Effect of Weathering on the Mechanical Properties of PVC Composite

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Abstract

Polyvinyl Chloride is one of the major used plastics in the world as it can be made into two totally different forms: Plasticized (flexible) and Unplasticized (rigid) with different formulations in each category which makes it a very versatile polymer. It has found many outdoor applications such as house sidings, windows, sewer pipes and doors frames, fences, decks, etc… With the growth in the building market and the push towards better performance; composite materials that are based on PVC are introduced. The mechanical properties can be highly improved by the addition of a reinforcement phase. In this study, the tensile properties of the PVC, PVC glass fiber composite and PVC mica composite are evaluated at time intervals while being subjected to a weathering condition that lasted up to 400 hours in a weather-ometer chamber. The effect of the addition of the silane coupling agent is also assessed. It has been observed that the weathering resulted in an increase in tensile strength and a decrease in elongation at break. This can be attributed to the formation of cross-links between the PVC polymeric chains. The silane resulted in an increase of the measured strength.

1-Introduction

Polyvinyl chloride (PVC) is the world's third most important thermoplastic polymer in terms of volume sales. The reasons behind the success and popularity of PVC include its excellent mechanical properties, versatility, competitive price, biological and chemical resistance, fire retardancy, recyclability and ease of processing [1,2]. On the other hand, some disadvantages of the PVC include its sensitivity to oxidative degradation and poor thermal stability [3].

PVC can be blended with a wide range of additives to improve stability, cost, mechanical properties, color and softening point. It is available in two forms Plasticized and Unplasticized. Plasticized PVC (PPVC) is a flexible polymer that finds applications mainly in wire coverings and shoe soles. While the Unplasticized PVC (UPVC) is a hard, tough form which is mainly used in pipes and window profiles [4]. Both forms are produced by the Egyptian Company for Petrochemicals (EPC).

Moreover, in the recent years, with the high demand for materials with improved properties, the PVC has entered the field of Composite materials. A composite is any combination of two or more phases that are chemically dissimilar and separated by a distinct interface. It takes advantage of the beneficial characteristics of each component material and can be tailored to give a combination of the most desired features. Weight reduction using composites has created a wide increase in the specific properties with a resultant huge market demand in automotive, industrial, aerospace and other industries. In recent years, manufacturers have turned to the use of lightweight composites without having to compromise strength and durability. For example in the field of automotive and flight industry, the resulting weight reduction realized by using composite materials reflects a considerable cost savings in terms of fuel.

Currently, the fiber-reinforced composites market is dominated by glass fiber. Even better performance can even be achieved with more expensive fibers such as Carbon fibers, Kevlar fibers and Silicon Carbide fibers. Other types of composite include particulate filled composite where some other inorganic fillers such as talc, mica, clay, and calcium carbonate are added as particles to the polymeric matrix [5].

Glass Fibers are the most common of all reinforcing fibers for polymeric matrix composites [6]. The principal advantages of glass fiber are low cost, high tensile strength, high chemical resistance, and excellent insulating properties. Also fiber-reinforced polymer composites have witnessed a rapid rise in its utilization in the past 30 years, due to their high strength and stiffness and light weight, compared to traditional structural materials, such as steel and aluminum. The reason for this superior performance is the synergistic combination of the two, or more, constituent phases. This synergy is brought about by the interaction between the fiber and the polymeric matrix. Glass-fiber reinforced composites are frequently used as building materials. Their enhanced tensile properties and durability make them suitable for thin constructional materials in both plain and complex shapes [7].

Mica is the generic name of a group of complex silicate minerals having laminate structure with different chemical composition and physical properties. Mica exists in nature different forms such as the Muscovite (white) and Phlogopite (dark brown) [8]. It exhibits a high elastic modulus ranging from 135 GPa to 210 GPa and density around 2.8 g/cm^3 [9]. It is widely used as reinforcing filler in polymer due to its excellent thermal, electrical, chemical and fire resistance. Commercial usage of mica as filler can be found in polymer composites involving polyolefin, polyester, polyamide, epoxies and polyurethanes. However, there are few reports on the PVC composites filled with mica [10]. Mica composites may be used in low cost housing, ceiling boards, roof tiles and dry walling [8].

