CORDS AND SURFACE-MARKINGS IN GLASSWARE¹

By F. E. WRIGHT

ABSTRACT

In the manufacture of glassware it is important to distinguish between surface-markings and cords, both of which are serious defects and detrimental to quality. To do this immerse the piece of glass under test in a liquid of the same refringence and sight through liquid and glass toward a distant light. Under these conditions surface-markings disappear altogether. Cords, on the other hand, stand out more distinctly than before.

The relative refringence of a cord compared with that of the adjacent glass can also be determined at the same time. For ordinary crown glasses monochlorobenzene is suggested as an immersion liquid. To lower its refractive index add benzene; to raise it add carbon bisulfide or monochloronaphthalene.

Cords are unwelcome guests in glassware because they appear even to the casual observer as flaws and blemishes in otherwise clear glass. Glass intended for the better grades of jars and tumblers, for chemical ware, electric lamp bulbs, lamp chimneys, and the like should be free from defects of this sort. To the manufacturer their presence may mean discard of the finished article and financial loss; they signify to him a fault in manufacture, such as inadequate mixing of the batch, pot or tank-wall solution, or improper furnace control. They cannot be removed by any subsequent manufacturing operation after the glass has left the melting furnace. Cords are the trails left by currents of material of slightly different chemical composition within the molten glass. To the eye they appear like cords, strings, threads, ribbons, veins, or streaks of colorless material suspended in the glass; hence the variety of names used to describe the different types of striae.

Optical effects similar to those produced by striae may also result from the presence of faint markings or irregularities on the surfaces of the finished glass article. Under certain conditions these markings may become sufficiently serious to cause rejection of the finished article.

¹ Received April 11, 1921.

It is important for the factory foreman to distinguish between cords and surface-markings so that in a given case he can diagnose the trouble correctly and then apply the proper remedy. The purpose of this note is to describe simple methods for the diagnosis of these defects in glassware; in particular to distinguish between surface-markings and striae or cords; and, in the case of cords, to ascertain their refringence relative to that of the enclosing glass and thus to ascertain their probable composition.

In the manufacture of glassware the ordinary factory procedure is to draw from the pool of molten glass within the melting furnace a sufficient quantity of glass on the end of a blow-iron or puntty, and, while the glass mass is still hot, to blow, press, or mould it into the desired shape. If on removal from the furnace the glass is too cold and too viscous, the corrugations and indentations on the surface of the ball of molten glass on the end of the blow-iron are not entirely effaced by flow, with the result that during the blowing or pressing operations these surface irregularities persist and are drawn out into fine thread and ribbon-like surface-markings which may resemble cords. They are less serious from a glass maker's standpoint than are cords because they can ordinarily be eliminated by simple means.

The obvious remedy for surface-markings is to increase the liquidity of the melt either by raising its temperature at the point where it is withdrawn from the furnace or by changing the composition of the batch so that at the given temperature the glass melt is sufficiently mobile.

Another source of trouble may be corrosion of the tank or pot walls whereby alumina is introduced as a silicate into the melt, thereby changing its viscosity locally; under these conditions cords may be expected in the glass in addition to surface-markings. The process of assimilation of clay material dissolved from the walls of the container is necessarily slow and the chances are favorable that strings, threads, and ribbons of the dissolved material are carried by convection or other currents into the body of the molten glass mass, and may persist as streaks of slightly different composition for long periods of time. Striae mark the stream lines or paths taken by some of these currents within the pool of molten glass. In each case it is desirable to ascertain the cause

of the local inhomogeneity in composition and to trace it back to its source. The following relations are significant in this connection. Observation has proved that the composition of the surface, to a depth of half a millimeter or more, of a pool of molten glass is slightly different from that of the main body of the melt. This is true even in an optical glass melt which is stirred vigorously for many hours. This surface film is higher in silica and lower in alkalis than the underlying glass; its formation is due to selective volatilization, especially of the alkalis, from the liquid glass. Its refractive index is lower than that of the subjacent glass; it is also generally more viscous because of its higher silica content and if carried down into the body of the melt gives rise to striae which, if heavy, are objectionable. In case alumina is introduced from the walls of the container, streaks of glass richer in alumina are to be expected and these, in ordinary glasses, may have a higher or a lower refractive index than the adjacent glass. If the refractive index of a cord is found to be higher than that of the glass surrounding it, the source of trouble may be corrosion of the container walls (pot solution) or an original difference in composition not entirely eliminated by diffusion within the pool of molten glass.

