EFFECT OF ALUMINUM PHOSPHATE ON MECHANICAL AND FLAME RETARDANT PROPERTIES OF COMPOSITES FIBREGLASS

Asmalina Mohamed Saat[1], Asmawi Abd Malik[1], Adila Azmi[1], Mohamad Fadzil Abd Latif[1], Nur Ermadiana Ramlee[1] and Mohd Rafie Johan[2,3]
[1]Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Lumut Perak, Malaysia
[2]Nanotechnology and Catalyst Research, Research Centre, Universiti Malaya, Kuala Lumpur, Malaysia
[3]Materials Engineering Research Group, Advance Materials research Laboratory, Department of Mechanical, Faculty Engineering, Universiti Malaya, Kuala Lumpur, Malaysia
E-Mail: asmalina@unikl.edu.my

ABSTRACT
In marine industries especially in fiberglass boat making, material selection is instrumental for optimal product performance and economy. Mechanical properties of laminated fiberglass composite containing polyester resin, fiberglass and new fire retardant additive fabricated by Hand lay-up technique were investigated. The fire retardancy mechanism and mechanical properties of aluminum phosphate ($AlPO_4$) were investigated in seven layers composite fiberglass system. E-glass / Polyester composite of $AlPO_4$ was prepared with various different ratio of Aluminum Phosphates. Composite system with addition of 5wt% $AlPO_4$ observed maximum strength in tensile, flexural and impact test. Fire retardant test also showed an optimised performance in similar ratio.

Keywords: FRP, phosphate, mechanical testing, fire retardant margins.

INTRODUCTION
The term fiberglass boat cover the composite materials using a common cost effective polymer resin, unsaturated polyester and reinforcement materials from fiberglass laminate layer materials. In composite fiberglass boat manufacturing polyester resin is widely used to produce small marine vessels such as life boats, yachts, commercial vessels and navy vessels due to its easy manufacturing process, low cost and exhibit excellent mechanical properties. Despite many advantages of composite fiberglass, they are still in need of improvement for fire performance of composite fiberglass without losing the existing important properties. In the composite fiberglass system, polyester has high flammable properties compared to fiberglass. The materials used in the construction of composite fiberglass boat should inhibit not only fire but also smoke propagation during a defined period of time. From a chemical point of view, fire retardants are divided into five main classes of inorganic compounds, which are divided into active and passive flame retardants. Active flame retardant is operated by releasing water at elevated temperatures [1], hence heat is adsorbed from the surface of the material. Meanwhile passive flame retardant produces char layer to inhibit the flame propagation[2–4]. The commercial fire retardants additive commonly used in the polyester system act are either passive, reactive or combination this system. Aluminum trihydroxide (ATH) is widely used as fire retardant additive in polyester system due to it good retardant properties but high ATH loading, detrimental the composite fiberglass strength. ATH were later used in combination with other fire retardant materials such as ammonium polyphosphate (APP) [5], aluminium diethyl phosphinate (AlPi) [6], graphite [7] and carbon nanotubes [8]. Aluminum phosphate is a phosphorus type fire retardant that recently explored its potential to retard the burning process in the polymer nanocomposite (polystyrene, polypropylene and poly vinyl alcohol) based system [9]. The application of aluminum phosphate in a polyester system is an interesting field to explore in terms of mechanical and flame retardant ability. Therefore, this paper focuses on analysing the effect of aluminum phosphate ratio on the mechanical properties specific to tensile, flexural and impact test. The evaluation of fire retardant properties was also conducted using UL94 vertical burning testing.

METHODOLOGY
A commercial unsaturated polyester resin (30 to 45% styrene monomer) with the trade name of Norsodyne 3338W from Polynt Composites Malaysia Sdn. Bhd. was used as matrix. Methyl Ethyl ketone Peroxide (MEKP) from Mepoxe was supplied by Pt Kawaguchi Kimia Indonesia. Meanwhile aluminum phosphate was by Sigma Aldrich. Mixture of polyester, catalyst and aluminum phosphate (0wt%, 5wt% and 10wt%) were hand stirred homogenously and applied to each of the seven layers of lamination fiberglass. The composite panels with 0˚ angle laminate layer were left cured for 24 hours. Figure 1 shows the design layer of composite fiberglass structure that consists of three types of fibreglass reinforcement, CSM300, CSM 450 and WR600. The cured panels were cut into respective dimension for tensile, flexural, impact and UL 94 fire retardant test. Tensile and flexural testing was conducted using universal testing machine Instron 1195 by referring to ASTM D3039 and D730 respectively. The crosshead speed for tensile was set to 10 mm/min, meanwhile for flexural test was 1.2 mm/min. The impact test specimen was conducted on Charpy Izod Impact Tester 300J (LS-22006-300J) according to the ASTM E23 using the Charpy test method. Samples prepared were V shape notch with 2 mm deep, 45˚ angle and 0.25 mm radius along the base. The fire retardant test was conducted for all samples referring to the UL94 vertical