It is well known that the interface between the two phases plays a key role in determining mechanical properties of the composite. Though there is a lack of understanding the process occurring at the atomic level of interfaces, and how these processes influence the global material behavior. These interfaces are zones of compositional, structural and property gradients. The stress transfer at the interface requires an efficient coupling between fiber and matrix. Thus additives to increase the bonding and adhesion between the reinforcement and the matrix are desired. Of these, the silane coupling agent is finding more and more importance in composite manufacture. It is added on the surface of the reinforcement before the application of the matrix. The silane coupling agent shows two classes of functionality, one which reacts of the silicate based reinforcement. The other group, usually an alkoxy group, is able to infiltrate and couple with the organic matrix [11].

Polymeric materials in many applications are subjected to the effect of atmospheric exposure: ultraviolet radiation (UV), high and low temperature cycles, wetting and drying cycles, and pollutants. This results in degradation which is manifested as loss of gloss, color, and mechanical properties. The very extensive research performed on the weathering of polymers in general and PVC in particular [12] has led to significantly improved formulations which can sustain longer exposure. Moreover, the presence of advanced weathering machines with appropriate filters that can generate an accelerated weathering exposure conditions, with the acceleration factors being the intensity of the source and the time of exposure, possibly coupled with elevated temperature, humidity and water spraying [12], has enabled a faster testing for weathering properties of materials.

In this study, the effect of the duration of the UV exposure on the tensile properties of PVC composite reinforced with different amounts and forms of either glass fibers or mica particles are studied. Moreover, the impact of the addition of silane coupling agent to the composite was also examined.

2- EXPERIMENTAL WORK

2.1 Materials

The polymer matrix used in this study is Plasticized PVC compound supplied by the Egyptian Petrochemicals Company. The PPVC is known to have higher toughness than the UPVC, but with lower modulus. Thus the fiber is expected to increase its modulus without much sacrificing its toughness. Table (1) shows the company specifications for these PVC Compound products.

Table (1) PVC compound Specifications of Egyptian Petrochemicals Co.

Type	Specific Gravity	Shore Hardness	Tensile Strength (MPa)
Shoes or Hoses	**1 – 1.45**	**55 – 80**	**11 - 22**
Cable	**1.35 – 1.5**	**70 – 85**	**14 - 22**

These two PPVC compound formulations are not only part of the main products of Egyptian Petrochemicals Company but also the main two applications of PPVC all over the world [13].

Three forms of E-glass fiber were used, Woven Roving (RC: RC-500 supplied by Vetrotex), Glass Tape (GT: RS-150 plain weave), and Glass Mat (GM: M5-300) as shown in Figure (1). These three forms of fiber are not previously evaluated with those two PVC formulations as indicated by the literature survey.

Figure (1) Forms of Glass Fiber Studied

The mica used was dry ground muscovite waste from soft mica plates, Hp 5-1 supplied from THC China. Powder from waste soft mica plates was dry-shredded into feed stock in a standard hammer mill (American Pulverizer Type M). The machine was equipped with a shift screen of 1 mm openings.

After grinding, the particle size was measured Figure (2), and the mean particle size was around 1443 nm.

Vinyl tri Methoxy Silane VS 604 (Union Carbide Corporation) was used as coupling agent. All materials were used as received from the manufacturers.