In a large pool or pot of molten glass the conditions are such that homogeneity throughout the mass is not and probably can not be attained. This means that, because of currents and differences of viscosity, some cords and striae are ever present within the metal and in process of further attenuation and assimilation. It is the task of the glass maker to keep these striae within bounds so that in the finished article they are fine and scarcely noticeable except on close inspection. The more definite facts he can obtain regarding cords and surface markings in any given case the better is he able to infer the real source of trouble.

The reason why cords and striae are visible in glass is because their index of refraction is different from that of the surrounding glass. If it were possible to ascertain the refractive index of a given cord or even its refringence relative to that of the glass in which it is embedded, a series of simple experiments with any given glass composition would enable the glass maker to determine the effects which changes in the composition of the glass produce on

the refringence relations. Having thus ascertained, for example, the changes produced by the addition of clay (pot-solution) and compared its effect with that produced by an excess of silica or a decrease in alkalies, he is able to state with some assurance in a given case whether pot-solution or volatilization is the cause of the cords.

The methods for distinguishing surface markings from cords are fortunately easy of application and do not require elaborate apparatus; furthermore the refringence of a cord relative to that of the surrounding glass can be readily ascertained. These methods will now be described briefly.

The effect of irregularities in the surface of glass on rays of light is to deflect them from their straight course. The more pronounced the markings, the greater the degree of deflection and the more readily are the markings seen. Their effect on rays of light is similar to that exerted by a hand lens or a burning glass, namely, to refract and diffract the light. The amount of deflection produced by a given lens or surface corrugation depends on the difference in refringence between the glass and its surrounding medium. It is possible to choose a liquid which for a given color of light has exactly the same refractivity as the glass; in this case the rays of light pass through the glass surface into the liquid without any perceptible deviation; the surface markings disappear altogether and can not be seen even under the most favorable conditions of observation. Cords and striae, on the other hand, are completely surrounded by glass and the liquid does not come into contact with them; under these conditions they do not disappear when the glass is immersed in a liquid of the same refractive index but become more conspicuous because all surface irregularities are virtually suppressed and these tend ordinarily to obscure or veil striae.

The refractive index of ordinary crown glasses for yellow light ranges between 1.515 and 1.525, and for these a satisfactory immersion liquid of about the same refractive index is mono chlor-benzene.¹ To determine whether the cord or striae-like mark-

¹ Obtainable from any dealer in chemical supplies. In a recent list from the Eastman Kodak Company the price for 5 kilograms of monochlor-benzene is stated to be \$3.

ings exhibited by a piece of glassware are actually cords or surface markings the article is viewed first in air and then while immersed in a tank of monochlorbenzene. A suitable tank can be made by bending a flat piece of heavy metal (iron, brass, or copper) into a flat-bottomed U-shape; this forms the bottom and two ends of the tanks; the two sides are of plate glass cemented to the metal with a mixture either of Le Page's glue and plaster of paris or of lime and zinc oxides in sodium silicate (water glass). A square fish aquarium serves the purpose well, provided its sides are of plate glass. For these experiments a distant source of light (electric lamp bulb ten or more feet distant) is used (figure 1).

FIG. 1.—Optical arrangement suitable for distinguishing between surface-markings and cords. The glass sample is immersed in a liquid having the same refractive index and contained in a tank with parallel glass sides. The immersed sample may be viewed against a distant light with or without the aid of a hand lens.

