M. D. G. Dabbs,[1] *B.Sc., and E. F. Pearson*,[1] *Ph.D.*

Some Physical Properties of a Large Number of Window Glass Specimens

In forensic science laboratories it is frequently necessary to compare the properties of glass fragments and excellent methods are available for determination of their refractive index and density. Following a comparison of glass fragments which prove to have similar physical properties it is often helpful to assess the frequency of their occurrence in relation to other glasses. However, there has been little work published [*1–3*] showing the refractive index or density distributions of window glasses in England and Wales.

The Atomic Weapons Research Establishment under contract to the Home Office undertook a nationwide survey of window glasses in which 94 fire brigades throughout England and Wales were asked to supply specimens of window glass broken at a predetermined number of fires. This assured a representative, random selection of glass.

Each brigade was asked to provide a certain number of specimens, which had been determined on a proportionate basis from the population covered by each brigade in England and Wales, as shown in Ref *4*. Envelopes on which was printed a short questionnaire (Appendix) asking for details of the age and type of building from which the glass specimens were obtained were sent to each brigade. The chief officers of each brigade were asked to distribute the envelopes so that each full-time station within the brigade enclosed a specimen of broken window glass from each of two separate fires. It was requested that single pieces of glass not more than a few square inches in size be picked from window glass broken in some way but not affected by intense heat during a fire.

The specimens were collected between August 1968 and May 1969. A total of 1272 specimens was requested from the fire brigades and 939 were received for analysis. The refractive index, density, thickness, and fluorescence of these specimens was measured at the Central Research Establishment and the correlation between the refractive index and density of each were determined.

Experimental

Analysis Procedures

Refractive Index Determinations—The specimens were cleaned in hot, concentrated nitric acid, rinsed in distilled water, and dried. Pieces of glass measuring approximately 2 by 2 cm were cut from the larger specimens and the refractive indices of those pieces which had smooth, undamaged surfaces were measured on a Hilger & Watts Abbé refractometer using sodium light illumination. Eight readings were taken on each piece, one reading on each edge of the two faces, and the results were averaged arithmetically.

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[1] Home Office Central Research Establishment for Forensic Science, Aldermaston, Reading, Berks, England.

Previous work [5] has shown that the standard deviation obtained with this procedure is 0.0001.

The refractive index of the patterned or damaged glass and those specimens which gave a poor reading using the Abbé refractometer was determined by the Becke line method using a Mettler FP2 hot stage [6]. One reading was taken on each specimen using silicone fluid MS710 (Midland Silicones Ltd., Barry, Glamorgan, England) as the immersion medium. The standard deviation obtained with this procedure has been shown [5] to be 0.00002.

Density Determinations—The density of each glass was determined from a specimen weighing 15 g or more by weighing in air and again in water using an Oertling constant load, single pan balance. The weight of the supporting thread was taken into account but no air buoyancy correction was made. Density was calculated from the formula

$$\text{density} = \frac{\text{weight of specimen in air} \times \text{density of water}}{(\text{weight of specimen} + \text{thread in air}) - (\text{weight of specimen} + \text{thread in water})}$$

The density of water (g/cm^3) at the temperature of the experiment was obtained from tables [7]. The standard deviation of this method was found to be 0.0003 g/cm^3.

Thickness Measurements—The thickness of those pieces of glass which had smooth, undamaged surfaces was measured to 0.05 mm using a vernier caliper gage.

Fluorescence Measurements—Each specimen of glass was examined on both sides for fluorescence using a Camag Universal ultraviolet lamp (TL-900/u) at 254 nm. One drop of hydrofluoric acid (40 percent) followed by one drop of a 0.1 percent solution of cacotheline in water was added to those specimens showing fluorescence at 254 nm. The color reaction (if any) was recorded.

Results

Refractive Index—The refractive index of 657 specimens was determined with the Abbé refractometer and of 282 specimens with the Mettler FP2 hot stage. A frequency distribution of the refractive index of all 939 specimens examined is shown in Fig. 1. Of the 282 specimens whose refractive index was determined with the Mettler FP2 hot stage, 128 were patterned or frosted glass, 129 contained fine cracks characteristic of heat damage, and the remaining 25 had previously given variable readings on the refractometer or failed to give a sharp cutoff between the light and dark zones in the refractometer telescope.

A chi squared test carried out between the undamaged specimens and those showing signs of heat damage gave a value for chi squared of 7.01 (four degrees of freedom). The value from tables [8] at the 10 percent level of significance is 7.78; thus, there is no evidence of a statistical difference between the results obtained with the two measurement techniques.

