Effect of weathering at different exposure angles on the tensile impact resistance of thermoplastics

Yamasaki, R. S.; Blaga, A.

Publisher's version / Version de l'éditeur:

Journal of Testing and Evaluation, 10, 4, pp. 156-161, 1982-07

National Research Council Canada
Conseil national de recherches Canada

EFFECT OF WEATHERING AT DIFFERENT EXPOSURE ANGLES ON THE TENSILE IMPACT RESISTANCE OF THERMOPLASTICS

by R.S. Yamasaki and A. Blaga

Reprinted from
American Society for Testing and Materials
Journal of Testing and Evaluation, July 1982
p. 156 - 161

DBR Paper No. 1047
Division of Building Research

Price $1.00 OTTAWA NRCC 20546

Canada

SOMMAIRE

La possibilité d'utiliser une matière thermoplastique comme revêtement extérieur dépend dans une large mesure de sa résistance aux chocs et de sa capacité à conserver cette propriété à l'usage. Une étude a été entreprise sur l'effet du climat canadien sur la résistance aux chocs de huit feuilles thermoplastiques commercialisées, certaines transparentes, certaines opaques, après leur exposition selon différents angles, et sur le mécanisme responsable de la diminution de leur résistance. La résistance aux chocs des thermoplastiques non exposés va de 98 kJ/m^2 pour le PMMA à 1 225 kJ/m^2 pour le PC. Après une exposition sud/verticale (S/V) et horizontale (H), la résistance de ces thermoplastiques est réduite de 20 % (S/V) et de 30 % (H) pour le PMMA après cinq ans, et de 65 % (S/V) et de 85 % (H) pour le PC recouvert d'un film protecteur, après un an. Pour la plupart des thermoplastiques essayés, la perte de résistance aux chocs peut être attribuée à une diminution de la capacité à se déformer plastiquement, ce qui rend le matériau plus fr

Authorized Reprint from
Journal of Testing and Evaluation, July 1982
Copyright
American Society for Testing and Materials
1916 Race Street, Philadelphia, Pa. 19103
1982

R. S. Yamasaki[1] *and A. Blaga*[1]

Effect of Weathering at Different Exposure Angles on the Tensile Impact Resistance of Thermoplastics

REFERENCE: Yamasaki, R. S. and Blaga, A., **"Effect of Weathering at Different Exposure Angles on the Tensile Impact Resistance of Thermoplastics,"** *Journal of Testing and Evaluation,* JTEVA, Vol. 10, No. 4, July 1982, pp. 156–161.

ABSTRACT: The ability of a thermoplastic to serve as an exterior building component depends to a large extent on its impact strength and the retention of this property during service. A study was undertaken of the effect of the Canadian climate on the tensile impact strength (TIS) of eight clear and opaque commercial thermoplastic sheets exposed at different angles, and on the mechanism responsible for their loss of impact strength. The TIS of unexposed thermoplastics ranged from 98 kJ/m^2 for poly(methyl methacrylate) (PMMA) to 1225 kJ/m^2 for ultraviolet-stabilized polycarbonate, surface unprotected (PC). Following south/vertical (S/V) and horizontal (H) exposure the TIS of these thermoplastics was reduced from 20% S/V and 30% H for PMMA after five years to 65% S/V and 85% H for PC with a protective film after one year. For most of the thermoplastics tested, loss of TIS may be attributed to deterioration of ability to undergo plastic deformation, rendering the material more brittle.

KEYWORDS: weathering, thermoplastic resins, exposure, tensile impact strength, exposure angle, plastic deformation

The ability of a plastic to serve as an exterior building component such as glazing, siding, window profile, and so forth depends to a large extent on the value of its initial impact strength and the degree of retention of this property during service. The Division of Building Research, National Research Council of Canada, has initiated a continuing program to assess the effects of the Canadian climate on the performance of representative commercial plastics. As part of this program, the effect of weathering at different exposure angles on the tensile impact strength of clear and opaque thermoplastics and the mechanism responsible for the loss of impact strength of these materials were determined.

