescents, perpendicular to the direction of motion of the point. Bits of metal left on the glass surface are clearly visible, but it will be seen that no material is removed and there is no groove in the glass surface as in the case of the scratches which Bailey describes. Figure 2 shows another section of the same scratch after etching for three minutes in a 2% solution of hydrofluoric acid; this treatment evidently develops the crescents so that they are much more clearly visible.

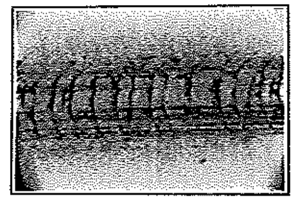

Fig. 1.—A chatter-sleek scratch made by dragging a blunt copper point over a clean piece of window glass. The series of percussion crescents perpendicular to the direction of motion are clearly visible. The dark markings parallel to the direction of motion are bits of metal which adhered firmly to the glass surface; 75×.

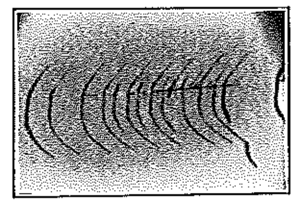

Fig. 2.—A chatter-sleek scratch made by copper, similar to that in Fig. 1 except that the percussion crescents have been developed and the adhering material removed by three minutes of etching with 2% hydrofluoric acid.

Similar chatter sleeks may be formed in the same way with loaded points of a variety of hard and soft metals. Heavily loaded blunt points of hard materials crush the glass in addition to forming chatter sleeks. As the load is increased from light to heavy, there is a transition from the third type of scratch, the chatter sleek, to the second, in which material is removed and crushed.

The tiny percussion-crescent cracks which constitute the chatter sleeks markedly decrease mechanical strength. A decrease in mechanical strength, therefore, does not depend on a groove type of scratch, i.e., the removal of material from the glass surface, but it may be produced by a single tiny percussion crescent or by any other minute break in the surface of the glass.

Because the chatter sleeks formed by metals dragged over glass surfaces have a pronounced effect on the mechanical strength of glass, it was considered important to get comparative data on the loads required by various metals to form the chatter sleeks, as well as any other factors which enter into the formation or prevention of the chatter sleek. These are the objectives of the experimental work which follows.

IV. Apparatus

The apparatus (Fig. 3) for scratching glass with metals consists mainly of an arm carrying a pointed tool of the metal under investigation, which rests on a glass surface and is loaded by means of weights placed directly above it. The tool is made from rod $^1/_4$ inch in diameter with one end turned to a hemispherical shape and polished with garnet paper. This blunt point is clamped to the arm at an angle of 45 degrees, and as the point in contact with the glass wears down, a new surface is obtained by turning the rod and reclamping it.

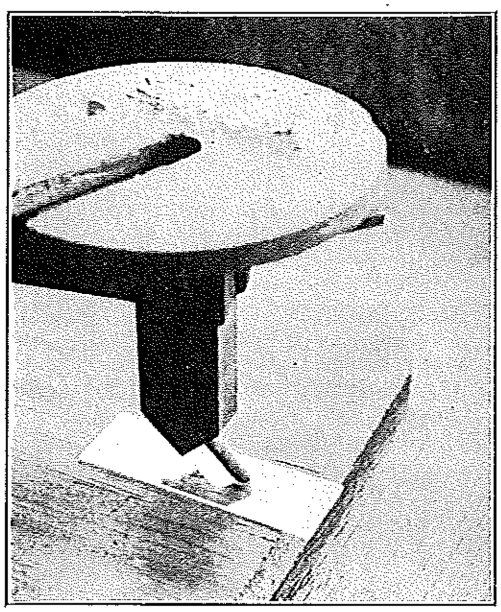

FIG. 3.—The scratching apparatus showing the hemispherical point, the angle of contact of the point with the glass surface, and the method of loading the point. The scratching is accomplished by pulling the glass specimen to the right.