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

burning test with a sample dimension of 125 x 13 x 3 mm. The sample was applied with blue flame at the bottom of specimen at 20mm distance and remains constant from 50 W burners. The flame applied for 10 second (t_1) referred as time required for the flame to extinguish. Then another 10 second (t_2) refers to after flame time and the next 10 second (t_3) as time required for fire to glow and disappear. Any burning drop that ignites the cotton piece located at the bottom of samples was recorded. The lengths of fire propagation were measured for all samples.

Figure-1. Design layered of composite fiberglass structure.

RESULTS AND DISCUSSION

Mechanical properties of composite fiberglass with various aluminum phosphate ratio for tensile, flexural and impact strength were evaluated. The composite fiberglass developed with 0° oriented fiberglass for all mechanical testing obtained maximum value of tensile, flexural and impact strength in sample with 5wt% aluminum ratio. Figure 2 shows the tensile stress (a) and strain (b) conducted for composite fiberglass respectively. The tensile and flexural stress and strain curve shows improvement in mechanical properties of the composites with increase in ratio of aluminum phosphate loading. The enhancements in tensile and flexural strength due to excellent bonding and compatibility between polyester, aluminum phosphate and fibreglass. The tensile stress and strain observed an improvement in elongation of sample with 50.09% and 21.28% respectively for sample with 5wt% of aluminum phosphate ratio. The efficiency reduce to 11.34 and -3.2% for stress and strain value respectively for sample with 10wt% aluminum phosphate ratio. Meanwhile, the flexural stress and strain observed maximum flexural strength 316.33 N/mm^2 in sample 5wt% ratio, however the flexural strain shows the lowest value with 7.89 % and -15.71 % reduction of elongation. The impact strength also observed similar trend as tensile with increased impact strength at 5wt% and decreased the strength value at 10wt% ratio of aluminum phosphate in the composite system. Table 1 summarize all the mechanical properties for composite fibreglass with various aluminum phosphate ratios (0wt%, 5wt%, 10wt %). The strength of composite fiberglass increased as the ratio of aluminum phosphate increase was due to excellent polyester matrix interface with aluminum phosphate and fibreglass. The adhesion between unsaturated polyester, aluminum phosphate and fibreglass is very effective due to stress transfer under tensile loading through phosphate group in polymer matrix. Pramanik, earlier also concluded that phosphate in poly vinyl alcohol help distribute the stress transfer and increase the mechanical properties of polymer matrix [10]. However at 10wt% ratio of aluminium phosphate, the tensile strength tended to decrease due to excess phosphate group in the system. The mixture of polyester with aluminum phosphate at high ratio of 10wt% observed viscous, sluggish solutions that promote the formation of void in the composite fiberglass.

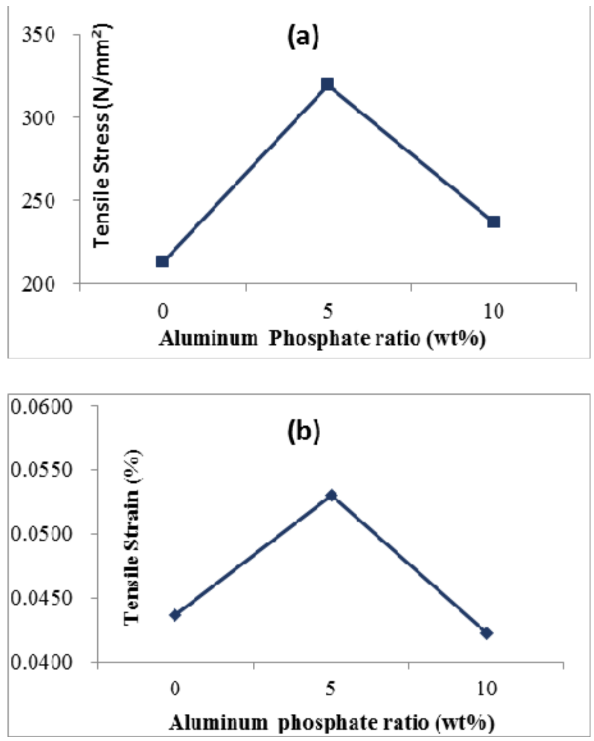
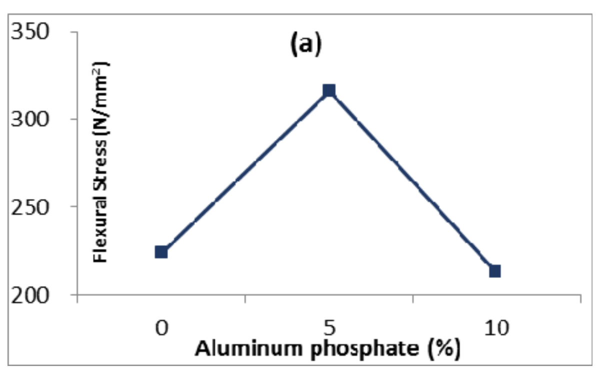


