

EFFECT OF AMMONIUM PHOSPHATES ON THE MECHANICAL PROPERTIES OF GENERAL-PURPOSE POLYSTYRENE (GPPS)

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ABSTRACT

Nine sets of 125 μm -thick pure (additive-free) high-impact polystyrene plastic film was prepared by compression moulding technique. 7.5 % (w/w) of three ammonium phosphate $[(\text{NH}_4)_3\text{PO}_4, (\text{NH}_4)_2\text{HPO}_4, \text{and } \text{NH}_4\text{H}_2\text{PO}_4]$ were added, singly and in combination, to the pure polystyrene granules to produce 125 μm -thick films by the same method. Four of the nine sets of the sample films were exposed rooftop at 45° , facing South for four weeks. Another four of the nine sets of the sample films were stored in a refrigerator for four weeks. Tensile strength, flexural strength, and elongation-at-break of the ninth set were determined. These mechanical properties were also determined for both the exposed and the stored sample films on weekly basis. From the results, a progressive decrease in the mechanical properties was observed as the time of exposure of the samples to sunlight is increased. Tensile and flexural strengths of the unfilled sample were found to be less than the filled sample films. However, elongation-at-break of the unfilled sample was found to be greater than the filled sample films. The results further showed that the tensile strength and elongation-at-break of all the samples decrease, on the average, by $8.53 \times 10^{-6} \text{ Nm}^{-2}$ and 0.07 %, respectively, during the four-week exposure. After one week of exposure to sunlight, the flexural strength of all the samples was found to decrease, on the average, by 10.25 MN/m^2 .

Keywords: Ammonium phosphate, elongation, polymer, polystyrene, tensile strength

INTRODUCTION

Plastics are the most fascinating materials known on account of their range of applications in everyday life for defence and civilian purposes. The property spectrum for plastics and their behaviours under the most diverse conditions are getting broader as research continues to lead to modification of polymers so that hundreds of plastic materials are available to provide the consumer with the properties required for just about any application (Hall, 2008). Today, plastic materials are considered to be an essential part of modern living due to their desirable features of relative ease of fabrication and

energy efficiency, light-weight, great strength, cheapness than the conventional materials (glass, wood, metals and ceramics). These attributes translate into excellent economics. Plastics have been described as mainstay of life and are being designed to meet ever exacting and specific consumer needs (Gosh, 2002; Harnandez, 2002).

Mechanical properties of polymers are those properties that are of end-use interest. These properties, such as tensile strength, dictate how the polymer actually behaves on a macroscopic scale. The effects on mechanical properties of polystyrene due to addition of various

additives have been the subjects of many studies (Turner, 2004).

Since the very early stages of the development of the polymer industry, it was realized that useful products could only be obtained if certain additives were incorporated into the polymer matrix. Polymers would not be able to perform such diverse functions without the aid of additives as most polymers have inferior mechanical properties than desired in their field of use. Plastic additives encompass a wide variety of materials added to plastic resins in order to enhance their quality. The term “additive” is used here to describe those materials which are physically dispersed in a polymer matrix



The general-purpose polystyrene (the unmodified variety) is rather brittle, glass-clear, and a hard polymer with easy processing characteristics and used for a myriad of applications. It is used in critical construction, electrical and transport applications in which high mechanical properties are mandatory (Eboatu *et al*, 1992). Polystyrene-based materials can be produced as very thin-walled containers for dairy products, foodstuffs, vending cups, packaging for eggs and meat (Doroudiani and Kortschot, 2004). Polystyrene-based plastics are used widely in vacuum cleaners, fridge liners, and spools. In the form of expanded foam, Polystyrene is used for insulation as ceiling tiles and blocks (McCrum *et al*, 1997; Bosman *et al*, 2004).

In this study, three ammonium phosphates [(NH₄)₃PO₄, (NH₄)₂HPO₄, and NH₄H₂PO₄] are incorporated into general-purpose polystyrene, singly and combined,

without affecting significantly the molecular structure of the polymer (Brunsveld *et al*, 2000).

The materials known in the plastics industry as fillers have been defined by the ASTM's Committee D-20 as “relatively inert materials added to a plastic to modify its strength, performance, working properties, or to lower cost” (Norton, 2002). Some workers have reported that mechanical properties of polystyrene can be varied over a wide range by adding fillers, thus making it one of the most versatile plastics (Bandyopadhyay and Chandra, 2007).

