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Experimental Study of Thermal Conductivity, Vicat Softening Point and Ignition Time of Pongamia Pod Powder Filled Areca Phenolic Composites

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ABSTRACT : *The enormous use of polymer materials in our daily life is due to their remarkable combination of properties like simple fabrication methods, low weight and their low cost. In this work, Thermal properties such as Vicat Softening point, Thermal Conductivity and Fire retardant property such as Ignition Time are investigated and analyzed. When the composites are exposed to heat above the glass transition temperature of resin matrix, this leads to reduction in stiffness and strength of material and degrades the mechanical properties due to thermal degradation and combustion of the resin. This poor fire resistance of composites has been a major factor to limit their wide spread of applications. Composites require high flame retardancy which can be obtained by adding a filler material. Thus improving the thermal properties and fire retardant behavior of polymers was a main challenge for extend their use to most of the applications. Thermal and fire resistant properties are investigated. Thermal properties improved with increase in Pongamia shell powder. Thermal stability, fire resistance properties improves with increase in fibre proportion. It is expected optimum composition of the current work APC15 (15% Areca Fibre, 65% Phenolic Resin and 20%of Pongamia shell powder) will be used in Aircraft industries, Aerospace applications, Chemical industries, Electrical system and Electronics, Automobiles, Shipbuilding, Wind turbine blades, Thermal encapsulation, Flip chip applications, Thermal interface materials.*
Keywords - *Thermal Conductivity, VSP, Vicat Softening Point, Ignition Time.*

I. INTRODUCTION

The use of fibre reinforced composite material as an alternative to traditional metal is becoming widespread. The main technological advantages of these materials are low weight, high specific strength, environmental resistance, high specific strength and long life. Compared to metals, composite materials can be made with relatively low tooling cost [1]. The class of fire retardant used depends upon the choice of polymer resin [3]. The combined challenge consists in developing effective and environment friendly flame retardant system for polymer materials and also modern applications of polymers as heat sinks in electronic packaging needs new composites with comparatively high thermal conductivity. So improving the thermal properties and fire retardant behavior of polymers was a main challenge for extend their use to most of the applications. Enhanced thermal conductivity in polymer materials may be achieved either by varying molecular orientation or by the addition of conductive fillers. Fire retardants are united with polymer resins to decrease their flammability, reduce production of volatiles and to reduce the pollutants. In the current work the new environment friendly polymeric matrix composite material was fabricated which having both good thermal and fire resistance properties by using Phenolic resins as base matrix (primary phase), Areca fibres as reinforcement material and Pongamia seed shell as filler materials(secondary phase).

1.1 Material Selection

1.1.1. Phenolic Resin (Phenol Formaldehyde) as Matrix

Pure Phenolic resin can be obtained through the condensation reaction between phenol (C6H5OH) and formaldehyde (CH2O). During reaction they producing methylene bridges between the phenol molecules, this is a condensation reaction as shown in the Figure 1.

Fig.1 Condensation Reactions for the formation of Phenol Formaldehyde.

Phenolic composites are mostly used for the production of responsible parts for various industries. Phenolic resins are known for their excellent thermal properties and chemical stability [10]. Phenolic resin composites are currently used in many aircraft interiors. Along with the a variety of polymer resins, Phenolic resin maintain its spot in several industries a from a century after its introduction since of its better heat and flame resistance, mechanical strength and also shows good chemical resistance in opposition to various solvents like acids, water etc. The Phenolic resin is shown in the Figure 1.