The glass was tested by pulling it at a uniform rate in the direction toward which the rod was inclined. Under these conditions, a series of percussion crescents might be formed, and at the same time a more or less high-pitched noise would be made by the tool and glass. The lowest value of load, or initial load, at which the percussion crescents were formed was found by varying the load in steps and by examining the glass microscopically after etching in hydrofluoric acid.

The removal of foreign material from the glass surface and from the scratching tool by thorough cleaning was necessary to get consistent and repeatable results; otherwise these materials lubricated the surfaces in contact and increased the load necessary for scratching. It is well known that lubrication is important in scratching glass by glass. Two bottles taken directly off the lehr, for example, will seize and scratch one another very easily when rubbed lightly together. If, however, the same bottles are allowed to stand in the open for a week, their surfaces will absorb enough foreign material to lubricate them and if they are rubbed together, seizure and scratching will not readily occur. An even greater lubricating effect may be obtained by rubbing the perspiration and natural oils from one's hand onto an otherwise fresh and clean bottle. From the nature of the processes responsible for the production of the scratches, it is to be expected that the cleanliness of the surfaces will likewise have an important role in the formation of chatter sleeks by blunt metallic points.

The glass therefore was cleaned, first by scrubbing with hot, soapy water and then by soaking in trisodium phosphate solution (3% NaOH equivalent) at 160°F. for 20 minutes, i.e., almost to the point that noticeable attack would occur on the glass surface. It was then washed in distilled water, dried in an oven, and tested shortly after being removed from the oven. The scratching point was also cleaned, and both the point and glass were handled with clean tongs in manipulating them. All of these steps were necessary to obtain the lowest values of the initial load for scratching, and the omission of any of them raised this figure; e.g., a final rinse by the laboratory tap water in place of distilled water would affect the result because the tap water is slightly contaminated with oil from the water pump.

V. Scratching of Clean Dry Glass by Steel

The results obtained for several different forms of steel and iron are given. Of these samples, soft steel

Sample No.	Steel	Initial load for scratching (kg.)
1	Soft steel (annealed)	0.23
2	" " (case-hardened)	.23
3	Drill rod (annealed)	.28
4	" " (tempered)	.20
5	Cast iron	.23

(samples Nos. 1 and 2) is a low-carbon steel, one sample of which was case-hardened in fused cyanide; drill rod (samples Nos. 3 and 4) is a medium-carbon steel, which may be highly tempered; and cast iron (sample No. 5) has the highest carbon content of these samples.

All of these materials have about the same initial load for scratching, and whether or not the steel is annealed has little effect on this figure. This behavior may be connected with shear-hardening of the point, which takes place as material is removed from the point. Hardened or tempered steel, however, scratches more uniformly than annealed steel; it is more consistent in its behavior, and for the same load, it does more damage to the glass, possibly because there is less wear on the point in this case.

VI. Scratching by Other Metals

Although different forms of steel give about the same initial load for scratching over a considerable range of hardness, other materials, which represent wider variations in hardness, give different initial loads (see Table I). The very soft metals, magnesium, tin, and lead, do not produce scratches in glass, but all of the others produce typical chatter sleeks. Figures 4 to 9 are photographs of the scratches produced by some of these materials. It is evident that there is a rough correlation between scratchability and hardness to the extent that the very hard metals, such as iron and chromium, produce scratches at the lowest values of load and in general produce many more percussion crescents at comparable loads.

TABLE I

Material	Initial load for scratching (kg.)
Chromium	0.20
Iron	0.23
Copper	0.51
Aluminum	1 to 2
Nickel	1 to 2
Brass	1.2 to 2
Zinc	2 to 3
Monel metal	2 to 3
Magnesium	No scratching
Tin	" "
Lead	" "

Except for chromium, all of these materials leave metal marks on the glass. With the soft metals, e.g., aluminum, both the metal mark and the crescents are wider than those produced by the harder materials, such as brass and steel, owing to the greater width of the contact point of the soft metal. This squashing of the soft metal points was minimized but not eliminated by rotating as well as by redressing the point frequently.

It is obvious that any flattening of the soft metal points and the resulting increased area of contact with the glass will decrease the load per unit area of the point. In Table I, only the actual initial loads are given, but because the actual point areas are not the same, it does not give a comparison in absolute measurements between the scratchabilities of the various metals.