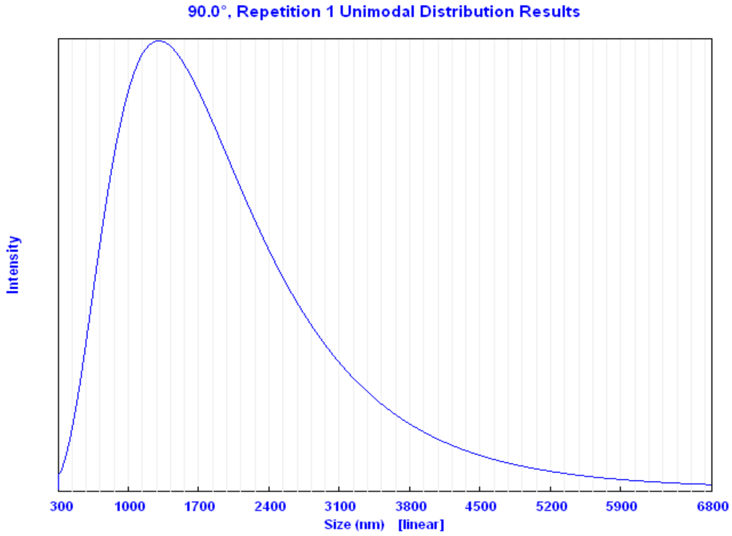

Figure (2): Particle Size Distribution of Mica

2.2 PVC formulations

Two formulations of PPVC are used in this study: Shoes (or hoses) and Cables. The ingredients of these formulations were mixed in a high speed Plasmec laboratory Mixer, model TRL-20/C, at 115°C and then cooled to 40°C. This procedure is the manufacturer recommendation.

2.3 Composite preparation

The composite preparation was performed in two steps. The first step is the preparation of 0.5 mm thick sheet using an oil-heated Brabender (PM-3000) at 170°C. Once formed, the sheets are allowed to cool, weighed and stacked with the pre-weighed glass fiber according to requirements. The second step consists of a compression molding process of these stacks into a 3 mm thick composite by means of a Presa 120TM Fabesint hydraulic press. The sheets are first heated to 165°C for 1 min, and then compressed to 20 bar for 2 min, and then the pressure was increased to 120 bar for 2 min. The heater is then switched off and the plate is left to cool downunder pressure till 70°C. The conditions for mixing, milling and compression of composites during their preparation (temperature, pressure and time) are recommended by the manufacturer for milling and compression of PPVC samples.

For the case of silane treated samples, the glass fiber was painted carefully with silane using a small brush.

For the case of the mica composite, the PVC was blended with the desired amount of mica powder in the Brabender Plasticord PL2000 for 3 min. The mixture is then compressed in the hydraulic press (Presa 120TM Fabesint) to form a 3 mm thick plate. The pressing process was carried out with the same order as the case of glass fiber composite. For silane treated samples, the silane was sprayed onto mica before Brabender mixing.

Three types of PPVC glass fibers composite were prepared: Shoes formulation + RC fibers, Shoes formulation + GT fibers, Cables formulation + GM fibers. While only the PPVC Cables formulation was used for the mica particles composite.

RC and GT forms of fiber glass were evaluated with hoses or shoes because they are suitable for cylindrical or hollow shapes in final applications. GM form of fiber glass and mica were evaluated with cables because they are suitable for laminated shapes in final applications.

2.4 Testing

The weathering process was carried out in the accelerated weathering chamber (Atlas Weather Ometer model CI 3000+), Figure (3) according to ASTM G155A.

Figure (3): Weather –O-Meter

Tensile tests were conducted for fresh samples and after weathering periods of 120 and 480 hours for glass fiber composite. For the case of mica composite, the tests were carried for fresh samples and after 100, 300, 400 hours. The tensile properties were measured using a Lloyd tensile testing machine, Type LR5K+, with a load cell 500 dN, according to ASTM D638M. Each testing parameter was measured for five samples and their average was reported.

3.Results and Discussion

3.1-PVC-glass fiber Composites

The mechanical properties after weathering for both PPVC-fiber glass composites are shown in Table (2) and figures (4-6) .

The modulus of the PPVC increased as the weathering period increased for both silane treated and untreated samples.