Experimental

Materials

Eight commercial sheet thermoplastics, four clear and four opaque, were chosen. The clear sheets were poly(methyl methacrylate) (PMMA), high-impact poly(methyl methacrylate) (HIPMMA), and two types of ultraviolet-stabilized polycarbonate, surface unprotected (PC), and protected with surface laminate film (SLPC) to reduce abrasion, all 3.2 mm thick. The opaque sheets included brownish-grey acrylonitrile-styrene copolymer modified with acrylic rubber to increase impact strength (ASA-BG) (3.2 mm thick), white acrylonitrile-butadiene-styrene copolymers containing rubber to increase toughness (ABS-W) (2.7 mm thick), and white and grey poly(vinyl chloride) siding (1.1 mm thick) (PVC-W) and (PVC-G), respectively. The latter two were backed with 9.5-mm thick fiberboard and mounted on plywood.

Instrumented Tension-Impact Tester

Of the various types of impact test in common use the tension-impact test ASTM Test for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials (D 1822) was chosen because its results have been found to correlate well with performance in actual applications [*1*]. As well, anisotropy can be studied, and test specimens can be small enough to permit a sufficient number (twelve or more) for proper evaluation per test panel.

To provide some understanding of the mechanism of failure, an instrumented version of the tension-impact tester [*2*] was selected. By monitoring the load-time relation during fracture and noting the time associated with elastic and plastic deformation [*3*], it is possible to determine to what extent weathering has impaired the distribution of elastic deformation (reversible strain) and plastic deformation (irreversible yield and flow) occurring during impact (Fig. 1).

The tensile impact properties of the thermoplastics were assessed with a Testing Machines Inc. (TMI) Model 43-18 Instrumented Tension-Impact Tester, with a 15-J hammer incorporating a strain-gauge transducer and operated at an initial loading velocity of 3350 mm/s. This was connected to a TMI

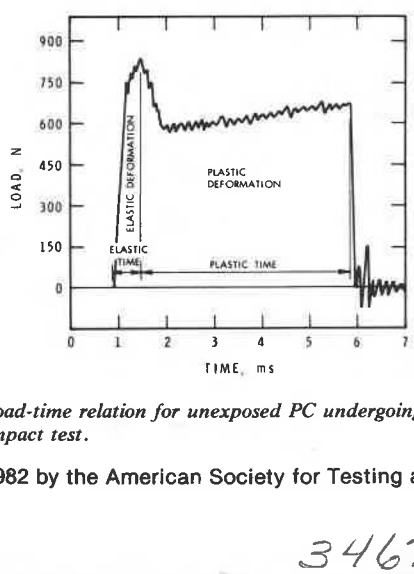

FIG. 1—*Load-time relation for unexposed PC undergoing fracture during tension impact test.*

[1]Research officers, Buildings Material Section, Division of Building Research, Montreal Rd., National Research Council of Canada, Ottawa, Ontario K1A OR6 Canada. Members of ASTM.

0090-3973/82/0007-0156$00.40

3467026

Signal Conditioner strain-gauge amplifier and a Hewlett-Packard (HP) Model 141A oscilloscope incorporating an HP Model 1421A time base and delay generator and an HP Model 1402A dual-trace amplifier. A Polariod Model 197A oscilloscope camera was used to photograph the load versus time display of the material response to impact. The load transducer was calibrated with a 2000-N Dillon force gauge.

Procedure

A set of five panels (165 by 305 mm, with length cut along the long axis of the sheet) of each thermoplastic was subjected to outdoor exposure at Ottawa (humid continental climate) beginning Feb. 1973 at each of two angles: facing south at vertical angle (S/V) and either horizontal (H) or, for PVC's, facing south at 45° (S/45). A test panel was removed annually from each set.

To determine tensile impact strength (TIS) and to check for anisotropy, two sets of twelve or more Type L dog-boned shaped specimens from each test panel were machined parallel and normal to their long axis and tested according to ASTM D 1822. The oscilloscope trace of the load versus time for each test specimen was photographed and times associated with elastic and plastic deformation were determined.

Results and Discussion

Anisotropy of Thermoplastic Sheets

As shown in Table 1, only SLPC, ASA-BG, and ABS-W of the eight thermoplastics displayed anisotropy, and this disappeared after one year of outdoor exposure. Further discussion is therefore confined to TISs of "dog-bones" fabricated parallel to the long axis. The anisotropy is caused by molecular orientation, which often occurs during processing of the polymeric material. The present results suggest that elevated temperatures resulting from solar radiation can remove anisotropy.

