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Factors Affecting the Refractive Index Distribution of Window Glass

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ABSTRACT: A 400-sample glass refractive index (RI) survey is reported. Differences in RI distribution between sheet and patterned glasses and between glass from old and young buildings are reported and discussed.

KEYWORDS: engineering, glass, refractive index

Previous workers have reported refractive index (RI) distributions for populations of window glass [*1–5*]. Variations in the distribution because of age of building [*2*] and type of building [*3*] have been noted. I wish to report a variation in refractive index distribution between sheet glass and patterned glass.

As part of a survey of New Zealand window glass, 400 samples were obtained from a Christchurch glazier who sampled broken windows repaired in the course of his work. Samples obtained in this manner thus represent a random cross section of windows being broken in Christchurch, from both innocent and criminal activities.

Method of Analysis

Samples were cleaned, crushed, and their refractive indices measured by the Becke line method, using a Mettler FP5 hotstage and DC710 silicone fluid [*6*]. Calibrated silicone fluid was obtained from the Home Office Central Research Establishment, and the calibration of the whole system was checked by analyzing standard optical glasses KF3, PK2, K7, PK52, KF9, and KzF2 obtained from Jena^{er} Glaswerk Schott & Gen. of Mainz, West Germany.

All readings were made in duplicate, and the standard deviation for the method was found to be 0.00003.

Results

The refractive index distribution of all samples is shown in Fig. 1. The 400 samples may be divided into six types of glass, as listed in Table 1.

The total of 401 arises because one sample is a colored plate glass and is listed under both headings.

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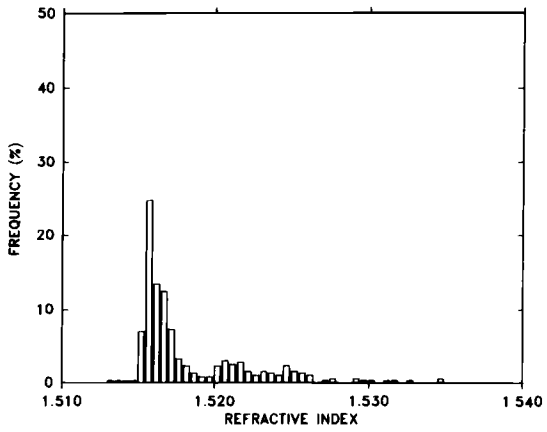

FIG. 1—*RI distribution of all samples.*

TABLE 1—*Six types of glass.*

Type of Glass	Number of Samples
Sheet	239
Patterned	103
Plate	25
Colored	18
Float	8
Wired	8
Total	401

The division into patterned, colored, and wired samples was based on macroscopic appearance. Float glass was distinguished by the characteristic tin fluorescence on one surface at 254 nm and all nonfloat flat (sheet + plate) glass with a thickness greater than 5 mm was deemed to be plate glass. This division was based on the thickness distribution of the 272 flat glass samples, which has a discontinuity at 4.5 to 5 mm, as shown in Fig. 2. The remaining 239 samples are sheet glass.

The refractive index distributions of sheet and patterned glasses are shown in Figs. 3 and 4, respectively.

The approximate age of the buildings was known for 390 of the 400 samples and a plot of building age versus refractive index for these samples is shown in Fig. 5. An examination of this plot shows there to be a change in refractive index distribution at approximately 30 years. The refractive index distributions of samples from buildings older and younger than 30 years are shown in Figs. 6 and 7, respectively.

These distributions may be further subdivided on the basis of glass type, and the distributions of sheet and patterned glasses from older and younger buildings are shown in Figs. 8 to 11, respectively.

The RI data is summarized in Table 2.

While the observed differences between the four smaller groups of glasses may just reflect the small sample size, those between sheet and patterned glass and between samples from old and young buildings do not. Comparing these two divisions of the samples by means of χ^2 tests (5 degrees of freedom, using the divisions in Table 2), values of χ^2 of 117.9 and 51.9, respectively, were obtained. From the tables, the value of χ^2 with 5 degrees of freedom for significance at 0.1% is 15.1. These differences are thus statistically highly significant.