With hard metals, it is easily demonstrated that the initial load, to produce scratching by a sharp point, is less than that for a blunt point because of the different area of contact. It is apparent, however, that even if this correction were made the softer metals would still scratch less easily than the harder ones and the very soft metals would not scratch glass at all.

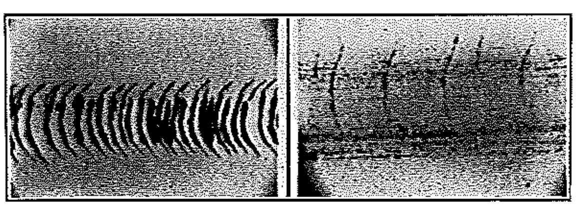

FIG. 4.—Typical chatter-sleek scratches formed by iron; *left*, etched; *right*, not etched.

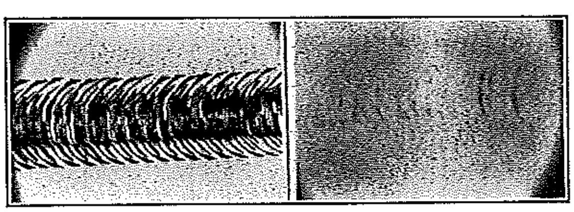

FIG. 5.—Typical chatter sleeks formed by nickel; *left*, etched; *right*, not etched.

VII. Effect of Dirty Surfaces

The foregoing measurements were made with dry glass. Table II shows the results obtained with brass and steel and with clean distilled water on the surface of the glass. The behavior of glass that was cleaned only moderately well is also shown.

Whether the glass is wet or dry evidently makes a difference in the initial load, especially in the case of somewhat dirty surfaces wherein the effect of water is to lower the initial load. Brass is more sensitive than steel in this respect, and glass surfaces somewhat more lubricated than those described cannot be scratched by

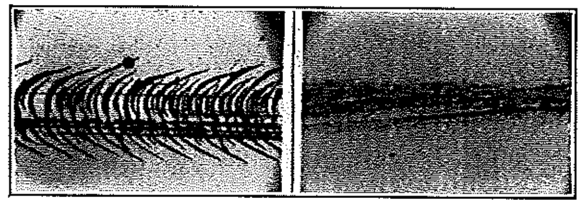

FIG. 6.—Typical chatter sleeks formed by chromium; *left*, etched; *right*, not etched.

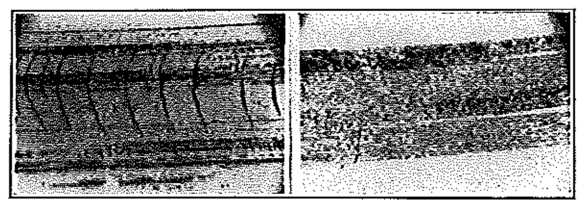

FIG. 7.—Typical chatter sleeks formed by zinc; *left*, etched; *right*, not etched.

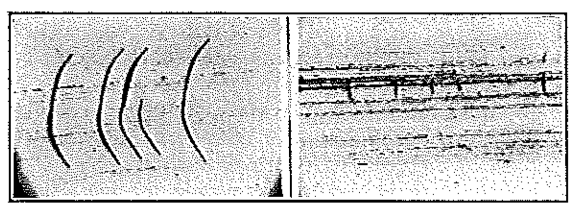

FIG. 8.—Typical chatter sleeks formed by aluminum; *left*, etched; *right*, not etched.

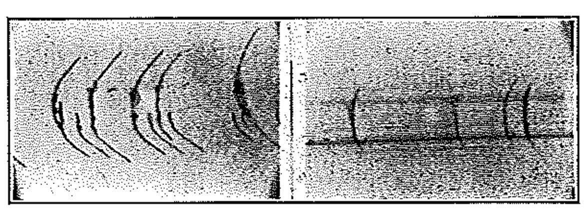

FIG. 9.—Typical chatter sleeks formed by brass; *left* etched; *right*, not etched.

dry brass although they may be scratched by wet brass. Water probably helps to remove foreign material from the surfaces in contact so that a figure nearer the initial load for clean glass is obtained. In the case of clean glass, there is no effect with iron when water is put on the glass, but the initial load with brass is increased. This is just the opposite behavior, but it is possible that the water is contaminating the clean glass.