Tensile Impact Strength of Unexposed Thermoplastics

Table 2 shows that the TIS of eight unexposed commercial thermoplastics covered a wide range from 98 kJ/m^2 for PMMA to 1225 kJ/m^2 for PC, a factor of twelve. Both are used as glazing material, the latter considered to be very tough. To improve the TIS of PMMA, high-impact HIPMMA with a TIS 2.5 times that of PMMA has been introduced to the market.

Effect of S/V Weathering on Tensile Impact Strength

The extent of deterioration of TIS as a result of S/V exposure ranged from a gradual loss of 20% in five years for PMMA, as shown in Fig. 2, to a rapid reduction by 70% in one year for ASA-BG (Fig. 3). Compared with PMMA, the high-impact HIPMMA lost its TIS more rapidly and retained only 35% after five years (Fig. 4). Thus, although the impact strength of HIPMMA was initially 2.5 times greater than that of PMMA, it was reduced to about the same value after five years' exposure (note difference in scales).

As illustrated in Fig. 5, the TIS of PC underwent considerable deterioration, reaching a plateau of 30% of its initial strength after approximately three years' exposure. Nevertheless, because of its very high original impact strength (1225 kJ/m^2) the TIS of PC was still about four times greater than that of PMMA or HIPMMA after five years' exposure. For SLPC (PC with a protective film) weathering reduced its TIS more rapidly and to a greater extent than for PC, becoming only 15% of the original after two years (Fig. 6). On further exposure, however, the TIS of SLPC increased until it was approximately equal to that of PC. This unusual behavior, which was accompanied by delamination of the protective film on the exposed side, was confirmed by additional determinations.

On outdoor exposure the TIS of ABS-W decreased rapidly by 70% after one year and then gradually by a further 10% in five years (Fig. 7). This behavior was similar to that of ASA-BG (Fig. 3) and may be due to the presence of rubber in both formulations.

On weathering the TIS of white PVC (PVC-W) declined slowly and steadily, 10% the first year and 70% after five years (Fig. 8); that of grey PVC (PVC-G) decreased more rapidly, 40% the first year and a further 20% after three years (Fig. 9).

Effect of H or S/45 Weathering on Tensile Impact Strength

The loss of TIS following weathering at H or S/45 ranged from a gradual decline of 30% in five years for PMMA (Fig. 2) to a rapid drop of 85% after one year for SLPC (Fig. 6). In spite of its relatively high initial impact strength, HIPMMA lost strength so rapidly with H exposure that in four years its TIS was comparable to that of PMMA (Fig. 5).

The TIS of PC also declined quickly, losing 70% of its initial value, and reached a plateau after approximately two years of H exposure (Fig. 5). For SLPC the reduction in TIS was even greater (Fig. 6), so that after one year it retained only about a third that of PC. With a further three years of exposure, as for the vertical panels, the TIS of SLPC increased to match that of PC, accompanied by delamination of the protective coating. This common oc-

TABLE 1—*Effect of weathering on anisotropy in tensile impact strength of thermoplastic sheets.*

Material	Test Direction Long Axis	Tensile Impact Strength, kJ/m^2 0 Year Mean	0 Year Standard Deviation	1 Year S/V Mean	1 Year S/V Standard Deviation	1 Year H Mean	1 Year H Standard Deviation
SLPC	perpendicular	529	50	354	35	131	14
SLPC	parallel	1051	56	380	27	143	13
ASA-BG	perpendicular	99	13	41	6	50	4
ASA-BG	parallel	180	17	47	5	61	8
ABS-W	perpendicular	179	23	81	10	78	5
ABS-W	parallel	290	36	90	5	84	7

TABLE 2—*Tensile impact strength of unexposed thermoplastics (measured parallel to the long axis).*

	TIS, kJ/m²			TIS, kJ/m²	
Material	Mean	Standard Deviation	Material	Mean	Standard Deviation
PMMA	98	9	ASA-BG	290	36
HIPMMA	250	7	ABS-W	180	17
PC	1225	61	PVC-W	416	40
SLPC	1051	56	PVC-G	403	35