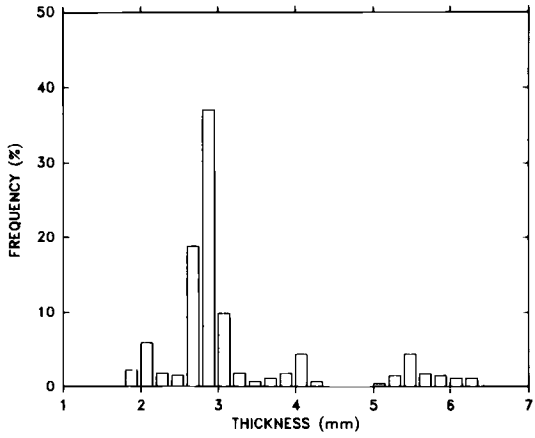

FIG. 2—*Thickness distribution of 272 flat samples.*

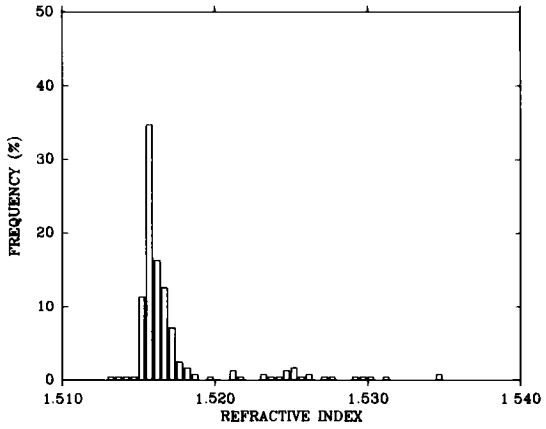

FIG. 3—*RI distribution of 239 sheet samples.*

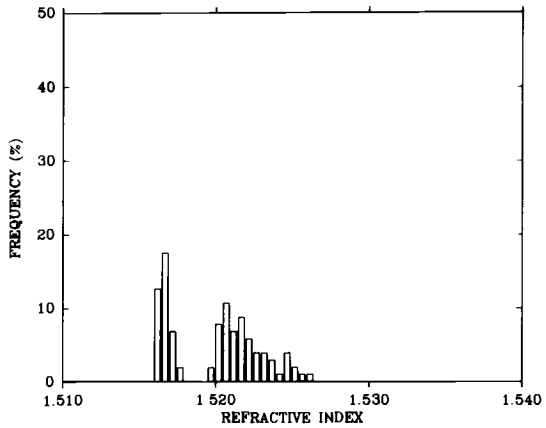

FIG. 4—*RI distribution of 103 patterned samples.*

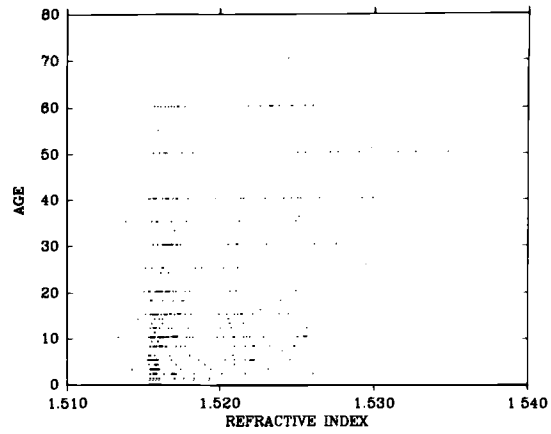

FIG. 5—*Age against RI for all samples.*

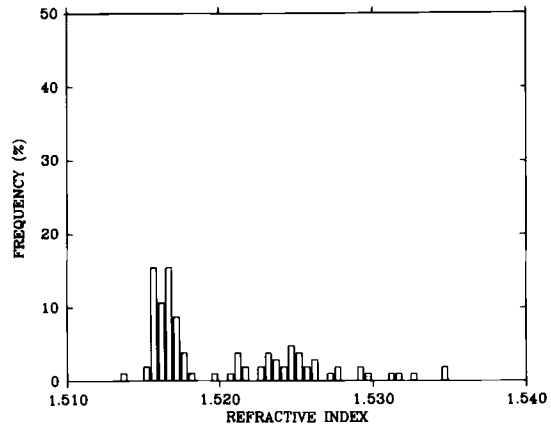

FIG. 6—*RI distribution for 104 samples from buildings aged 30 years and greater.*