Polystyrene is synthesized by the free radical vinyl polymerization of styrene:

and their mechanical properties studied in comparison to the pure/control sample.

MATERIALS AND METHODS

Materials: Commercial general-purpose polystyrene granules (Polystyrol) were obtained from Fluka Chemie GmbH, Switzerland, and the three ammonium phosphates ((NH₄)₃PO₄, (NH₄)₂HPO₄, and NH₄H₂PO₄) used in formulating the films were all analytical-reagent grade obtained from Hoescht Chemicals, AG, Germany.

Sample Preparation: The formulations from which the samples are prepared are shown in Table 1. 125 μm-thick film of pure (additive-free) Polystyrol is prepared by compression moulding technique in a 12.20 X 1.22 X 0.13 cm mould for 5 minutes at a pressure of 4.72 Pa using a Tetrahedron Automatic Press. The above procedure is repeated by adding 7.5 %

w/w of the three fillers ((NH₄)₃PO₄, (NH₄)₂HPO₄, and NH₄H₂PO₄), singly, in pairs and all the three fillers combined, to the pure Polystyrol granules.

Natural Outdoor Ageing (Weathering):

Nine sample coupons (measuring 0.03 m X 0.02 m) are cut and their mechanical properties determined. Four sets of the nine sample sets are mounted on wooden rack frames and then exposed rooftop in an open space for four weeks (1st May to 29th May, 2009) at 45°-Angle (Slant Exposure) facing South (average room temperature

being 29.5 °C). To assess the extent of deterioration of the mechanical properties (tensile strength, flexural strength and elongation-at-break) are determined for each sample coupon on a weekly basis. Three replicate measurements are made and the average value reported for each of the exposed sample coupons. Visual examination of each sample coupon is also carried out. Four sets of the nine sample films sets are stored in a refrigerator as control and for comparison and the above procedure repeated for each sample coupon.

Table 1: Amount of the components (% w/w) used in preparation of the sample film formulations.

Component	Amount (% w/w)							
	100	92.5	92.5	92.5	92.5	92.5	92.5	92.5
PS	100	92.5	92.5	92.5	92.5	92.5	92.5	92.5
(NH ₄) ₃ PO ₄	0	7.5	0	0	0	0	0	0
(NH ₄) ₂ HPO ₄	0	0	7.5	0	0	0	0	0
NH ₄ H ₂ PO ₄	0	0	0	7.5	0	0	0	0
(NH ₄) ₃ PO ₄ + (NH ₄) ₂ HPO ₄	0	0	0	0	7.5	0	0	0
(NH ₄) ₃ PO ₄ + NH ₄ H ₂ PO ₄	0	0	0	0	0	7.5	0	0
(NH ₄) ₂ HPO ₄ + NH ₄ H ₂ PO ₄	0	0	0	0	0	0	7.5	0
(NH ₄) ₃ PO ₄ + (NH ₄) ₂ HPO ₄ + NH ₄ H ₂ PO ₄	0	0	0	0	0	0	0	7.5
Sample Code	A	B	C	D	E	F	G	H

Determination of Mechanical Properties: Standard ASTM methods (Anon, 2002) for the determination of tensile strength, flexural strength and elongation-at-break for the sample films are carried out using Automatic (Digital) Universal Testing Machine, Micro Vision Industries, India, Serial Number 183.

RESULTS AND DISCUSSION

The mechanical properties (tensile strength, flexural strength and elongation-at-break) of the pure/unfilled (control) and the ammonium salt-filled general-purpose polystyrene films are shown in Tables 2, 3 and 4, respectively.