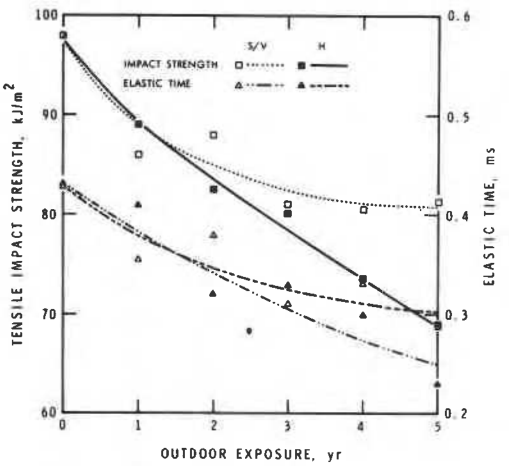

FIG. 2—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of PMMA.*

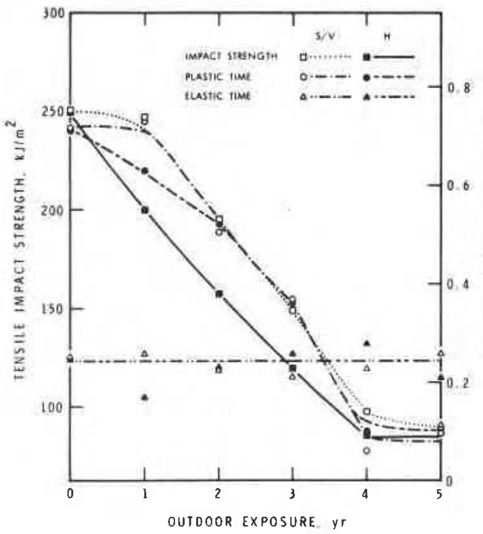

FIG. 4—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of HIPMMA.*

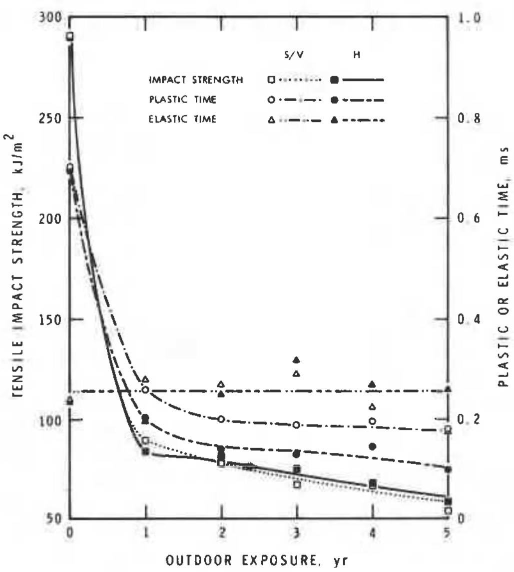

FIG. 3—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of ASA-BG.*

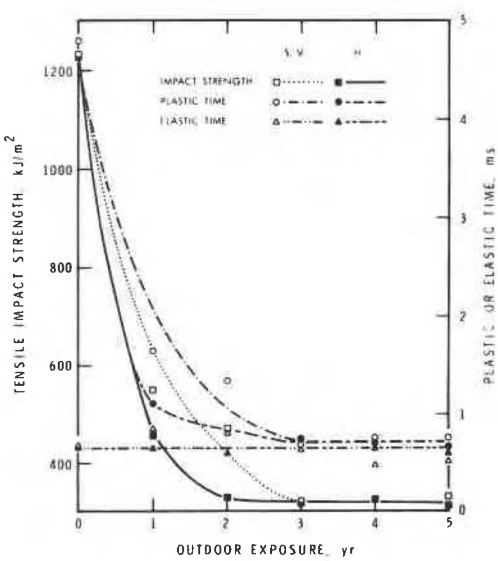

FIG. 5—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of PC.*

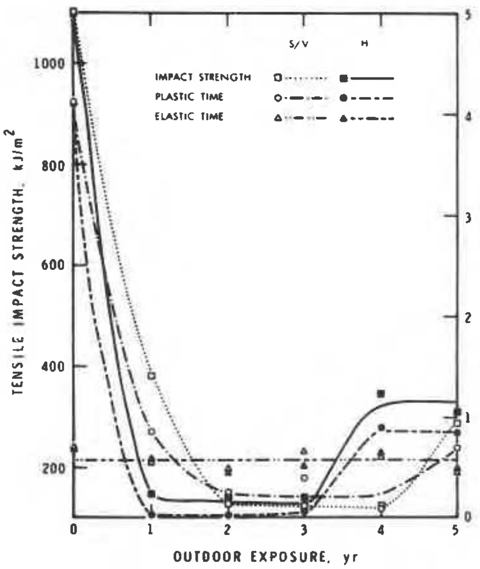

FIG. 6—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of SLPC.*

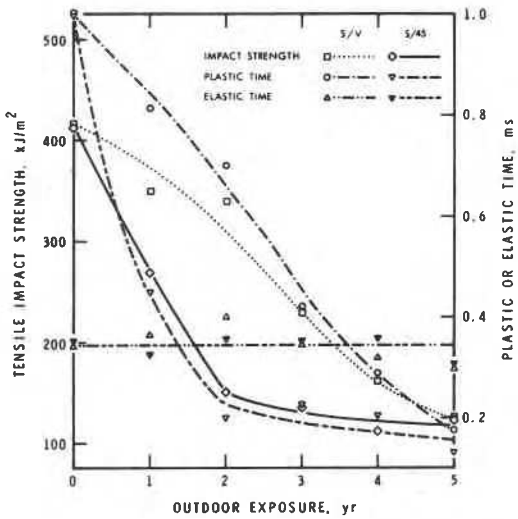

FIG. 8—*Effect of weathering at S/V and S/45 exposure angles on the tensile impact properties of PVC-W.*

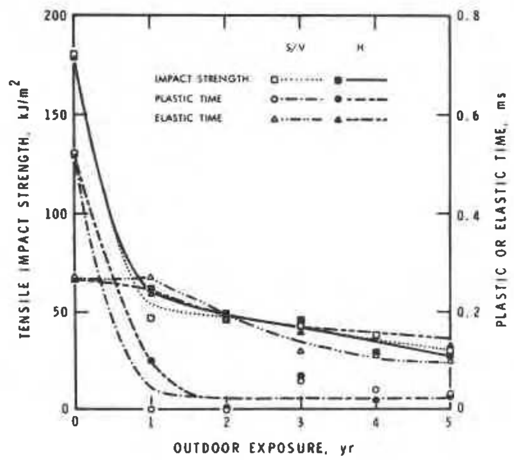