The composite modulus, ***E***, showed a systematic increase with the increase of fiber content. This is attributed to the fact that the modulus of the fiber is much higher than the modulus of the PPVC and that the composite modulus is a function of the fiber content and modulus, according to the formula [14]:

$$E_{composite} = E_{fiber}V_{fiber} + E_{PVC}V_{PVC}$$

where ***E*** is the modulus and ***V*** is the volume fraction

The strength showed a slight increase with the increase of the fiber content, and in some cases the strength decreased. This might be a result from the debonding at the fiber-matrix interface resulting from the high loading of fiber. Also, the composite showed a decrease in the elongation at break with the increase of fiber loading.

For the effect of the weathering, the composite showed an increase in modulus, an increase in strength, and a decrease in elongation at failure.

This can be attributed to that during weathering of the PPVC, different processes take place in parallel which affects the properties of the polymer: elimination of HCl, degradation, discoloration, and crosslinking [15]. The crosslinking is expected to have these effects on the PPVC. The only exception to this founding was the case of cables formulation with the GM glass fiber, which can be the result of the increase of debonding of the fiber-matrix.

The silane is found to increase the properties of the composite. This shows the importance of the bonding between the fiber and the matrix. It is to be noted that for the case of the strength of the cables formulation with the GM fiber, the silane presence resulted in an increase in the strength with the increase of the fiber content, instead of the decrease found in the silane untreated samples.

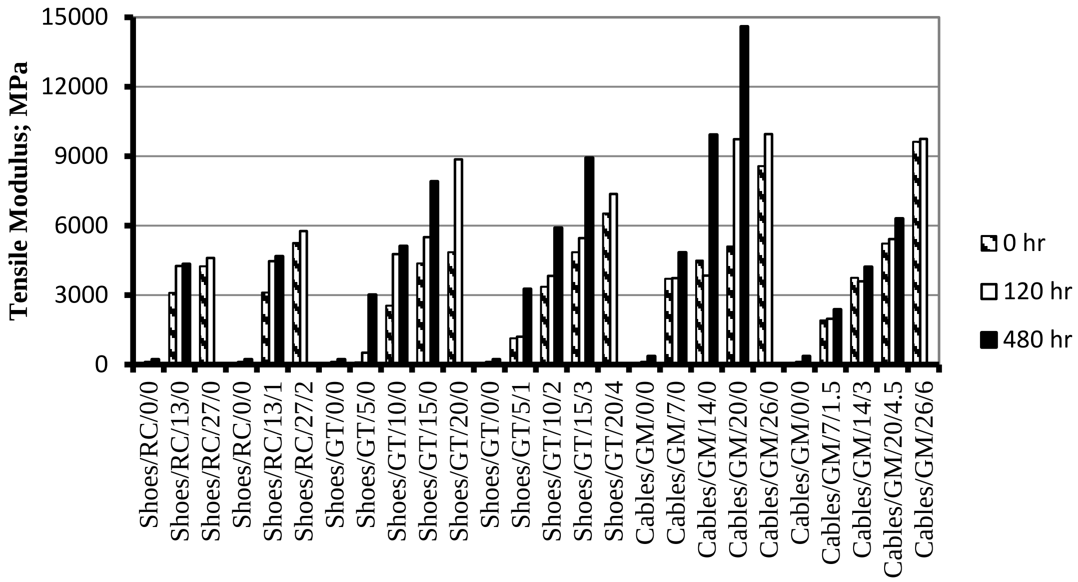

Figure (4): Tensile Modulus of PVC glass fiber composite
" The first number indicates the percent fiber and the second number indicates the percent silane"