Density—The density of 338 specimens was determined in duplicate. A frequency distribution of the densities is shown in Fig. 2.

Thickness—Of the 939 specimens received for analysis, 128 were either frosted or patterned glass. A total of 850 were suitable for thickness measurement and the frequency distribution of the thicknesses is shown in Fig. 3.

Fluorescence—Table 1 shows the color of fluorescence and reaction to cacotheline (due to the presence of tin) of those specimens exhibiting fluorescence at 254 nm.

The Effect of Building Age—The refractive index distribution of 400 glass specimens taken from buildings with an estimated construction date before 1901 is shown in Fig. 4. This figure also shows the refractive index distribution of 263 specimens taken from buildings with an estimated construction date between 1901 and 1944 as well as the

TABLE 1—*Specimens showing fluorescence at 254 nm.*

Specimen Number	Color of Fluorescence	Sides	Reaction with Cacotheline
9	Amber	Both	None
51	Blue	Both	None
100	Green	One	Violet coloration
123	Blue	Both	None
198	Yellow	One	None
280	Violet	Both	None
307	Violet	One	None
343	Violet	One	None
377	Green	Both	None
403	Violet	One	None
421	White	Both	None
571	White	One	None
606	Violet	Both	None
610	Blue	One	None
698	Blue	One	None
699	Blue	One	None
701	Green	Both	None
792	Violet	Both	None
831	White	Both	None
849	Blue	One	None
927	White	Both	None

refractive index distribution of 241 specimens taken from buildings with an estimated construction date between 1945 and 1969. Thirty-five buildings were not classified as to construction date.

The Effect of Building Type—Information was obtained on five types of building, namely, private dwellings (460 specimens), factory premises (151), offices (20), shops (96), and all other types of buildings (212). In order to make statistical comparisons the specimens from