FIG. 7—*Effect of weathering at S/V and H exposure angles on the tensile impact properties of ABS-W.*

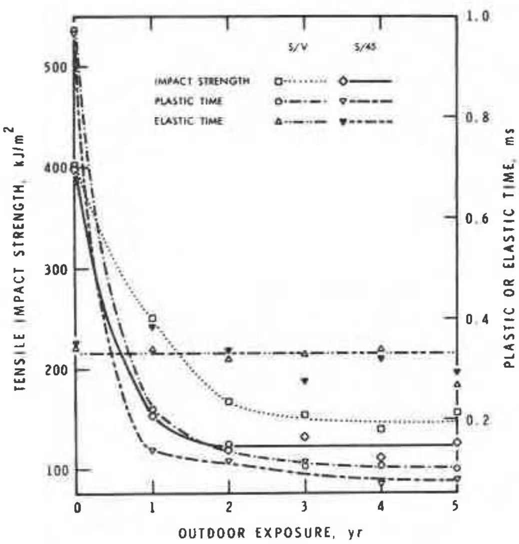

FIG. 9—*Effect of weathering at S/V and S/45 exposure angles on the tensile impact properties of PVC-G.*

currence in both exposures indicates that the laminate on the surface probably lowered the retention of TIS of PC on weathering. Tensile strength of PC is known to be reduced by modification of the chemical composition of the surface [*4*].

Horizontal exposure rapidly reduced the impact strength of ABS-W by 65% after one year and by 85% after five years to the lowest value (27 kJ/m^2) of all the thermoplastics tested (Fig. 7). Its overall effect on ASA-BG was similar (Fig. 3).