1.1.2. Reinforcement as Areca Fibre

Among all the natural fibre-reinforcing composite materials, Areca fibre appears to be a promising material because it is inexpensive; availability is abundant in South India and a very high potential perennial crop. Areca fibres belong to the class of Areca catechu L., under the family of palmecea and originate from the Malaya peninsular of East India. It is the Chief industrial cultivation is in South-East and South-West part of India. It was approximated that 6-7 Lakh tones of Areca fibre husk is present in south-west of India. The Areca fibre husk is a rigid fibrous portion which covers the endosperm. Also it constitutes 35–45% of the entire volume of the fruit. Areca fibre husk are largely composed of hemicelluloses and not of cellulose content [9]. The Karnataka state is the first both in terms of area & production followed by Kerala & Assam states. Also the area under areca nut cultivation has risen more quickly in Shimoga district as compared to Dakshina Kannada & Uttara Kannada districts. Table 1 Shows Chemical compositions of few natural fibres. The extracted areca fibres are shown in Figure 2 and Table 1 shows the Chemical compositions of few natural fibres.

Fig. 2 Areca fibres

TABLE 1 Chemical Composition of few Natural Fibres.

Natural Fibres	Lignin composition (%)	Hemicelluloses composition (%)	Cellulose composition (%)
Areca	13.2-24.6	36-64	--
Sisal	10-15	12	65-72
Maize stalk	10-14	20-23	37-42
Banana	5	19	62-60
Coir	40-46	0.14-.25	32-43

1.1.3. Pongamia Shell (Pod) Powder as Filler

Here Pongamia pod powder is used as filler in this investigation. Pongamia pinnata is a fast growing medium sized ever green tree. The Pongamia pinnata pod (shell) as shown in Figure 3 is a by-product, but when burnt, it has comparable energy to Brown coal, hence it can be use in either as a gasifier or just thrown back to the soil for fertilizer. Shell-approx 54% of the total seed in shell weight, can be use directly as a solid fuel for boilers; converted to sun diesel (biomass to liquid); or as an organic fertilizer.

Fig. 3 Pongamia pinnata shell powder

II. LITERATURE SURVEY

Cedric Sauder et al., [1] have designed high temperature fibre –testing apparatus and it is dedicated to determination of various properties at very high temperatures including electrical conductivity, young's modulus, thermal expansion coefficient strength. Two types of carbon fibres (a Pan-based and a Rayon-based fibre) have been investigated at temperatures up to 20000c.The measured properties are discussed with respect to micro structural features.

Suhreta Husic et al., [2] have described the thermal and mechanical properties of un treated E-glass fibre reinforcement composites prepared with soybean oil-based polyurethanes and petrochemical polyol. The results showed that mechanical properties such as tensile and flexural strength, tensile and flexural modules of the soypolyol based composites were comparable with those from composites based on petrochemical polyol. Since soya based polyurethanes offer better thermal, oxidative and hydrolytic stability than petrochemical based once.

P.K. Rohatgi et al., [3] have studied the coefficient of thermal expansion of commercially available pure aluminum and aluminum alloy composites containing hollow fly ash particles. Results show that the thermal expansion coefficient of fly ash filled composites lower than the pure aluminum composites.

III. EXPERIMENTATION

Experimentation is the significant part of this present work because the properties of newly fabricated composite materials were determined. After the completion of fabrication process the specimens were cut into the dimension according to the ASTM standards. Finally the specimens were tested for their thermal, fire resistance and mechanical properties.

3.1. Properties Tested

The fabricated slabs were prepared to specimens according to the fallowing ASTM standards whose details are shown in Table 2.

Table 2 ASTM STANDARDS

Properties	ASTM Standards
Thermal	Thermal Conductivity-ASTM E 1530 Vicat Softening Point (VSP)-ASTM 1525 Ignition Time

3.2. Thermal Conductivity

It is defined as the rate at which heat passes through a specified material, expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance. Fourier law of conduction states that, heat spontaneously flows from a region of higher temperature to a region of lower temperature due to temperature gradient. Thermal conductivity can be measured by employing this law. All measurements are carried out approximately in the similar temperature range. Thermal conductivity is the property of a material's ability to conduct heat.