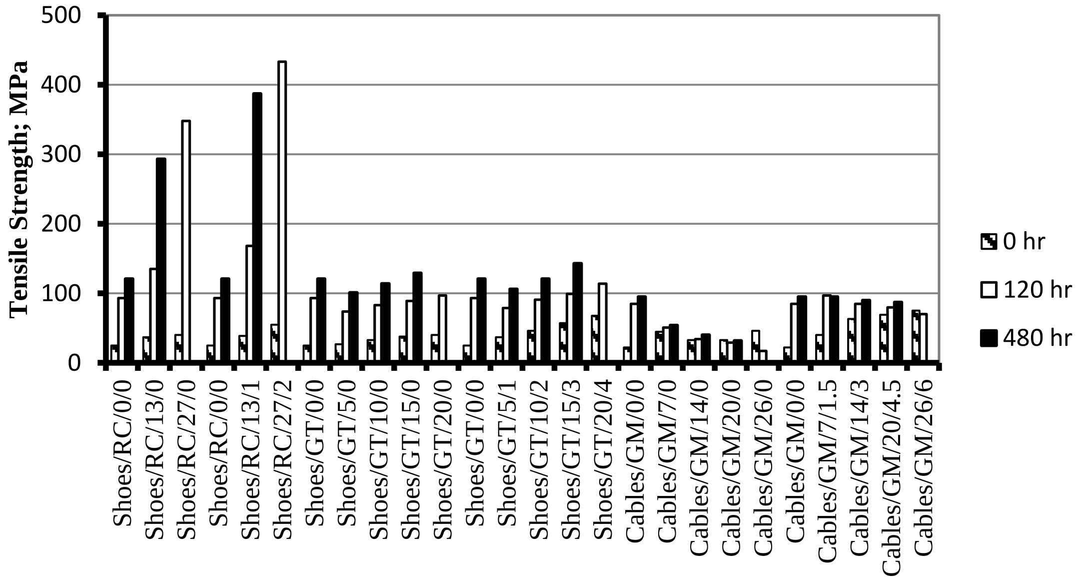

Figure (5): Tensile Strength of PVC glass fiber composite
" The first number indicates the percent fiber and the second number indicates the percent silane"

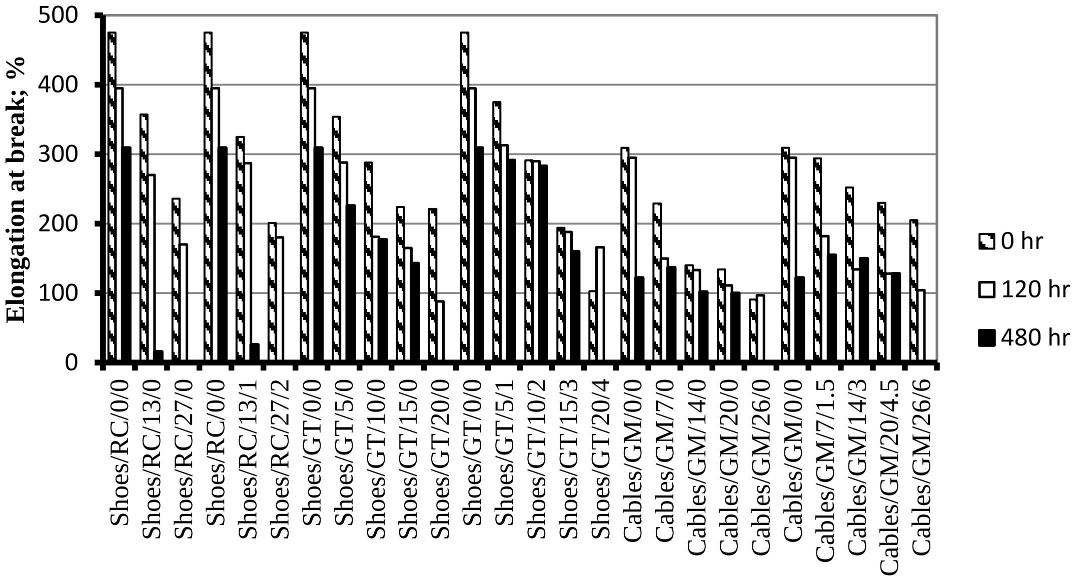

Figure (6): Percent Elongation at break of PVC glass fiber composite
"The first number indicates the percent fiber and the second number indicates the percent silane"

3.2-PVC-Mica Composites weathering properties

The mechanical properties after weathering for PVC-mica composites are shown in Table (3) and figures (7-9) .

It is found that the gradual addition of the mica resulted in increasing the tensile modulus of the composite. Also, the mica addition resulted in increasing the tensile strength of the composite, with a maximum increase at 5% silane, and then it drops gradually. Moreover, the mica addition resulted in the steady decrease of the elongation at break of the composite.