Both PVC-W and PVC-G are siding materials not normally used horizontally. They were tested, therefore, at S/45, the conventional accelerated natural weathering position. The TIS of PVC-W decreased relatively rapidly, 60% in two years, then slowly by a further 10% in five years (Fig. 8); that of PVC-G deteriorated more rapidly, by about 70% in two years, but reached the same terminal value.

Effect of Exposure Angle on Loss of Tensile Impact Strength

The horizontal and S/45 exposures were, in general, more damaging to the TIS of thermoplastics than S/V exposure. Thus, for the same period of five years H exposure reduced the TIS of PMMA 50% lower than S/V exposure. For HIPMMA, H exposure lowered the TIS to the same final value as S/V exposure, but in four years rather than five, or 20% less time. This was also the case with PC, but with a reduction of about 30% in exposure time: three years for S/V to two years for H. Finally, H and S/V exposures reduced SLPC to the same minimum TIS, the former taking 50% less time (one year) than the latter (two years).

For both ABS-W and ASA-BG the degradative effect of H exposure on TIS was similar to that of S/V exposure. The similarity for these exposures may be attributed to the very low durability of the materials. The formulations, in which rubber is incorporated to improve impact strength, do not appear to be suitable for outdoor applications, probably because rubber is susceptible to oxidation.

Comparison of the time required for S/V and S/45 exposures to reduce the TIS of PVC-W to the same value shows that the acceleration factor of the S/45 with respect to S/V exposure is about 2. With PVC-G, for up to three years of S/V exposure the 45° acceleration factor is also about 2.

Comparison of Figs. 8 and 9 shows that during the period when most changes occurred for both S/V and S/45 exposures, PVC-G lost TIS two to three times more rapidly than PVC-W. As the compositions of PVC-G and PVC-W differ only by the presence of carbon black in the former (in fact, carbon black increases its resistance to ultraviolet degradation [5]), the wide difference in degradation rate may be attributed to differences in the conditions experienced by the materials. In particular, because of its darker color, PVC-G experiences about 10 to 20°C greater solar radiation heating than PVC-W [6]. This can accelerate chemical reaction by a factor of 2 to 4 [7], and could account for the higher degradation rate.

Effect of Weathering on Tensile Impact Deformation

To discover which deformation property, elastic or plastic, confers TIS on PMMA, the load versus time curve of unexposed PMMA (Fig. 10) was compared with that of PC (Fig. 1). The result suggests that PMMA fractured during elastic deformation and did not, therefore, undergo plastic deformation. To determine how weathering impaired the ability of PMMA to undergo elastic deformation during impact, elastic time versus duration of outdoor S/V and H exposures was plotted (Fig. 2). The correspondence between the effect of weathering on elastic time and on TIS for each exposure suggests a correlation between these characteristics of PMMA. The correlation with both exposures is illustrated in Fig. 11; and furthermore, it yields a correlation coefficient r of 0.92 (Table 3), confirming that TIS reduction of PMMA as a result of weathering may be attributed to loss of ability to undergo elastic deformation, and that such a loss is greater for H exposure than for S/V exposure.

For HIPMMA, time-associated changes in plastic and elastic behavior for S/V exposure are shown in Fig. 4; comparison of changes in plastic time with those of the corresponding TIS indicates correlation, which is confirmed in Fig. 12. Elastic time, however, remained unchanged with exposure. This was also true for H exposure, with $r = 0.99$ for both exposures (Table 3). Loss of TIS, therefore, may be ascribed to the impairment of HIPMMA in undergoing plastic deformation, that is, it became less ductile.

