NOTES ON DIAGNOSING CAUSES OF CORDS IN GLASS

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ABSTRACT

The physical properties, *e. g.*, refractivity, viscosity, and expansion coefficient, of cords generally differ from those of the mass of the glass. Methods are described for rapidly ascertaining the relative values of these properties. This information, together with a knowledge of the batch ingredients and possible impurities may afford in certain cases a means of determining the cause of the cords.

A great deal of information may often be obtained very rapidly by using the following methods of examination:—

1.—Are the cords of higher or lower refractive index than the mass of the glass?

Fig. 3

A straight line, such as a window blind cord or line drawn on paper, is observed through the glass under examination in such a way that the line is intersected obliquely by the cord. The line should not be too far away, nor the glass too near the eye, in order that both should appear simultaneously in focus. A cord of high refractive index would then cause distortion as in Figure 1, and one of low refractive index as in Figure 2. It is obvious that precisely the same effect would be caused by a

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streak irregularity in the surface—a ridge in the first case and a depression in the second; and some such irregularity is nearly always present in the cords which occur in practice.

In all but the most extreme cases, however, the refractive index effect would outweigh that due to irregularity of surface. Immersion in a homogeneous liquid of suitable refractive index would in any case eliminate this source of error.

2.—Is the cord of higher or lower viscosity than the remainder of the mass?

If a cross-section is taken along the cord, and its direction noted, particularly whether it emerges from the glass surface (as it frequently does), one can generally state whether the cord was of higher or lower viscosity than the remainder of the glass when moulding occurred.

FIG. 4.

In the diagram (Fig. 3) the left hand figure represents the cross-section of a gathering in process of blowing, and the black dot is a cord. Then the cord will flow outward in a more or less stream-like manner, finding an outlet at the free surface, as indicated by the successive figure to the right, and if of lower viscosity it will at the surface flow over the remainder of the glass. If it is of higher viscosity this will not occur, but the remainder of the glass will flow over it.

This effect may be further illustrated by the photographs reproduced. Figure 4 is a low power photomicrograph of a portion of the side of a bottle, viewed through the side in the ordinary way, but with the surfaces ground and polished. Two cords are seen crossing at right angles, one clear and

distinct, the other rather diffuse. The former was due to a fold in the glass, the latter to a cord such as I have described. Cross-sections of each of these cords were cut by planes perpendicular to the plane of the paper. These were polished and photographed. That of the vertical cord (Fig. 5) which the original sample showed clearly as a fold, is not quite so convincing in the photograph. The other cord, however, shows in cross-section (Fig. 6) a decided streaming outwards, and it should be noted that a streak of severe double refraction was present in the glass which coincides with the stream, and which could not be removed by annealing.

FIGS. 5 AND 6.

3.—Had the glass in the neighborhood of the annealing temperature a higher or lower coefficient of expansion?

If by observation in polarised light the direction of strain is noted within the cord, namely, whether it is compression or extension, one can immediately say whether the coefficient of expansion of the substance of the cord was higher or lower than that of the mass of the glass.

4.—Occasionally devitrification occurs within the cord. If this is the case, it indicates a high probability that the cord is more liable to devitrification than the remainder.

Generally speaking, cords are not the result of devitrification of a portion of the glass of the same composition as the mass. On the contrary, in those cases when devitrification is present within the cords, the glass forming the cord has been contaminated in such a way, for example, by excessive lime content, as to give rise to devitrification.

All cords examined by the writer have had physical properties differentiating them in a marked degree from the mass of the glass. It does not appear that cords can occur in a homogeneous melt, even though, in the process of gathering and moulding, extreme differences of temperature and consequently of viscosity, have been temporarily introduced. There is, indeed, an action which tends to rapidly efface such differences of temperature. Those regions which are hotter are, of course, less viscous, and in the blowing rapidly become thinner than the remainder. Once thinner, radiation soon renders them cooler than the remainder; and it is then the latter which begins to get thin more rapidly. Briefly, then, so long as one portion of the article is thicker than the rest, it remains hotter, and hence gets thin more rapidly; while so long as one portion is thinner than the remainder it soon gets cooler, and therefore gets thin more slowly. There is thus a powerful influence at work, tending towards uniformity alike of thickness and temperature. Folds of course do occur owing, probably, to a very sudden chilling of that portion of the glass which touches the mould first.

Contamination may easily occur through the careless introduction into the furnace of some substance of low surface tension, followed immediately by such a substance as will float, and, by dissolving, cause cords—lime, for instance—which will be carried rapidly across the surface in an undissolved state, unless an effective surface baffle is employed, thus increasing locally the lime content. Or the impurity (*e. g.*, lime) may by its own solution, cause variations of surface tension, causing it to travel across the surface.

If, then, the co-relation between

- (a) refractive index,
- (b) viscosity,
- (c) coefficient of expansion,
- (d) liability to devitrification,

and the various constituents or impurities of the glass are known, a very rapid diagnosis may be made in many cases, and may immediately fix the cause of the cords.

Discussion

BY G. W. MOREY:—Careful study of the imperfections in glass may be made to yield information of great value to the glassmaker, and often may suggest a modification of procedure which will eliminate the cause of the imperfection. The determination of the relative refractive index by the method suggested, which is essentially that already described by Wright,¹ is of especial value in ascertaining the source and cause of cords and striae and has many times proven serviceable to me. It is surprising how prominent a cord appears whose difference in refractive index from the surrounding glass is only one point in the third decimal place, and this amount is generally sufficient to enable one to ascertain which of the two has the higher refractive index, especially if the glass be immersed in a liquid of approximately the same refractive index. In the writer's experience, cords of higher refractive index than the glass are of rare occurrence, and have been caused by insufficient mixing of the melt.

It is correct to state that if the cord has a different coefficient of expansion than the glass, strain will result, but this is caused by the difference of expansion coefficient not only in the neighborhood of the annealing range but also, and more particularly, below the annealing range. Indeed, such glass might be cooled throughout its annealing range in such a manner that no strain appeared, but when cold, strain would be present.

It is of course conceivable that devitrification might take place within the cord, but, as a rule, when crystalline material is found in cords, it is more probable that the crystalline material itself is the cause of the cord. The optical identification of the crystalline material as described by Bowen² is of the greatest value in locating the source of cords caused in this manner.

¹ Wright, *Jour. Am. Ceram. Soc.*, **4**, 655-661 (1921).

² *Ibid.*, **1**, 594-605 (1918).