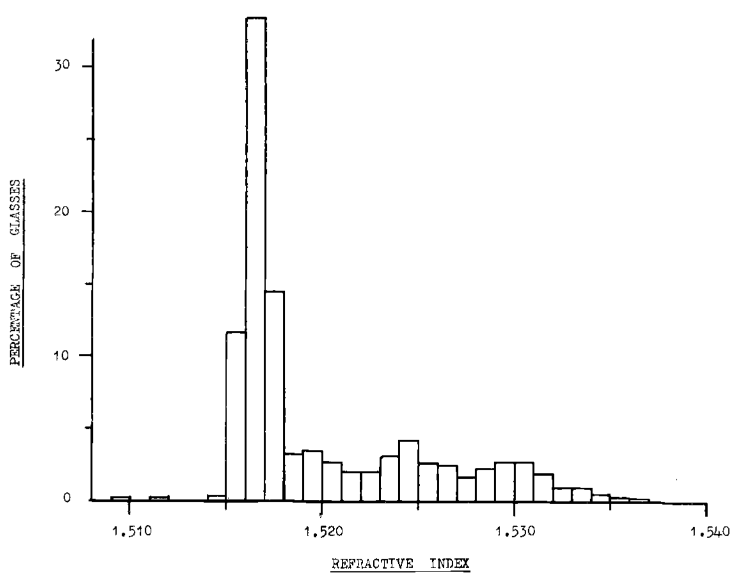

FIG. 1—*Refractive index distribution of 939 fire survey specimens.*

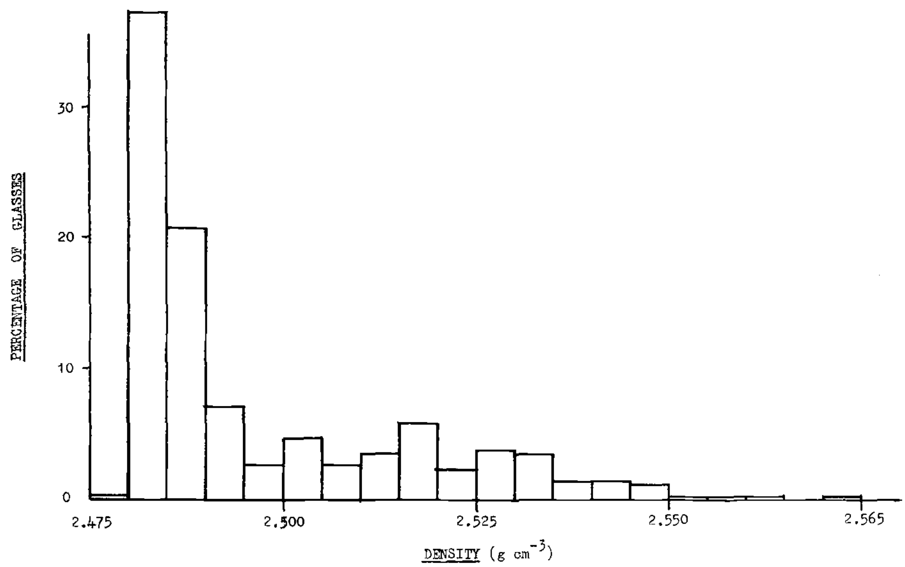

FIG. 2—*Density distribution of 338 specimens of window glass broken in fires in England and Wales.*

factory premises, offices, and shops were grouped together. The refractive index distribution of each of the three resulting building types, (*i*) private dwellings, (*ii*) factories, offices, and shops taken together, and (*iii*) all other building types, was compared to the combined refractive index distribution using the chi squared test.

The following chi squared values were obtained: (*i*) private dwellings, 21.0 (19 degrees of freedom); (*ii*) factories, offices, and shops, 19.3 (13 degrees of freedom); (*iii*) all other building types, 18.6 (13 degrees of freedom). In the case of private dwellings the value of chi squared obtained is less than the value at the 20 percent level of significance from

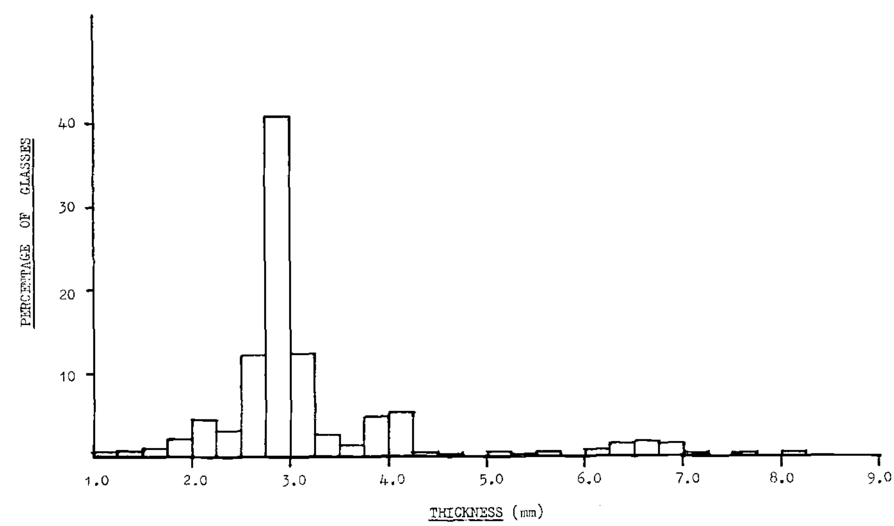

FIG. 3—*Thickness distribution of 850 specimens in the fire survey.*

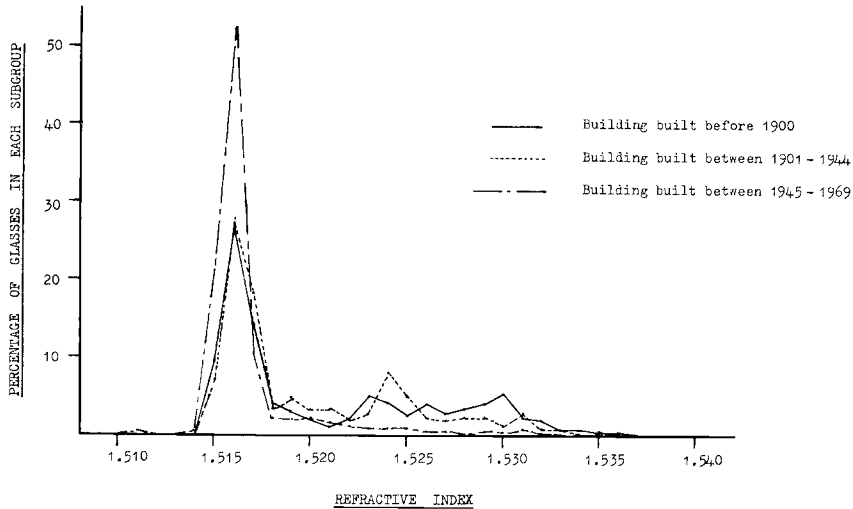

FIG. 4—*Relation of age of building to the refractive index distribution of glass broken in fires in England and Wales showing glasses as a percentage of each subgroup.*

tables; for factories, offices, and shops and for all other building types the values of chi squared obtained are less than the corresponding values at the 10 percent level of significance taken from tables.