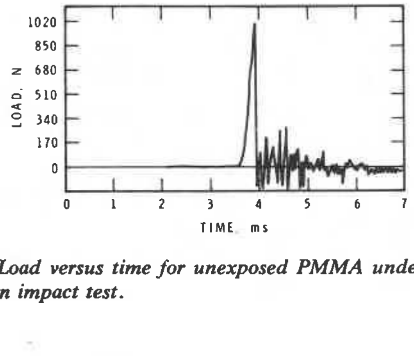

FIG. 10—*Load versus time for unexposed PMMA undergoing fracture during tension impact test.*

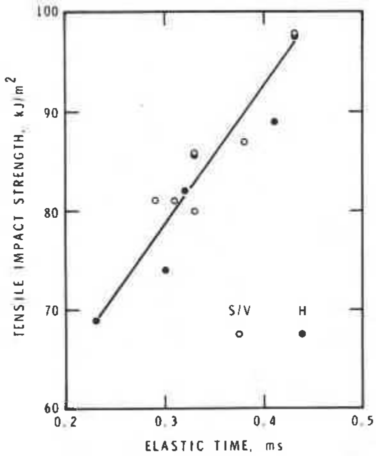

FIG. 11—*Correlation of tensile impact strength with elastic time for PMMA on exposure to weathering at S/V and H angles.*

TABLE 3—*Extent of correlation between tensile impact strength and plastic time of thermoplastics subjected to weathering.*

Material	Correlation Coefficient	Material	Correlation Coefficient
PMMA	0.92	ASA-BG	0.97
HIPMMA	0.99	ABS-W	0.97
PC	0.99	PVC-W	0.98
SLPC	0.98	PVC-G	0.95

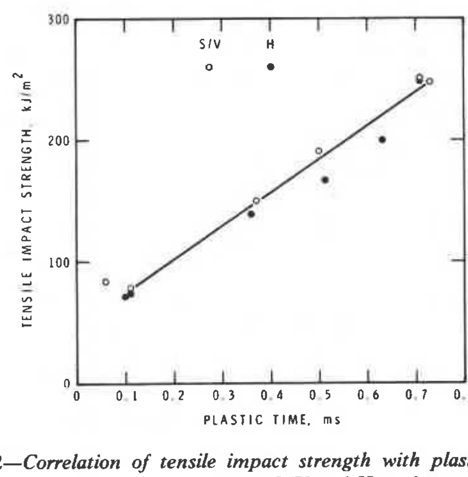

FIG. 12—*Correlation of tensile impact strength with plastic time for HIPMMA on exposure to weathering at S/V and H angles.*

For ABS-W on both S/V and H exposures, as shown in Fig. 7, plastic times were reduced to essentially zero after about a year, the rate correlating ($r = 0.97$ [Table 3]) with that of loss of TIS. Elastic times were relatively unchanged for the first year (Fig. 7), then declined, the rates roughly correlating ($r = 0.83$) with those of TIS (Fig. 13). Thus a decrease in the TIS of ABS-W caused by weathering may be attributed to a rapid and eventually complete loss of plastic extensibility amounting to about 70% of total strength, that is, it became brittle, followed by a decline in elastic deformation capability for the remaining exposure period.

For PC, SLPC, ASA-BG, PVC-W, and PVC-G outdoor exposure also reduced duration of plastic time. When analyzed in the

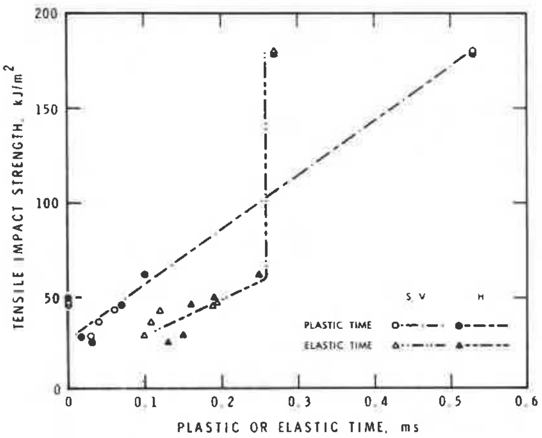

FIG. 13—*Correlation of tensile impact strength with plastic and elastic times for ABS-W on exposure to weathering at S/V and H angles.*

same way as for thermoplastics, such changes (Figs. 5, 6, 3, 8, and 9) correlated with corresponding changes in TIS, as shown in Table 3. Elastic time remained relatively constant. Thus, for these thermoplastics impairment of TIS may be ascribed to loss of plastic flow.