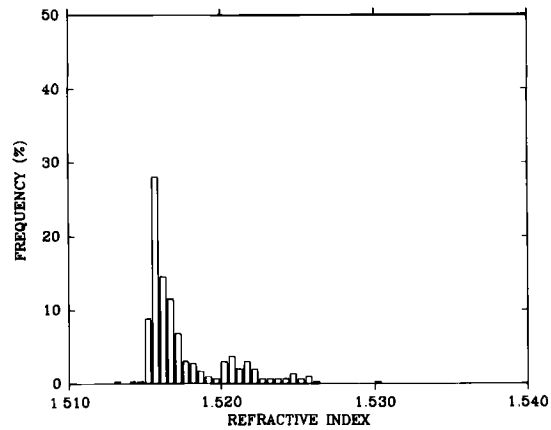

FIG. 7—*RI distribution for 286 samples from buildings aged less than 30 years.*

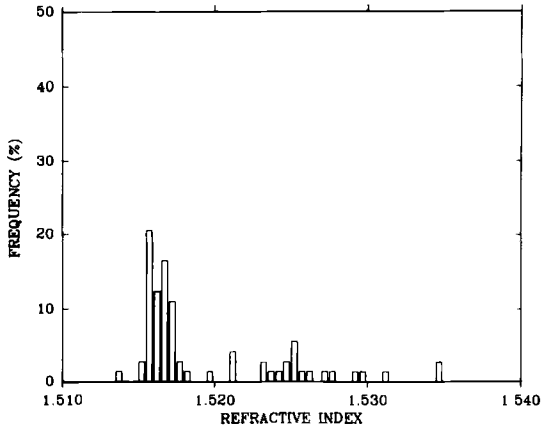

FIG. 8—*RI distribution for 73 sheet glasses from buildings aged 30 years and greater.*

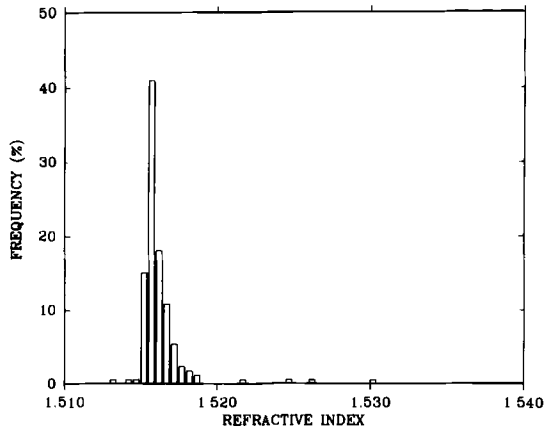

FIG. 9—*RI distribution for 166 sheet glasses from buildings less than 30 years old.*

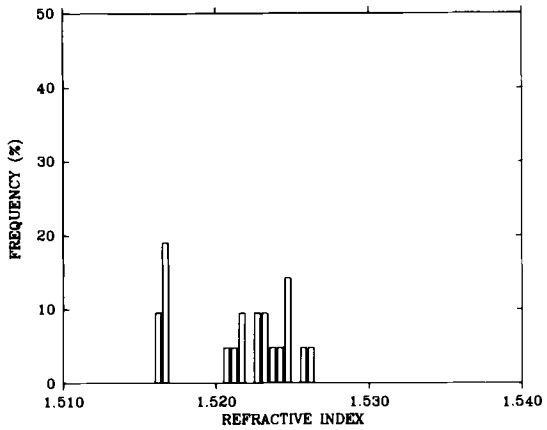

FIG. 10—*RI distribution for 21 patterned glasses from buildings aged 30 years and greater.*

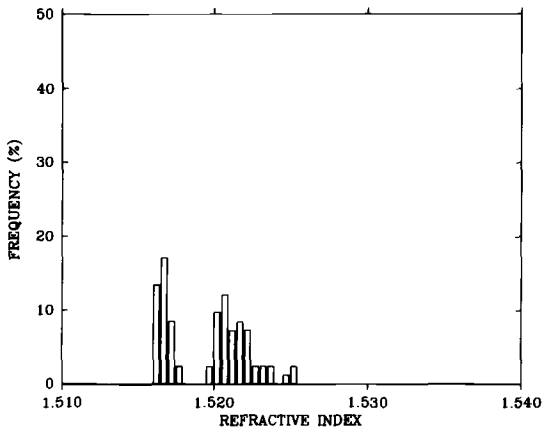

FIG. 11—*RI distribution for 82 patterned glasses from buildings less than 30 years.*

Discussion

There are two outstanding features about these distributions.