Table II

	Condition of glass	Initial load (kg.)
Softsteel point	Dry, well cleaned	0.23
	" slightly dirty	.67
	Wet, well cleaned	.23
	" slightly dirty	.44
Brass point	Dry, well cleaned	1.2
	" slightly dirty	2.6
	" brass oxidized	3.2
	Wet, well cleaned	1.8
	" slightly dirty	2.0
	" brass oxidized	4.0

This work indicates that many soft materials will produce chatter sleeks in glass surfaces. The severity of damage as well as the initial load for scratching, in general, depends on the hardness of the material that is producing the scratch. It is also evident that lubricating films tend to prevent the formation of percussion crescents in the glass surface.

VIII. Production of Chatter Sleeks

Because of the periodic recurrence of the individual crescents which make up a scratch of this type, vibrations both of the point and of the glass are involved in the production of these crescents. In a section of one scratch, there were about 400 crescents to the centimeter, and because the glass was moved past the point at a speed of about 1 cm. per second, the cracks were formed at a rate of 400 per second. Sound of this frequency may be heard as the tool passes over the dry glass. A very high pitched note is also often heard, but this probably is a natural frequency of the glass, which is excited by the lower vibration.

The energy and amplitude of the vibrations of the point depend in a complicated way on the geometry of the point and of the system supporting it. Because of the low frequency usually involved, the mechanical system supporting the point probably is contributing something to the amplitude of the vibration; at these frequencies, which are not far from the natural frequencies of the supporting system, the support cannot be rigid, but it must also undergo harmonic motion and, to this extent, reinforce the energy of the vibrating point.

It is evident, therefore, that the nature of the mechanical system holding the point as well as the dimensions of the point itself are important in determining the initial load at which scratching will occur and also the severity of the damage to the glass. This has been substantiated by the results obtained from a much lighter system, holding a much smaller point; with this system, the initial load with iron points was decreased from 0.23 to 0.025 kg. The figures in Table II, which gives the initial load for scratching various materials, are therefore relative only to one particular apparatus. They indicate, however, the relative initial loads and scratching powers of these materials in any reasonably similar mechanical system.

The theory has been advanced from time to time that friction between the two surfaces heats up a thin surface layer of metal in contact with the glass until it melts and sticks to the glass. It is supposed that the metallic point heats up and sticks and then pulls against the glass until a typical percussion crescent is formed. The frequency of the vibrations corresponding to the production of the percussion crescents should accordingly be determined, not by the mechanical system supporting the point, but by the refractoriness* of the point by the pressure upon it and by the speed at which the glass is drawn past the point. Because many metals having lower tensile strengths than glass can produce these crescents, the problem must be a dynamic one in which the inertia of the moving point is used to build up the forces required to break the surface. Inasmuch as the production of the chatter sleeks is essentially a dynamic process, the individual elements may be referred to as "percussion crescents."

The coefficient of friction between the point and the glass is important in getting energy into the vibrating system, and the melting of a thin surface layer, if it occurs, will influence the scratches to this extent. This, however, is only a means by which the coefficient of friction may be increased and not fundamental to the production of the crescents. The varying behavior of the softer metals is connected as much with their hardness and tensile strength, and possibly with their modulus of elasticity, as with their refractoriness.

The fact that glass, if clean, may be scratched by materials very much softer than itself is a matter of great practical importance. The fact that the scratches so produced are of the chatter-sleek type affects the subsequent course of events and the strength of glass in a very peculiar fashion. These matters will be discussed in a later communication.

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* Bailey discusses the fusibility and refractoriness of glass, quartz, and abrasives, and calls attention to the fact that heating processes bring new factors into the scratching of glass surfaces, but he does not explicitly apply this idea to metallic scratching points (see footnote 3).