Influence Of Composition Of uPVC On The Impact Resistance Of Window Profiles Exposed To Weathering

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ABSTRACT

The durability of unplasticized poly(vinyl chloride) (uPVC) components used in the building industry is a function of the interaction of several factors. Types and quantities of additives incorporated to the PVC resin, defining the formulation of the PVC compound used in the production of these components, are among the most important such factors. White uPVC window profiles with different formulations have been exposed to five years of natural weathering under Brazilian climatic conditions. Results of Charpy impact tests were used to assess the influence of three factors on the durability of the profiles: additivation levels of titanium dioxide, nature of the impact modifier and nature of the thermal stabilizer. Statistical analysis of the results made it possible to rank these factors according to their influence in component durability.

Results presented in this paper indicated the need for several additional experiments in order to check changes in molecular mass, color and elasticity modulus. Such experiments were later carried out. Comparison of all these data with results from profiles subjected to accelerated weathering led to straightforward criteria for prediction of the potential behaviour of uPVC, to be described in a future paper.

KEYWORDS

PVC; Plastics, Durability; uPVC profiles; PVC formulation.

1 INTRODUCTION

The use of rigid PVC profiles for windows and external sidings is just starting in Brazil. Lack of information on the material behaviour during its lifetime, when subjected to solar radiation and temperatures prevalent in Brazil, is one of the main factors that hinder growth of uPVC use. This study addresses this issue.

2 METHODOLOGY

2.1 Experiment planning

Durability was assessed by means of the Charpy impact resistance. Samples cut from white extruded uPVC profiles were exposed to natural weathering conditions, at an angle of 45 degrees north, according to the ASTM D1435 Standard, 1994, for periods up to five years. The natural weathering station is located in the city of Piracicaba, State of São Paulo, Brazil (lat. 22º43' South, long. 47º25' West; 580 m high).

In order to reduce statistical uncertainty, tests were performed on ten specimens for a given set of conditions and the average value was calculated to represent the measured properties (BS 7413' 1994 and ASTM D256, 1984). Thus, the value of the Charpy impact resistance of a given formulation, after a given exposure period, for example, is the average of the breaking energy of ten specimens.

2.2 Selection of formulations

Durability is central to the performance of PVC windows. Resistance of a compound formulation to weathering is therefore an extremely relevant property to be predicted. White profiles were selected for the experiment because as they are pigmented with titanic dioxide, they usually exhibit better durability irrespective of weather conditions (Lee et.aliii, 1995; Lemaire, 1996; Rabinovitch, 1993).
The four impact modifiers then (1988) in use in Brazil were used in the experiment: acrylic (ACR), chlorinated polyethylene (CPE), acrylonitrile-butadiene-styrene (ABS), and metacrylate-butadiene-styrene (MBS). Such modifiers are still (2004) the most widely used in Brazil. Four thermal stabilizers were analyzed: a complex of lead, barium and cadmium (Pb/Ba/Cd), lead (Pb), a complex of barium and cadmium (Ba/Cd), and tin (Sn).

Due to the high cost of titanium dioxide, the experiment was conducted for three additivation levels: 3 combined with anti-UV additives, 5 and 10 phr (parts per hundred resin). The titanium dioxide (TiO_2) pigment promotes opacity and PVC resin protection against degradation due to ultra violet (UV) radiation.

For practical reasons related primarily to the extrusion process, not all possible combinations of these factors were tested: only 19 of 37 compound formulations could be exposed to natural weathering. Table 1 shows all compound formulations that were processed and how many were tested.

	Pb/Ba/Cd	***Pb***	***Sn***	***Ba/Cd***	***Number of compounds processed/studied***
Acrylic	4 / 2(1)	6 / 2(1)	2 / 0	5 / 3	17 / 7
CPE	3 /3	3 / 3	7 / 0	(3)	13 / 6
ABS	3 / 3(2)		1 / 0		4 /3
MBS	3 / 3(2)				3 / 3
Total	13 / 11	9 / 5	10 / 0	5 / 3	37 / 19

(1) Only compounds with 3 and 10 phr of TiO_2 were exposed to weathering.
(2) In this case, as ABS and MBS impact modifiers reduce weathering resistance of the final compounds, it was utilized only one thermal stabilizer, just to compare mechanical properties to others impact modifiers.
(3) CPE impact modifiers were not combined with Ba/Cd thermal stabilizer because it is very difficult to find the correct lubrification.