Thermal conductivity measurements are carried out under steady state condition. According to ASTM E 1530 disc shaped specimens with diameter of 50 mm and thickness of 10 mm. A known constant heat of 1.5 watts is applied from one side of the specimen. When the thermal equilibrium is attained and the system approaches to steady state situation, the temperature of top and bottom surfaces were measured by using thermocouples which were installed on the specimen. Knowing the values of heat supplied, temperatures, and thickness, the thermal conductivity was determined by employing one-dimensional Fourier's law of conduction. All measurements are carried out approximately in the similar temperature range.

Thermal conductivity is calculated as,

$$K = \frac{Q \times t}{A \Delta T}\ W/mK$$

Where,

- Q = Heat in W, V in volts, I in ampere
- $Q = V \times I = 30 \times 0.05 = 1.5$ watts
- A = area of specimen in $mm^2 = 1.963 \times 10^{-3} mm^2$
- t = Thickness = 10 mm
- ΔT = Bottom surface Temperature of specimen – Top surface temperature of specimen

The Thermal conductivity is calculated by dividing constant heat flux by temperature difference of bottom and top surface temperature where constant heat is obtained from Electric Heater. The thermal conductivity test arrangement and its specification were shown in Figure 4 and Table 3.

Fig. 4 Thermal conductivity testing device

Table 3 Specifications of Thermal Conductivity Testing Device

Machine Name	**Thermal conductivity testing apparatus**
Voltage	230 volts
Power	100 watts
Frequency	50 Hz

3.3. Vicat Softening Point

Vicat softening temperature or Vicat hardness is the determination of the softening point for materials that have no definite melting point, such as plastics. It is taken as the temperature at which the specimen is penetrated to a depth of 1 mm by a flat-ended needle with a 1 mm2circular or square cross-section.

Standards to determine Vicat softening point include ASTM 1525. The specimens were tested according to ASTM 1525 in International Apparatus. The test specimens were made according to the ASTM standards. The dimensions of the specimens are 127 mm x 12.7 mm x 3.2 mm.

Vicat Softening Temperature was introduced as measurement technology as a substitute value for melting-point. It describes the temperature at which a circular indenter with a cross-section of 1 mm² under a standardized loading of 10 N or 50 N penetrates exactly 1 mm into the specimen. The Vicat Softening Temperature is standardized ASTM D 1525. The Figure 5 shows the VSP testing machine and Table 4 shows specification this machine.

Fig. 5 VSP Testing Apparatus

Table 4 Specification of VSP Testing Apparatus

Name of machine	**VSP testing machine**
Manufactured by	International Equipments
Temperature range	Ambient to 3000C
No of stations	3 stations
Rate of heating	1200C / hr and 500C / hr
Sensor	Range up to 10 mm with resolution of 0.01 mm.
Power	240 volts, 50Hz, single phase