Figure-2. Tensile (a) stress and (b) strain for composite fibreglass with various aluminum phosphate ratios (0wt%, 5 wt%, 10 wt%).



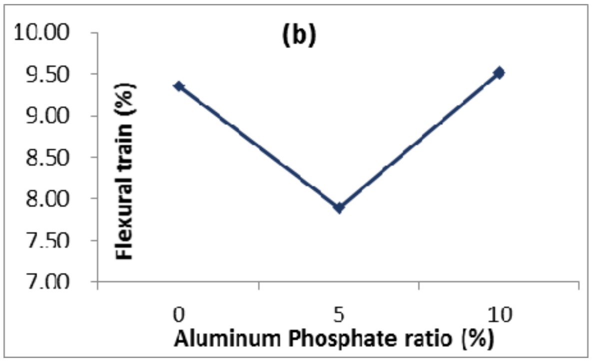


Figure-3. Flexural Stress (a) and strain (b) for composite fibreglass with various aluminum phosphate ratios (0wt%, 5 wt%, 10 wt%).

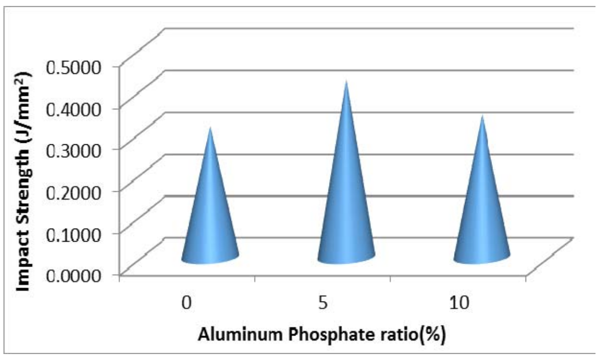


Figure-4. Impact Strength for composite fibreglass with various aluminum phosphate ratios (0wt%, 5 wt%, 10 wt%).

Table-1. The mechanical properties of composite fibreglass with various aluminum phosphate ratios (0wt%, 5wt%, 10wt %).

Sample No		1	2	3
Aluminum phosphate ratio (wt%)		0	5	10
Tensile	Strength (N/mm^2)	212.95	319.61	237.10
	Efficiency (%)	0	50.09	11.34
	Strain (%)	0.0437	0.0530	0.0423
	Efficiency (%)	0	21.28	-3.20
Flexural	Strength (N/mm^2)	224.07	316.33	213.04
	Efficiency (%)	0	41.17	-4.92
	Strain (%)	9.36	7.89	9.52
	Efficiency (%)	0	-15.71	1.71
Impact	Strength (J/mm^2)	0.3126	0.4256	0.3416
	Efficiency (%)	0	36.15	9.28

Table-2. UL94 vertical burning for composite fibreglass with various aluminum ratios (0wt%, 5 wt%, 10 wt%).

Samples no		1	2	3
Aluminum phosphate ratio (wt %)		0	5	10
t_1 (10s)	self-extinguishing	No	No	No
	Non burn length (mm)	99	117	114
t_2 (20s)	After flame	-	-	-
	Non burn length (mm)	84	104	106
t_3 (30s)	Non burn length (mm)	56	93	96

Table-2 shows the UL94 vertical burning for fire retardant properties Polyester resin observed the maximum propagation of fire burning with remaining only 56 mm length left. The propagation of fire burning increased as the aluminum phosphate increased at final time 30s (t_3). However, at 5wt% ratio of aluminum phosphate the t_1 obtained slow ignition and propagation of fire burning.