Table 1. Compound formulations processed/studied

Codes used to identify the compounds are summarized in Table 2.

Impact modifiers 2 letters		*Thermal Stabilizer 1 letter*		*Additive (phr of TiO_2)*
LL		L		N
AC	ACR (acrilyc)	**P**	Pb	**3**
CP	CPE	**S**	Sn	**5**
AB	ABS	**B**	Ba/Cd	**10**
MB	MBS	**C**	Pb/Ba/Cd	

Example: ABC5: Compound with ABS impact modifier, thermal stabilizer Pb/Ba/Cd and 5 phr of TiO_2.

Table 2. Compound coding.

2.3 Natural weathering

Climatic variables were measured several times per day during the 5-year period of the experiment (January, 1989 – December, 1993): global solar radiation (cal/cm².day), hours of sunlight (hours/day), rain (mm), relative humidity (%), wind velocity - maximum, minimum and average (m/s), temperature – maximum, minimum and average (°C). The yearly values of meteorological data for the weathering station are summarized in Table 3.

Year	*Total global yearly radiation kLy*[(1)]	*Total hours of sunlight per year* [(1)]	*Maximum average temperature (average of monthly maxima), °C*	*Average temperature (average of monthly average temperatures) °C*
1989	131.4	2 579	27.9	21.2
1990	133.7	2 579	28.8	22.1
1991	131.0	2 511	28.5	22.0
1992	126.6	2 289	28.1	21.8
1993	128.4	2 352	28.6	22.3
Average	**130.2**	**2 462**	**28.4**	**21.9**
Total	**650.9**	**12 310**		

(1) Values obtained from the sum of values of daily solar radiation and insolation measured in Piracicaba during the experiment (1 kLy = 1 kLangley = 1.000 cal/cm^2)

Table 3. Meteorological data for the city of Piracicaba – yearly values between 1989 and 1993.

3 RESULTS

Values of the Charpy impact resistance of each of the 19 evaluated formulations, for different exposure times, are summarized in Table 4.

Formulations	*1*	*2*	*3*	*4*	*5*	*6*
Content of TiO_2 pigment	*3 phr*	*5 phr*	*10 phr*	*3 phr*	*5 phr*	*10 phr*
Modifier	MBS			ABS		
Stabilizer	Pb-Ba-Cd			Pb-Ba-Cd		
0 years	11.8	12.6	18.2	10.7	11.5	16.6
1,17 years	7.7	10.7	13.1	7.0	7.7	13.7
2 years	9.3	9.0	11.3	8.1	8.7	13.5
3 years	5.1	6.5	6.7	5.1	5.8	9.1
4 years	6.0	7.4	8.6	7.1	7.5	10.7
5 years	3.4	4.0	4.5	3.4	4.9	7.8

Formulations	*7*	*8*	*9*	*10*	*11*	*12*
Content of TiO_2 pigment	*3 phr*	*5 phr*	*10 phr*	*3 phr*	*5 phr*	*10 phr*
Modifier	CPE			CPE		
Stabilizer	Pb			Pb-Ba-Cd		
0 years	14.1	16.6	16.6	16.7	16.5	15.5
1,17 years	12.9	16.8	15.0	15.0	13.6	15.8
2 years	14.4	20.4	18.8	14.8	14.3	16.4
3 years	13.6	19.1	15.7	13.0	14.7	15.6
4 years	14.7	19.2	17.1	13.0	14.8	16.1
5 years	10.4	N/D	14.5	7.2	9.8	11.5

Formulations	*13*	*14*	*15*	*16*	*17*	*18*	*19*
Content of TiO_2 pigment	*3 phr*	*10 phr*	*3 phr*	*10 phr*	*3 phr*	*5 phr*	*10 phr*
Modifier	Acrylic		Acrylic		Acrylic		
Stabilizer	Pb		Pb-Ba-Cd		Ba-Cd		
0 years	12.7	18.6	11.1	14.2	15.0	12.2	15.5
1,17 years	13.9	18.3	12.1	17.2	14.1	12.9	14.3
2 years	16.1	19.3	13.3	15.1	15.2	14.1	18.3
3 years	12.6	18.7	11.6	13.9	13.4	13.0	14.0
4 years	11.3	18.3	12.2	16.7	15.0	13.5	14.3
5 years	4.8	16.9	8.4	11.8	13.0	11.6	14.4

Table 4. Charpy impact resistance after natural weathering of the 19 formulations evaluated (kgf.cm/cm or kJ/m^2).