The Effect of Geographical Location—The specimens were divided into four groups according to the geographical location of the building from which the specimen was taken. The divisions followed national and county boundaries and were arranged as follows:

Group 1—Buckinghamshire, Bedfordshire, Berkshire, Essex, Hampshire, Hertfordshire, Kent, London, Middlesex, Oxfordshire, Surrey, Sussex (320 specimens received).

Group 2—Cambridgeshire, Cheshire, Derbyshire, Huntingdonshire, Leicestershire, Lincolnshire, Norfolk, Northamptonshire, Nottinghamshire, Staffordshire, Suffolk, Warwickshire, Worcestershire (207 specimens received).

Group 3—All of Wales, Cornwall, Dorset, Devon, Gloucestershire, Herefordshire, Monmouthshire, Shropshire, Somerset, Wiltshire (128 specimens received).

Group 4—Cumberland, Durham, Lancashire, Northumberland, Westmorland, Yorkshire (284 specimens received).

The refractive index distribution of each of these four groups was compared to the combined refractive index distribution using the chi squared test. The following chi squared values were obtained:

Group 1, 20.3 (17 degrees of freedom)
Group 2, 10.3 (13 degrees of freedom)
Group 3, 8.9 (6 degrees of freedom)
Group 4, 15.4 (17 degrees of freedom)

The values of chi squared obtained for groups, 1, 2, and 4 are less than the values at the 20 percent level of significance obtained from tables. The value of chi squared obtained for group 3 is slightly higher than the value as the 20 percent level but is less than the value at the 10 percent level of significance.

Correlation of Refractive Index and Density Values—The correlation coefficient between refractive index and density was calculated to be 0.93 for the 338 specimens for which both parameters were measured. Application of students t test gave a value for t of 46.4. The value of t from tables at the 0.1 percent level of significance is 3.29 so the correlation is highly significant. Figure 5 shows the refractive index and density values of 100 of the specimens for which both parameters were measured. The number of points shown in the figure was limited to 100 for the sake of clarity.

Specimens Received for Analysis—A chi squared test comparing the number of specimens received from each of the 94 brigades (a total of 939) to the number requested (a total of 1272) gave a value for chi squared of 40.2 (57 degrees of freedom), which is less than the value at the 95 percent level of significance from tables.

Discussion

The fact that the refractive index distribution of those damaged specimens whose refractive index had been determined with the Mettler FP2 hot stage was statistically similar to the distribution of those whose refractive index had been determined with the Abbé refractometer shows that the former specimens should not be excluded from the survey. The greatest differences between the various refractive index distributions are those associated with buildings of different age.

It is known from information supplied by the manufacturers that in England and Wales most of the window glass manufactured since 1945 has a refractive index in the range 1.515 to 1.518. The refractive index distribution of window glass from buildings with an estimated date of construction after 1945, shown in Fig. 4, is in agreement with the manufacturers' information. It is clear however, that there is a considerable amount of glass in older buildings having a refractive index outside the range of modern production window glass.

It can be seen from Fig. 5 that at a given value of refractive index the range of density values obtained for glasses which can be considered to be older glasses (having a refractive

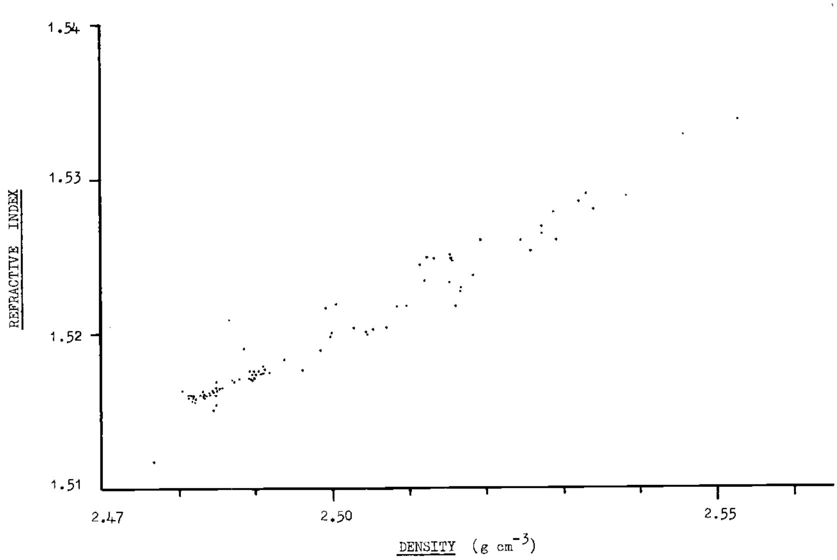

FIG. 5—*Plot of refractive index against density for 100 specimens of glass from the fire survey.*