IV. RESULTS AND DISCUSSION

4.1. Thermal Conductivity

TABLE 5 Thermal Conductivity of Materials

APC05	**40.4**	**28.9**	**0.80**
APC10	41.3	29	0.65
APC15	44.7	31.1	0.51
APC35	44.0	29.1	0.49

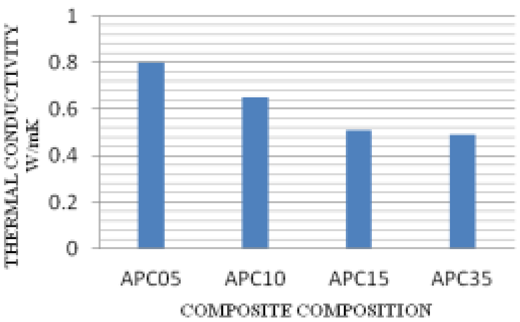

Fig. 6 Thermal Conductivity v/s Composite Composition

The Figure 6 shows the graph of Thermal conductivity vs. Composite materials. From the Figure 6, results shows that the thermal conductivity of APC05 is greater than APC10, APC15 and APC35. Also it was observed that the thermal conductivity decreases with the increase in the fibre composition. This is because that the Pongamia pinnata shell powder has high heat carrying capacity, excellent heat conductivity, and good electron mobility as compare to the Areca fibres. As such if thermal conductivity is high, the material will more rapidly approach equilibrium with its surrounding, while if thermal conductivity is low, more energy will be stored and it will be harder to transmit heat through its material and a longer duration will be taken to reach its equilibrium state. But from above calculated thermal conductivity for composite material was much lower than metals. Because in metals the molecules are closely packed and when heat is applied there will be quick transfer of thermal energy takes place between the molecules. Also in metals the outer electrons are not closely bonded, when heat is applied these electron releases from atom structure and helps in heat transfer between the molecules.

4.2. Vicat Softening Point (VSP)

It is defined as the temperature at which standard composite material penetrates to a fixed depth by flat ended needle of 1 mm^2 circular cross section. In current work penetration depth was 1 mm under load of 2 kg and heating rate of 2 °C/min. This test results are mainly used by the industries in the manufacture of component using composites which have to work under given stress and temperature conditions. This test was mainly used to test polymers, polymer compounds and composites. The VSP value should also be higher for the use of composites in the High temperature applications. Otherwise there was a possibility of composite materials failure under specified load. The Table 6 shows the calculated Vicat Softening Point (VSP) for different fabricated composite materials.

TABLE 6 Vicat Softening Point in °c

Composite Materials	**Vicat Softening Point in °C**
APC05	144.2
APC10	148.3
APC15	151.2
APC35	155.4

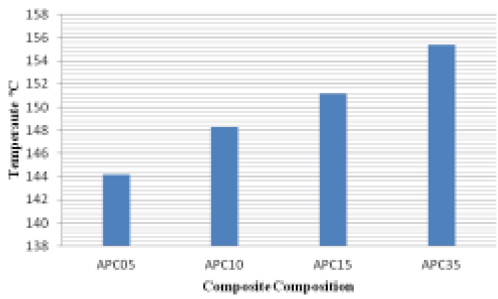

Fig.7 Vicat Softening Point (VSP) v/s Composite Composition

The Figure 7 shows the graph of temperature vs. composition of the composite. From the Figure 6.7, it can be observed that APC35 has comparatively high VSP than other composites like APC05, APC10 and APC15. It also shows that APC05 with higher percentage of Pongamia shell powder has the least VSP as compared to other composites. It is because as shell powder concentration increases, voids between the molecules increases so density also decreases. Hence when circular edged needle of 1 mm2 cross section applies load on the specimen it can easily penetrate into depth of 1 mm in the specimen at lower temperature compare to specimen with lesser concentration of Pongamia powder. Hence VSP increases with increase in the fibre concentration.

4.3. Ignition Time

Ignition time is the period of time that a composite material can with stand under a constant heat flux before igniting or it is the time taken for a composite material to start burning. The Ignition time can be used as measure of the flammability resistance of material. Clearly it is desirable to use composite material with high ignition times in high fire risk applications. Increase in the ignition time reduces the fire hazard of composite material used in an aircraft. Ignition time of the fabricated specimen has to be tested in both vertical and horizontal direction as the composite material may be used in vertical or horizontal direction in any applications. Hence the ignition time of composites should be maximum in the case of fire risk situations.

4.3.1. Vertical Burning (VB)

The Table 7 shows the Ignition Time for different fabricated composite materials.

TABLE 7 Ignition Time for VB

Composite materials	Time to ignition in Seconds
APC05	14.3
APC10	14.68
APC15	17.69
APC35	18.6

4.3.2. Horizontal Burning (HB)

The Table 6.9 shows the calculated Ignition time (HB) for different fabricated composite materials.