A first attempt at linear correlations of resistance with the independent variables proved unsuccessful (R^2=0,59), as might be expected from the generally non-linear trends observed in Table 4 and in Figures 1 and 2.

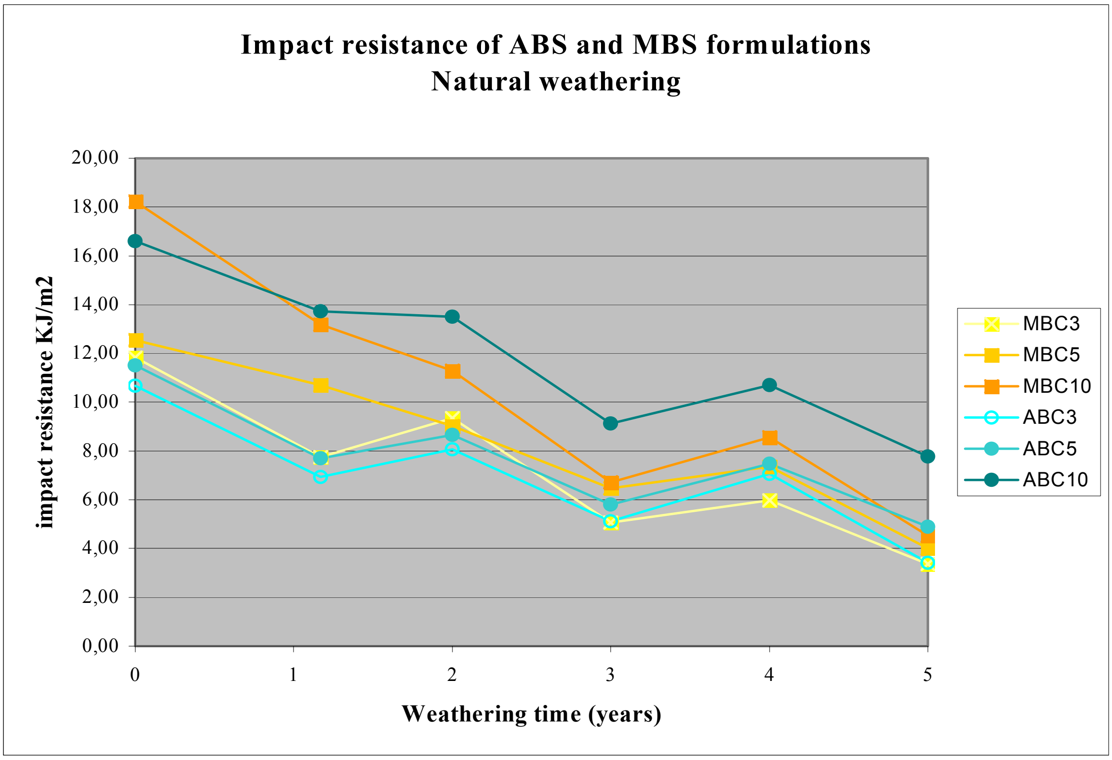

Figure 1. Impact resistance of MBS and ABS formulations, in natural weathering

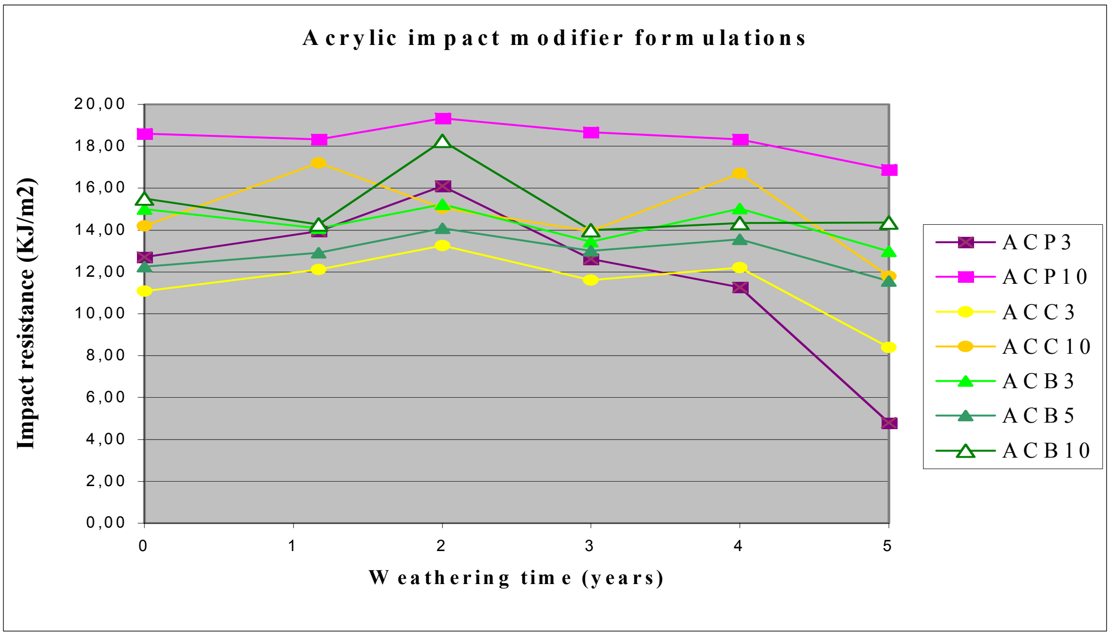

Figure 2. Impact resistance of acrylic impact modifier formulations: thermal stabilizers influence versus TiO_2 content

As a matter of fact, decreasing rates of decay are commonly observed in degradation processes. This conceptual model was not applied due to the rather significant fluctuations observed (see Figures 1 and 2 for example).

Considering the common practice of taking the relative decrease of PVC resistance to represent weathering, a new variable was defined, the relative decrease in resistance at time t = 5 years:

[RI (t=0)-RI (t=5)] / RI (t=0)], or, ΔRI (t=5) / R (t=0)

This new variable, if divided by the exposure period, becomes the average annual rate of decrease in resistance for the period.

A linear multiple regression model was applied to this new variable. Time and TiO_2 pigment content were both, of course, defined quantitatively, while different impact modifiers and stabilizers had to be associated to dummy variables for the purpose of the regression.

Only 18 points were considered for the regression because one of the formulations was lacking the value of the 5-year exposure impact resistance (CPP5 – Table 4).