Regarding the weathering effect, the modulus increased with the increase of the weathering period, except for the case of the 2% silane, where the 400 hr. samples showed a lower modulus than the 300 hr. samples. However, no systematic trend was detected when studying the effect of the weathering on the tensile strength. For the case of the elongation at break, the weathering resulted in a sharp decrease in its value, especially for the samples with 2% silane. These observations might be the result partial cross linking of the PVC, with the resultant increase in stiffness. There was generally an increase of the modulus of the composite upon the increase of the silane. This is due to the increase of the bonding between the matrix and the particles. However, there was no obvious organized effect for the silane coupling agent on the strength of the composite. Also, a decrease in the elongation at break was detected with the 2% silane samples after weathering.

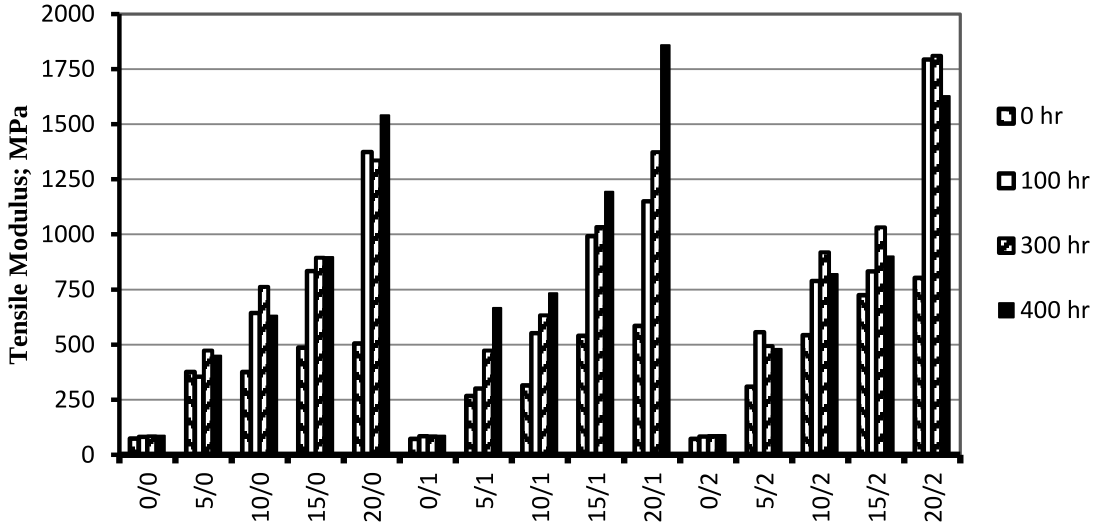

Figure (7): Tensile Modulus of PVC (cables formulation) - composite

"The first number indicates the percent mica and the second number indicates the percent silane"