index in the range 1.519 to 1.535) is much greater than that for modern glass. Because of the ease of measurement of the refractive index of glass using modern instruments and because accurate density determinations can be difficult, particularly when dealing with small specimens, a refractive index measurement may often be the method of first choice for the forensic scientist. The high correlation between refractive index and density shows that, in general, only limited additional information can be expected if a density determination is carried out as well as a refractive index determination. However, despite the high correlation a density determination may provide useful additional information, and this is more likely to be the case with glass having a refractive index in the 1.519 to 1.535 range.

Several well known equations relate refractive index and density and several papers [9–11] have been published which consider these relationships. The equations are

1. Gladstone-Dale $k = \frac{n - 1}{d}$

2. Lorentz-Lorenz $k = \frac{n^2 - 1}{n^2 + 2} \times \frac{1}{d}$

3. Eykman $k = \frac{n^2 - 1}{n^2 + 0.4} \times \frac{1}{d}$

4. Lichtenecker $k = \frac{\log n}{d}$

5. Newton-Drude $k = \frac{n^2 - 1}{d}$

where

k = constant,

n = refractive index, and

d = density.

Each equation implies a linear relationship between the refractive index and the density; however, several workers [1,12] have shown that the relationship is not always exactly linear and sometimes shows considerable deviation from linearity. This deviation is confirmed in the work reported in this paper, although the correlation between refractive index and density is extremely significant.

It has been shown only recently [5] that a variation in refractive index and density across a single sheet of modern window glass can exist. This heterogeneity may result in slight discrepancies between the refractive index and density determinations, but the combined measurement error and the inherent heterogeneity of the glass specimens do not account for the observed deviations from linearity. This wide deviation may be due to the fact that glass is a multicomponent mixture and changes in the amounts of two components produce a series of glasses whose refractive indices and densities vary essentially linearly. The addition or removal of components or variations in different components probably result in a different series of glasses whose refractive indices and densities again vary linearly but with a different constant of linearity.

There is no evidence in this survey that the refractive index distribution from any of the four geographical groups considered is different from the refractive index distribution of the survey taken as a whole. Although this similarity of distribution would also be expected for the respective density distributions, the information presented in this report should not be extended to include similarity in composition. There is no evidence in this survey that the refractive index distribution of any of the three building types, namely private dwellings, factories, offices, and shops taken together, and all other building types, is different from the refractive index distribution of the survey taken as a whole.

Of the 939 specimens examined 21 exhibited fluorescence and this appears to be a useful parameter. One specimen showed the presence of surface tin, that is, surface fluorescence on one side at 254 nm and a violet coloration after treatment with hydrofluoric acid and cacotheline solution. The fact that this fluoresecnce was detected on one side only suggests that this specimen was produced by the float process. Float glass taken over England and Wales as a whole evidently accounts for only a small percentage of all window glass.

Summary

Nine hundred and thirty-nine glass specimens have been collected from the scenes of fires in England and Wales. The refractive index of each glass was measured and, in addition, the density of approximately one third of the glasses was determined. The distributions of refractive index, density, and thickness are shown, and the variation in the refractive index distributions between different types of building, between buildings of different ages, and due to the effect of geographical location have been examined. No significant difference was found between glasses from different geographical locations or glasses from different building types when compared to the survey as a whole. The differences in the refractive index distributions between buildings of different ages are shown. The correlation between refractive index and density is discussed and shown to be 0.93 for these glasses.

Acknowledgments

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APPENDIX

The following is a copy of the questionnaire sent with each specimen envelope in the survey of window glass broken during fires:

PLEASE COMPLETE BEFORE RETURNING GLASS SPECIMEN

Brigade:
Station:
Call no.:

Type of building from which specimen was taken

(Tick as appropriate below)

Private dwelling:
Factory premises:
Offices:
Shops:
Other buildings (give details):
Approximate date of building construction (if known):

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Home Office Central Research Establishment
Aldermaston, Reading, Berks, R97 4PN
England