Table 5, transcribed directly from the electronic spreadsheet used to carry out the multiple regression, shows a value of about 0.8 for the determination coefficient and a high value of the F statistic; thus, pointing at a reasonable linear fit.

More importantly, the t-statistic and the corresponding P-value help rank the regressors: the lower the P-value, the lower the probability of the coefficient of that particular regressor being zero. In other words, the lower the P-value, the higher the importance of that regressor in explaining the decrease in resistance.

Regression statistics	
R multiple	0.888
R-square	0.789
R-square adjusted	0.744
Standard error	0.026
Number of observations	18.000

ANOVA

	d.f.	*SS*	*MS*	*F*	*F significance*
Regression	3.000	0.034	0.011	17.488	5.2E-05
Residual	14.000	0.009	0.001		
Total	17.000	0.043			

	Coefficients	*Standard error*	*t*	*P-value*
Intersection	0.215	0.021	10.428	5.5E-08
Variable X 1=TiO_2	-0.005	0.002	-2.463	2.7E-02
Variable X 2=modifier	-0.028	0.007	-4.063	1.2E-03
Variable X 3=stabilizer	-0.018	0.010	-1.821	9.0E-02

Table 5. Summary of results

4 CONCLUSIONS

The results of the experiment indicate that the choice of impact modifier is the most important factor controlling decrease in resistance in the experimental conditions analyzed. The TiO_2 pigment content comes next, followed by the type of thermal stabilizer.

These conclusions can be better visualized in Figure 3, which derives from the linear multiple regression.