Table 2 displays the results of the tensile strength of the seven 125 µm-thick ammonium phosphate-filled general-purpose polystyrene and the control (unfilled/sample A) films exposed to

sunlight at 45°-Angle (Slant Exposure) facing South for four weeks. It can be seen that there is a progressive decrease in the values of tensile strength with the number of weeks of exposure to sunlight. Considering the values of tensile strength of the samples one week after exposure to that of the pre-exposure values, sample A decreases by $1.14 \times 10^{-6} \text{ Nm}^{-2}$. For sample B, the decrease is $1.25 \times 10^{-6} \text{ Nm}^{-2}$. The loss in tensile strength, respectively, are $1.35 \times 10^{-6} \text{ Nm}^{-2}$ for sample C, $1.15 \times 10^{-6} \text{ Nm}^{-2}$ for D, $2.20 \times 10^{-6} \text{ Nm}^{-2}$ for E, $2.11 \times 10^{-6} \text{ Nm}^{-2}$ for F, $2.15 \times 10^{-6} \text{ Nm}^{-2}$ for G and $32.19 \times 10^{-6} \text{ Nm}^{-2}$ for sample H. Considering the weekly decrease in tensile strength of the samples, it can be seen that, on the average, each sample decrease by about $2.10 \times 10^{-6} \text{ Nm}^{-2}$. Specifically, the control sample (A) decreases by $2.25 \times 10^{-6} \text{ Nm}^{-2}$ from first week to second week $2.24 \times 10^{-6} \text{ Nm}^{-2}$ from second week to

third week and $2.02 \times 10^{-6} \text{ Nm}^{-2}$ from third week to fourth week. Similar proportion of

decrease in tensile strength was obtained for the filled samples.

Table 2: Tensile strength of the seven 125 μm -thick ammonium phosphate-filled general-purpose polystyrene and the control (unfilled/sample A) films before and after being exposed to sunlight for four weeks.

Sample	Tensile strength ($\times 10^{-6} \text{ Nm}^{-2}$)				
	Pre-exposure	First week	Second week	Third week	Fourth week
A	35.98	34.84	32.59	30.35	28.33
B	48.90	47.65	45.32	43.20	41.04
C	49.88	48.53	46.32	44.21	42.11
D	47.64	46.49	44.35	42.28	40.07
E	53.97	51.77	49.63	47.42	45.22
F	55.79	53.68	51.46	49.24	47.13
G	54.54	52.39	50.18	48.03	47.93
H	60.76	57.57	55.30	53.13	51.03

Considering the total decrease in tensile strength from Table 2, it can be observed that the samples, on the average, decrease by about $7.95 \times 10^{-6} \text{ Nm}^{-2}$. Sample A decreases by $7.65 \times 10^{-6} \text{ Nm}^{-2}$ during the four-week exposure to sunlight. This implies that the difference in tensile strength values from the pre-exposure to that of the fourth week is $7.65 \times 10^{-6} \text{ Nm}^{-2}$. For sample B, it is $7.86 \times 10^{-6} \text{ Nm}^{-2}$, $7.77 \times 10^{-6} \text{ Nm}^{-2}$ for C, $7.54 \times 10^{-6} \text{ Nm}^{-2}$ for D, $8.75 \times 10^{-6} \text{ Nm}^{-2}$ for E, for $8.66 \times 10^{-6} \text{ Nm}^{-2}$ F, $6.61 \times 10^{-6} \text{ Nm}^{-2}$ for G and $9.73 \times 10^{-6} \text{ Nm}^{-2}$ for H.

Comparing the tensile strength values of the filled samples to that of sample A (pure/unfilled) general-purpose polystyrene, it can be seen that sample A

has the least tensile strength ($34.84 \times 10^{-6} \text{ Nm}^{-2}$) after one week of exposure. This result implies that the three ammonium phosphate salts have increased the tensile strength of the general-purpose polystyrene plastic film.

Table 3 presents the results of the flexural strength of the seven 125 μm -thick ammonium phosphate-filled general-purpose polystyrene and the control (unfilled/sample A) films exposed to sunlight at 45° -Angle (Slant Exposure) facing South for four weeks. It can be seen, from Table 3, that flexural strength of the control (unfilled/sample A) film has the least pre-exposure value of 67.70 MN/m^2 .

Table 3: Flexural strength of the seven 125 μm -thick ammonium phosphate-filled general-purpose polystyrene and the control (unfilled/sample A) films before and after being exposed to sunlight for four weeks.