Surface markings on a piece of glass examined under these conditions of immersion disappear altogether, whereas striae and cords stand out more clearly than ever. It may be noted that in every case it is necessary to have all surfaces of the article under examination in contact with the liquid in order to avoid total reflection and other disturbing phenomena. This means that lamp bulbs, tumblers, and other hollow articles should be filled with the liquid as well as immersed in it.

A simple test to ascertain if the liquid and the immersed piece of glass have the same refringence is to sight through the immersion tank toward the distant light and to note that the light does not shift its position when the immersed piece of glass is placed in the line of sight. If the light does shift, the refringence of the liquid is either too high or too low. Let us suppose the piece of glass is wedge shaped. Move it so that the thin edge crosses the line of sight first; then if the light is seen to shift *toward* the glass block, the liquid has a lower refractive index. Thus if the

block with its sharp edge to the left, is moved across the line of sight from right to left and the source of light is thereby deflected toward the right, the refractive index of the liquid is too low, and vice versa. When the refractive index of the liquid and glass are the same for yellow light, red and blue color fringes appear on opposite sides of the glass block. The refractive index of the immersion liquid can be lowered by the addition of benzol or some still lower refracting liquid; it can be raised by adding monochlornaphthalene¹ or carbon bisulfide or other strongly refracting liquid.

The immersion test is extremely simple and enables the operator to determine definitely at a glance whether the source of trouble is surface markings or cords. It is a fact of observation that in blown or pressed ware the surface markings are confined chiefly to the exterior surfaces and appear rarely on the inner surfaces.

With the aid of a pocket hand lens or low-power magnifying glass (watch-maker's glass) it is possible at the same time to determine the refringence of a cord relative to that of the adjacent glass. To do this, sight toward the distant light through the magnifying glass and in the direction of the glass article immersed in the tank (figure 1). Move the eye and lens toward or away from the piece of glass until the cords are brought to sharp focus and the fine details can be readily seen. Now draw the eye and lens a short distance back from the position of sharp focus and observe the change in illumination over the cord or striae. In case the cord has a higher refractive index than the glass, the rays of light are convergent and the center of the cord in the new position appears brighter than the adjacent field. The reverse is true for a cord of lower refractive index; also for a cord of higher refractive index when the eye and lens are moved from the position of sharp focus nearer to the cord. In these cases the center of the cord appears darker than the adjacent field.

Under these conditions of observation, diffraction phenomena give rise to series of narrow alternate light and dark bands which at first may be disturbing to the observer; but after a few trials their presence is recognized as inevitable and they do not actually

¹ Made by the Condensite Company of America, Bloomfield, N. J., under the trademark "halowax oil."

interfere seriously with the results. They can be largely eliminated if a different mode of illumination be used, namely, a ground-glass plate, a foot square, not too far distant (several feet), and illuminated from behind by an electric lamp bulb; directly in front of the plate a perforated screen or lattice work is placed. The bars in a distant window may serve the purpose equally well. Under these conditions of oblique or half-shadow illumination, the cords exhibit a one-sided illumination and appear to stand out in relief. In this method a hand lens is not required, but may be used to render details more easily seen. From the relation of the shadow-side of the cord to that of the direction of the incident light the relative refringence of the cord can be readily deduced. For example, let the line of sight be toward the sky or horizon as seen through a distant window. Bring the sample of glass into the line of sight and look at it instead of at the distant window. Note that now the sides of the window are no longer sharp; but there is a gradual transition from light near the center of the window to dark beyond the sides. If a cord in the glass sample falls within the half-shadow on the left of the window and the side of the cord facing the shadow (left side) is brighter than the opposite (right) side, the refringence of the cord is higher than that of the surrounding glass. Because of the variety of shapes of cords, several cords should be tested before a definite conclusion is reached. If surface-markings are present, the sample should be tested while immersed in the proper liquid.

GEOPHYSICAL LABORATORY
CARNEGIE INSTITUTION OF WASHINGTON
MARCH, 1921