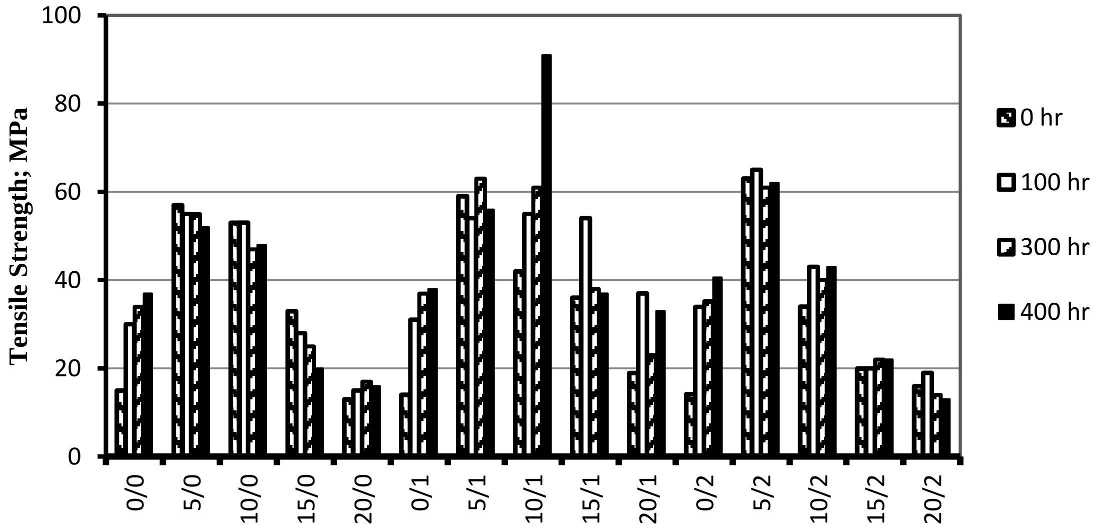

Figure (8): Tensile Strength of PVC (cables formulation) - composite

"The first number indicates the percent mica and the second number indicates the percent silane"

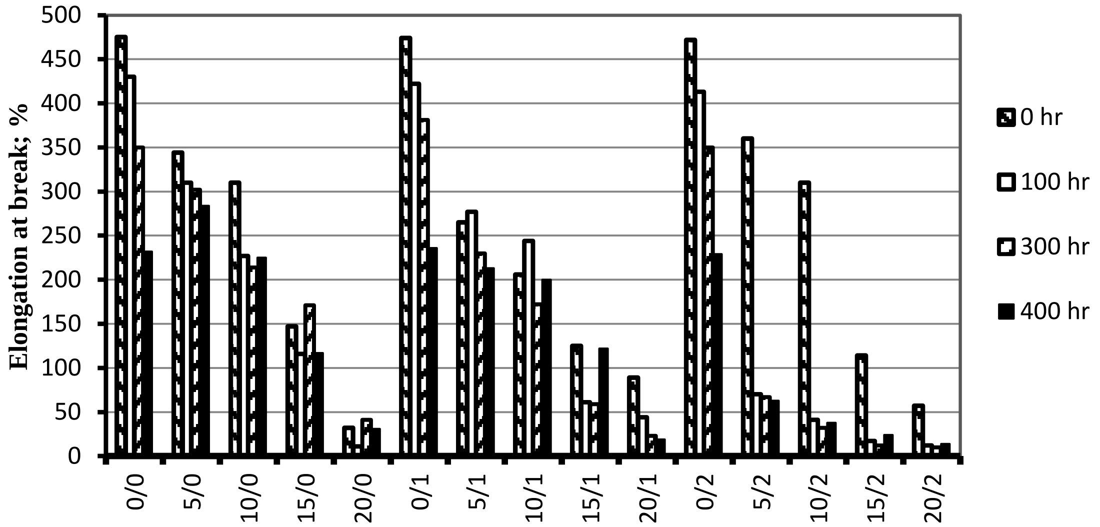

Figure (9): % Elongation of PVC (cables formulation) - composite
"The first number indicates the percent mica and the second number indicates the percent silane"

4-Conclusion

In this study, PVC composites were made from a selected combination of some PPVC formulations and forms of fiber glass or mica particles. The tensile properties of these composites where determined before and during weathering intervals.

It was concluded that fiber glass and mica reinforcements can offer new behavior for the PPVC. These additives caused a general increase in modulus and strength, and a decrease in elongation at break. The weathering generally increased the modulus and decreased the elongation at break. The addition of the silane coupling agent also increased the modulus and decreased the elongation at break.