In a previous investigation [*4*] the effect of weathering on the relation between molecular weight and tensile properties of PC was determined. Comparison of these results with the corresponding present ones shows good agreement, although the tensile loading rates were quite different (0.04 versus 3350 mm/s in the present investigation). The elastic time and the corresponding time to yield (elapsed time for ϵ_y, Fig. 14 [*4*]) remained unchanged, and the plastic time and the corresponding net time to break (elapsed time for ϵ_b [*4*]) decreased by 80 and 90%, respectively. Decrease in TIS, as for tensile strength, may be attributed, therefore, to a reduction in molecular weight of the surface region of PC as a result of a chain scission caused by solar ultraviolet radiation.

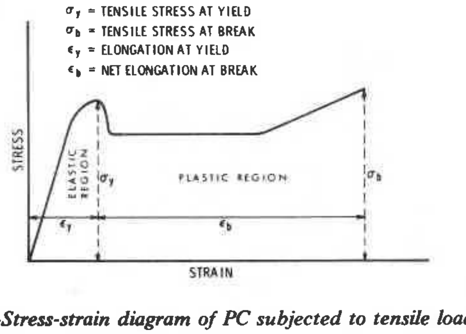

FIG. 14—*Stress-strain diagram of PC subjected to tensile loading* [4].

Summary and Conclusions

1. Tensile impact strength (TIS) (parallel to the long axis of a sheet) of eight commercial thermoplastics ranged from 98 to 1225 kJ/m^2 for PMMA and PC, respectively, a factor of 12.

2. Three unexposed thermoplastics, SLPC, ASA-BG, and ABS-W, displayed anisotropy in TIS. This property disappeared in one year's outdoor exposure.

3. Weathering reduced the TIS of thermoplastics, horizontal (H) or south/45° (S/45) exposure being more severe than south/vertical (S/V) exposure. This reduction ranged from 20% S/V and 30% H after five years for PMMA to 65% S/V and 85% H after one year for SLPC.

4. The TIS of a high-impact PMMA was initially 2.5 times greater than that of PMMA, but this was reduced with weathering until the difference was nullified after four years.

5. As long as the film remained intact, weathering impaired the TIS of surface-laminated PC to a greater extent than that of unlaminated PC.

6. For most thermoplastics tested, loss of TIS because of weathering may be attributed to deterioration of ability to undergo plastic deformation, rendering the material more brittle. This is probably caused by a decrease in molecular weight, since it is known that PC and other thermoplastics undergo chain scission on exposure to solar ultraviolet radiation.

Acknowledgments

The authors wish to thank V. S. Ramachandran and H. E. Ashton for assistance in preparing this manuscript and C. C. Barrett and R. Lacroix for carrying out the impact tests.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

References

[*1*] Bragaw, C. G., "Tensile-Impact: a Simple, Meaningful Impact Test," *Modern Plastics*, Vol. 33, No. 10, June 1956, pp. 199-206.

[*2*] Kelly, P. P. and Dunn, T. J., "Instrumental Tensile Impact Testing of Thermoplastic," *Materials Research and Standards*, Vol. 3, No. 7, July 1963, pp. 545-549.

[*3*] Dunn, J. L. and Heffner, M. H., "Outdoor Weatherability of Rigid PVC," *Society of Plastics Engineers, Technical Papers*, Vol. 19, May 1973, pp. 483-488.

[*4*] Yamasaki, R. S. and Blaga, A., "Degradation of Polycarbonate Sheeting on Outdoor Exposure. Relationship Between Changes in Molecular Weight and Tensile Properties," *Materials and Structures*, Vol. 10, No. 58, July/Aug. 1977, pp. 197-204.

[*5*] Nass, L. I., "Actions and Characteristics of Stabilizers," in *Encyclopedia of PVC*, Vol. I, Marcel Dekker, Inc., New York, 1976, p. 343.

[*6*] Yamasaki, R. S. and Blaga, A., "Hourly and Monthly Variations in Surface Temperature of Opaque PVC During Exposure Under Clear Skies," *Materials and Structures*, Vol. 9, No. 52, July/Aug. 1976, pp. 231-242.

[*7*] Frost, A. A. and Pearson, R. G., *Kinetics and Mechanism*, John Wiley & Sons, Inc., New York, 1953, p. 23.