Table 8 Ignition Time for HB

Composite materials	Time to ignition in Seconds
APC05	16.2
APC10	15.17
APC15	18.9
APC35	19.4

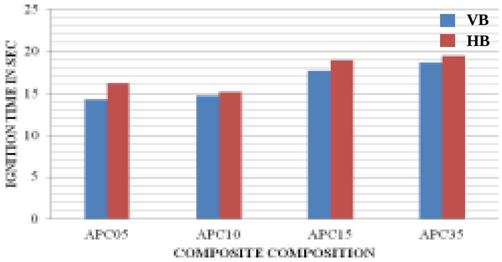

Fig. 8 Ignition Time for VB and HB v/s Composite Composition

The Figure 8 shows the graph of Ignition Time for VB and HB vs composition of the composite. From the Figure 6.8 it can be observed that ignition time of APC 15 and APC35 is higher than the APC 5 and APC10. So from graph it was clear that as the Areca fiber compositon increases the Ignition time is also increases. It is because in order to ignite material additional energy may required to vaporize the flammable volatiles and also endothermic decomposition of fibers cools the condensed phase and the released water also cools and dilutes the flammable products in the vapour phase. This effect increases with increase in the composition of fiber. So igniton time increase with increase in the composition of areca fiber. Hence it can be stated that the fire resistance behaviour of the composites increse with increase in the fibre composition.

V. CONCLUSION

The following conclusions were drawn from the present work carried out.

- Thermal conductivity was less than one for all the composites. Also it was very less when compare to the metals. From the results APC05 shows maximum thermal conductivity of 0.8 W/m K. The thermal conductivity decreases with decrease in Pongamia pod powder composition.
- From the graph it was observed that the APC35 shows the maximum Vicat softening point of 155.4°C. Also VSP increases with increase in fibre concentration.
- The Thermal properties improved with the increase in the Pongamia pod powder concentration in the composites. Thermal stability improves with increases in the fibre concentration.
- From the fire resistance tests, it was observed that APC35 shows maximum ignition time of 18.4 Seconds (VB) and 19.4 seconds (HB).
- Thus, composite APC15 (Phenol formaldehyde = 65%, Pongamia Pinnata Pod Shell Powder 20% and Areca husk fibre=15%) is a good composite material with satisfactory strength,

thermal stability and fire resistant property when compared to other compositions like APC05, APC10 and APC35.

- Hence optimum composition of the current work APC15 will be used in Aircraft industries like Doors and Elevators, Aerospace applications, Chemical industries like Tanks, Pipes and Pressure vessels, Electrical s/m and Electronics, Automobiles, Ship building, Wind turbine blades, Thermal encapsulation, Flip chip applications, Thermal interface materials and even in the engine parts of modern automobile.