Hapuarachchi, supported our findings with observation of combination ATH and APP that contained phosphate group delayed the ignition time of composite fire retardant materials [5]. Ribiero also observed that the combination of alumina (0-5wt%) and phosphine (10-15wt%) that contained aluminum and phosphorus element improved the fire retardant properties of unsaturated polyester [11]. Aluminum phosphate shows good prospect as new fire reatardant material with a low loading ratio of aluminum phosphate. The fire retardant result supported the mechanical data that at 5wt% aluminum ratio producde a maxium interaction between aluminum phosphate and composite fibreglass with the highest strength value and slow ignition time at t_1. Furthermore, at was also reported earlier that excessive amount of phosphate was detrimental to the properties of fire retardant composite fibreglass [7].

CONCLUSIONS

The addition of 5wt% Aluminum phosphate produces optimum fire retardant and mechanical properties of new fire retardant composite fibreglass. This new fire retardant composite observed an improve interaction between polyester, fibreglass and aluminium phosphate which reflects its mechanical and flammability properties. However, excess aluminium phosphate will affected both mechanical and fire retardant properties of this new composites. This finding shows that aluminium phosphate is a good prospective as a new fire retardant material in composite fibreglass.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

ACKNOWLEDGEMENTS

This work was financially supported by UniKL Short Term Grant (UniKL/Cori/STRG/15126). Author also appreciates of the collaboration with Nanotechnology and Catalyst Research, UM Research Centre and Materials Engineering Research Group, Advanced Materials Research Laboratory, Department of Mechanical, Faculty Engineering, Universiti Malaya, Kuala Lumpur, Malaysia. The author gratefully acknowledge on both of support.

REFERENCES

[1] B. K. Kandola, J. R. Ebdon, and K. P. Chowdhury, “Flame retardance and physical properties of novel cured blends of unsaturated polyester and furan resins,” Polymers., vol. 7, no. 2, pp. 298–315, 2015.

[2] K. Varga, M. F. Noisternig, U. J. Griesser, L. Alja, and T. Koch, “Thermal and Sorption Study of Flame Resistant Fibers,” vol. 89, pp. 50–59, 2011.

[3] R. D. Banu, “Studies on Flame Retardant Polyester Composites for Naval Application,” B.S. Abdur Rahman University, 2012.

[4] L. P. Salgaonkar and R. V. Jayaram, “Thermal and flame-retardant properties of polyester fabric grafted with polyanilines,” J. Appl. Polym. Sci., vol. 93, no. 4, pp. 1981–1988, 2004.

[5] T. D. Hapuarachchi and T. Peijs, “Aluminium trihydroxide in combination with ammonium polyphosphate as flame retardants for unsaturated polyester resin,” Express Polym. Lett., vol. 3, no. 11, pp. 743–751, 2009.

[6] E. Gallo, “Progress in polyesters flame retardancy : new halogen- free formulations,” Universita Degli Studi Di Napoli Federico II, 2009.

[7] P. Penczek, R. Ostrysz, and D. Krassowski, “Fire Retardant Additive ‘Expandable Graphite as a Fire Retardant in Unsaturated Polyester Resins ,” November, 2012.

[8] F. Laoutid, L. Bonnaud, M. Alexandre, J. Lopez-cuesta, and P. Dubois, “New prospects in flame retardant polymer materials : From fundamentals to nanocomposites,” Mater. Sci. Eng. R, no. 2008, pp. 1–116, 2009.

[9] N. Wang, “Flame Retardancy of Polymer Nanocomposites based on Layered Aluminum Phosphate and Computational Study of Intercalation of Amines into α-Zirconium Phosphate and Adsorption of a Model Organic Pollutant,” 2011.

[10] tN. Pramanik, S. Mohapatra, S. Alam, and P. Pramanik, “Synthesis of hydroxyapatite/poly(vinyl alcohol phosphate) nanocomposite and its characterization,” Polym. Compos., vol. 29, no. 4, pp. 429–436, Apr. 2008.

[11] M. C. S. Ribeiro, S. P. B. Sousa, P. R. O. Nóvoa, C. M. Pereira, and A. J. M. Ferreira, “Fire retardancy enhancement of unsaturated polyester polymer resin filled with nano and micro particulate oxide additives,” Mater. Sci. Eng., vol. 58, no. 012020, pp. 0–9, 2014.