Table (2) Tensile Properties of PPVC-Glass Fiber Composites after different Weathering periods

Composite	Fiber (wt %)	Silane (wt %)	Tensile Modulus (MPa)			Tensile Strength (MPa)			Elongation %		
			0 hr	120 hr	480 hr	0 hr	120 hr	480 hr	0 hr	120 hr	480 hr

RC+Shoes	**0**	**0**	22	115	230	25	93	121	475	395	309
	13	**0**	3105	4260	4348	37	135	293	357	270	16
	27	**0**	4250	4600	x	40	348	x	236	170	x
RC+Shoes+Silane	**0**	**0**	22	115	230	25	93	121	475	395	309
	13	**1**	3110	4462	4668	39	168	387	325	287	26
	27	**2**	5256	5768	x	55	433	x	201	180	x
GT+Shoes	**0**	**0**	22	115	230	25	93	121	475	395	309
	5	**0**	95	517	3021	27	74	101	354	288	226
	10	**0**	2540	4768	5120	33	83	114	288	181	177
	15	**0**	4370	5506	7903	38	89	129	224	165	143
	20	**0**	4850	8865	x	40	97	x	221	88	x
GT+Shoes+Silane	**0**	**0**	22	115	230	25	93	121	475	395	309
	5	**1**	1140	1210	3270	37	79	106	375	313	291
	10	**2**	3365	3830	5900	46	91	121	291	290	283
	15	**3**	4852	5465	8930	57	99	143	194	188	160
	20	**4**	6524	7361	x	68	114	x	103	166	x

GM+Cable	**0**	**0**	75	115	369	22	85	95	309	295	122
	7	**0**	3700	3731	4843	45	51	54	229	150	137
	14	**0**	4494	3848	9920	33	34	40	140	133	102
	20	**0**	5099	9735	14594	33	29	32	134	111	100
	26	**0**	8575	9949	x	46	17	x	91	97	x
GM+Cable+Silane	**0**	**0**	75	115	369	22	85	95	309	295	122
	7	**1.5**	1916	1985	2373	40	97	95	294	182	155
	14	**3**	3747	3591	4213	63	85	90	252	134	150
	20	**4.5**	5221	5423	6309	69	80	87	230	128	128
	26	**6**	9620	9746	x	75	70	x	205	104	x

x: Required higher Load Cell than available (500dN cell).

Table (3) Tensile Properties of PPVC-Mica Composites at Different Weathering Intervals

Tensile Modulus (MPa)

Mica wt%	0 % Silane				
	0	5	10	15	20
0 hr	75	377	376	487	506
100 hr	81	354	644	833	1374
300 hr	84	473	763	894	1336
400 hr	87	450	632	898	1540

Mica wt%	1 % Silane				
	0	5	10	15	20
0 hr	72.7	267	315	540	586
100 hr	84	301	552	992	1150
300 hr	85	473	633	1034	1374
400 hr	88	666	734	1193	1858

Mica wt%	2 % Silane				
	0	5	10	15	20
0 hr	73.7	310	543	725	803
100 hr	83	556	788	832	1793
300 hr	86	494	920	1033	1811
400 hr	90	481	820	900	1627

Tensile Strength (MPa)

Mica wt%	0 % Silane				
	0	5	10	15	20
0 hr	15	57	53	33	13
100 hr	30	55	53	28	15
300 hr	34	55	47	25	17
400 hr	37	52	48	20	16

Mica wt%	1 % Silane				
	0	5	10	15	20
0 hr	14	59	42	36	19
100 hr	31	54	55	54	37
300 hr	37	63	61	38	23
400 hr	38	56	91	37	33

Mica wt%	2 % Silane				
	0	5	10	15	20
0 hr	14.2	63	34	20	16
100 hr	33.9	65	43	20	19
300 hr	35.2	61	40	22	14
400 hr	40.6	62	43	22	13

Elongation (%)

Mica wt%	0 % Silane				
	0	5	10	15	20
0 hr	475	344	310	147	32
100 hr	430	310	227	116	11
300 hr	350	302	214	171	41
400 hr	232	284	225	117	31

Mica wt%	1 % Silane				
	0	5	10	15	20
0 hr	474	265	206	125	89
100 hr	422	277	244	61	44
300 hr	381	230	172	59	23
400 hr	236	213	200	122	19

Mica wt%	2 % Silane				
	0	5	10	15	20
0 hr	472	360	310	114	57
100 hr	413	70	41	17	12
300 hr	350	67	32	12	10
400 hr	229	63	38	24	14

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