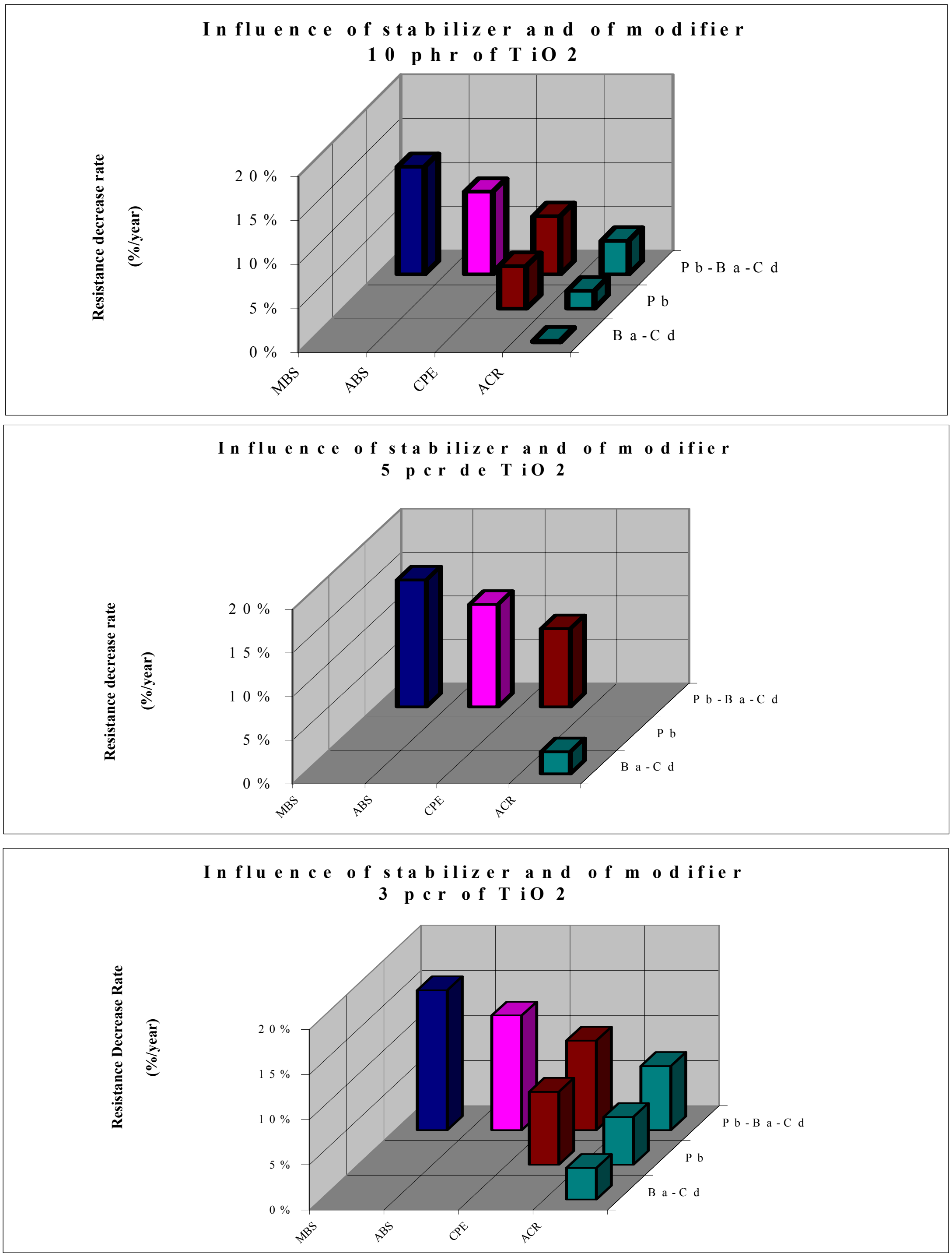

Figure 3. Influence of modifier and of stabilizer

5 FINAL REMARKS

The results presented herein were the basis of a more encompassing set of experiments, which included determination of the changes in molecular mass, color and elasticity modulus, as well as their extension to uPVC specimens subjected to accelerated weathering.

This experimental program led to the proposal of straightforward criteria for prediction of the potential behavior of uPVC compounds under Brazilian climatic conditions, as shown in Hachich, 1999.

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