1. There are differences between sheet and patterned glass with the patterned samples having a bimodal distribution with modes at 1.5165 to 1.5169 and 1.5205 to 1.5209 and sheet glass being unimodal with the mode at 1.5155 to 1.5159. Patterned glasses also have generally higher RIs than sheet glasses: 61% of the patterned samples have RIs higher than 1.520 and no sample has an RI lower than 1.5160.
2. There is a difference in total spread of RI between older and younger sheet glasses.

The differences noted above could arise from three possible causes.

(1) different manufacturing procedures for different types of glass,
(2) changes in manufacturing procedures with time, and
(3) different manufacturing procedures in different countries.

These three causes will be discussed separately:

(1) Window glass is manufactured by three different processes [*7*]:

(a) drawn sheet,
(b) float, and
(c) rolled plate(≡ patterned glass, wired glass, and polished plate).

To facilitate these different methods of manufacture, rolled plate typically has a slightly different composition from sheet glass, and will be higher in calcium oxide content and lower in silicon dioxide and magnesium oxide content [*8*] by up to 1.5% in each case. These compositional differences are, together with the concommitant increase in density [*9*], sufficient to explain the higher refractive indices found here for patterned glasses.

(2) The difference in spread between older and younger sheet glasses is presumably due to the greater quality control exercised over composition and raw materials during the past 30 years [*2*].

The difference in distribution between sheet and patterned glasses is not caused by increased quality control. Comparing the sheet with the patterned samples from the younger age group by means of the χ^2 test yields of a value for χ^2 of 110.7 (5 degrees of freedom), which is very similar to that obtained for sheet versus patterned samples as a whole, suggesting that the cause of this difference is not time dependent.

TABLE 2—*Refractive index data.*

Glass Type	Number of Samples						
	Total	Up to 1.5164	1.5165 to 1.5169	1.5170 to 1.5174	1.5175 to 1.5204	1.5205 to 1.5234	1.5235 and above
All	400	184	50	29	43	49	45
Sheet	239	153	30	17	13	6	20
Patterned	103	13	18	7	12	41	12
Plate	25	16	1	1	3	1	3
Colored	18	0	0	1	5	1	11
Float	8	0	0	0	8	0	0
Wired	8	2	1	3	2	0	0
<30 years[a]	286	150	34	19	34	35	14
≥ 30 years[a]	104	30	16	9	6	13	30
Sheet <30 years[a]	166	126	18	9	9	1	3
Sheet ≥ 30 years[a]	73	27	12	8	4	5	17
Patterned <30 years[a]	82	11	14	7	12	33	5
Patterned ≥ 30 years[a]	21	2	4	0	0	8	7

[a]This refers to age of building, which is not necessarily the same as age of sample.

(3) Until the early 1960s, all window glass used in New Zealand was imported. Since that date, sheet glass has been manufactured locally, but all other types of glass are still imported.

It could be suggested that the difference in RI distribution between sheet and patterned glass is due to these two types of glass being imported from different countries. However, a study of the figures for the importation of glass into New Zealand over the years 1940 to 1980, sampled at five yearly intervals [*10*], shows that, in any one year, the percentages of sheet glass and patterned glass imported from any particular country are approximately the same. Thus any differences in RI distribution as a result of different countries of origin will tend to cancel each other out.

Conclusions

Two main conclusions may be drawn from the above:

1. There is a statistically highly significant difference between the refractive index distributions for sheet and patterned glasses. Typical compositional differences between those two types of glass are sufficient to explain the higher refractive indices found for patterned glasses.
2. The difference of refractive index distribution with the age of the building is caused by improved quality control of raw materials and composition over the past 30 years, as has been reported previously [*2*].

Acknowledgment

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References

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