Sample	Flexural strength (MN/m^2)				
	Pre-exposure	First week	Second week	Third week	Fourth week
A	67.70	62.35	62.24	62.15	62.03
B	80.75	73.65	73.56	73.45	73.34
C	80.68	73.61	73.50	73.48	73.37
D	80.74	73.63	73.52	73.50	73.41
E	94.32	84.21	84.12	84.03	83.92
F	94.23	84.13	84.04	83.93	83.83
G	93.99	83.97	83.88	83.79	83.68
H	109.49	94.36	94.25	94.13	94.03

A closer look at the table also reveals that sample A has the least loss in flexural strength in the four-week exposure period. Sample H can be seen to have the largest pre-exposure value of flexural strength and the largest loss in the four-week exposure period. Comparing the pre-exposure flexural strength values and those of the first week for all the samples, it can be seen that sample A has lost 5.35 MN/m^2 after one week exposure to sunlight. This implies that the difference between the flexural strength of sample before exposure and that obtained after a week of exposure (62.35 MN/m^2) is 5.35 MN/m^2 . For sample B, 7.10 MN/m^2 was lost after a week of exposure. Sample C lost 7.07 MN/m^2 , D lost 7.11 MN/m^2 , E lost 10.11 MN/m^2 , F lost 10.10 MN/m^2 , G lost 10.02 MN/m^2 and sample H lost 15.13 MN/m^2 . In general, it can be seen that the ammonium salt fillers have increased the flexural strength value of the unfilled general-purpose polystyrene (sample A). A progressive reduction in the flexural strength values for all the samples can be noted throughout the four-week exposure

period. Comparing the results of Table 2 (tensile strength) to that of Table 3 (flexural strength), it can be seen that, on percentage bases, the samples lost more of their flexural strength than their tensile strength during the four-week exposure period.

In Table 4 are shown the results of elongation-at-break of the seven $125 \mu\text{m}$ -thick ammonium phosphate-filled general-purpose polystyrene and the control (unfilled/sample A) films exposed to sunlight at 45° -Angle (Slant Exposure) facing South for four weeks.

It can be noted that, in contrast to values shown in Tables 2 (tensile strength) and 3 (flexural strength), the results displayed in Table 4 (elongation-at-break) showed that sample A has the highest value of 2.78 %. Comparing the pre-exposure elongation-at-break values and those of the first week for all the samples, it can be seen that sample A has lost 0.20 %. For sample B, 0.13 % was lost after a week of exposure. Sample C lost 0.12 %, D lost 0.10 %, E lost 0.08 %, F lost 0.06 %, G lost 0.04 % and sample H lost 0.02 %

Table 4: Elongation-at-break of the eight $125 \mu\text{m}$ -thick general-purpose polystyrene sample films before and after being exposed to sunlight for four weeks and the control (unexposed sample).

Sample	Elongation-at-break (%)				
	Pre-exposure	First week	Second week	Third week	Fourth week
A	2.78	2.58	2.53	2.48	2.43
B	2.48	2.35	2.32	2.29	2.26
C	2.44	2.32	2.29	2.26	2.23
D	2.31	2.21	2.18	2.15	2.12
E	2.06	1.98	1.90	1.81	1.72
F	1.93	1.87	1.79	1.70	1.61
G	1.89	1.85	1.76	1.67	1.58
H	1.81	1.79	1.68	1.57	1.46

If the elongation-at-break values of the samples are compared, it can be noted that the decrease in samples B, C and D (the three ammonium salts added singly) is at least 0.23 % less than sample A. Samples E, F and G (the three ammonium salts added in pairs) are at least 0.34 % less than sample A. For sample G (all the three

ammonium salts added), the elongation-at-break value is at least 0.79 % less than sample A.

Comparing the elongation-at-break values of all the samples for the four-week exposure period, it can be observed that sample A has lost 0.05 %, samples B, C and D have lost, on the average, 0.03 %.

Samples E, F and G have lost, on the average, 0.08 %. For sample H, the loss is 0.11 %.

CONCLUSION

Flexural strength and elongation-at-break of the unfilled sample film were found to be less than and greater than, respectively, the filled sample films. Tensile strength of the unfilled sample was also found to be less than those of the filled sample films. Consequently, since tensile strength quantifies how much stress a material will endure before failing, the three ammonium sulphate salts are strongly recommended for inclusion in formulation of the general-purpose polystyrene films requiring much resistance to tensile forces in outdoor applications.

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