REFERENCES

[1]. Suhreta Husic, et al., "Thermal and mechanical properties of glass reinforced soy-based polyurethane composites", Composites science and Technology, 2005 PP 19-25.
[2]. Li-Ping Gao, et al., "A flame-retardant epoxy resin based on a reactive phosphorus-containing monomer of DODPP and its thermal and flame-retardant properties", Polymer Degradation and Stability, 2008 PP 1308-1315.
[3]. Terse E. Glodek, et al., "Properties and performance of fire resistant eco-composites using polyhedral oligomeric silesquioxane (POSS) fire retardants", Composites Science and Technology, 2008 PP 2994-2674.
[4]. A.Shojaei, et al., "Thermally conductive rubber-based composite friction materials for railroad brakes- Thermal conduction characteristics", Composites Science and Technology, 2007 PP 2665-2674.
[5]. L. Wierzbicki, et al., "Thermal conductivity of the epoxy resin filled by low melting point alloy", Archives of material science and engineering, May 2013 Vol .61, Issue 1, PP 22-29.
[6]. Mingchao Wang, et al., "Surface fictionalization on the thermal conductivity of graphene–polymer nanocomposites", IJSNM, 2014 Vol. 5, No. 2, PP 123–132.
[7]. Hani Mahmood Hussien, "Studying the Ultrasonic Properties, DC Conductivity and Coefficient of Thermal Conductivity of PVA-Egg Shells Composite", Advances in Physics Theories and Applications, ISSN 2224-719X, ISSN 2225-0638 Vol.18.
[8]. Srinivasa C. V., Bharath K. N., "Effect of Alkali Treatment on Impact Behavior of Areca Fibres Reinforced Polymer Composites", World Academy of Science, Engineering and Technology, 2013 Vol.7 No, 4.
[9]. G.C. Mohan Kumar, "A Study of Short Areca Fibre Reinforced PF Composites", Proceedings of the World Congress on Engineering, 2008 Vol. 2.
[10]. Rafie R. Mohammad, "Characterization of a Phenolic Resin and Caria Species Fibre Composite".
[11]. Balaji.R, "Effect of Micro silica in Woven Ceramic Fibre / Phenolic Resin Composites", International Journal of Research in Engineering and Technology.
[12]. Timothy C. Chao, Satyendra K. Sarmah, "Flammability Studies Of Silicone And Phenolic Resins and Their Composite Laminates".
[13]. M. Mamatha, H. B. Aravinda, "Adsorption of Ferrous and Ferric Ions in Aqueous and Industrial Effluent onto Pongamia pinnata Tree Bark", International Journal of Chemical, Nuclear, Materials and Metallurgical Engineering, 2012 Vol.6, No.7.
[14]. S Arivoli1, V Marimuthu, "Mechanistic Studies of Copper (II) Ion Adsorption on Activated Pongamia Pinnata Shell Nano Carbon", European Journal of Environmental Ecology, 2015 ISSN – 2393-9672.
[15]. Aboli Lale, D K Kulkarni, "A Mosquito Repellent Karanj Kunapa from Pongamia pinnata", Asian Agri-History, 2010 Vol. 14, No. 2.
[16]. Pramod Kumar, Munesh Kumar, "Pharma cognostic and Phytochemical Investigation of Pongamia pinnata", Open Access Scientific Reports.
[17]. Shwetha. K. C, Dr. D. P. Nagarajappa, M. Mamatha, " Removal of Copper from Simulated Wastewater Using Pongamia Pinnata Seed Shell as Adsorbent", Int. Journal of Engineering Research and Applications, June 2014 Vol. 4, Issue 6(Version 5), pp.271-282.
[18]. Rohini. J. S, Dr. D. P. Nagarajappa, "Removal of Nickel from Simulated Wastewater using Pongamia Pinnata Seed Shell as Adsorbent", International Journal of Engineering Research & Technology, June 2014 Vol. 3 Issue 6.
[19]. S. U. Choudhury, S. B. Hazarika, "Natural Fibre Reinforced Polymer Biocomposites and Blends: Synthesis, Characterization and Applications".
[20]. K.Devendra1, T. Rangaswamy, "Evaluation of Thermal Properties of E-Glass/ Epoxy Composites Filled by Different Filler Materials", International Journal Of Computational Engineering Research, Vol. 2 Issue.5.
[21]. Rajpal Singh Bhoopal, Pradeep Kumar Sharma, "Effective Thermal Conductivity of Polymer Composites Using Local Fractal Techniques", International Journal of Innovative Technology and Exploring Engineering, 2013 ISSN: 2278-3075, Vol.2, Issue.3.
[22]. Sarka Keprdova, Jiri Bydzovsky,"The Influence of Physical-Mechanical and Thermal Properties of Hemp Filling Materials by the Addition of Energy Byproducts", International Journal of Civil, Structural, Construction and Architectural Engineering, 2014 Vol.8, No.6.
[23]. Dr.G.Ramachandra Reddy, Dr.M.Ashok Kumar," Fabrication and Performance of Hybrid Betel Nut (Areca Catechu) Short Fibre/ Sansevieria Cylindrica (Agavaceae) Epoxy Composites", International Journal of Materials and Biomaterials Applications, 2011.
[24]. Nadeem Iqbal1, Sadia Sagar Iqbal, "Acrylonitrile Butadiene Rubber/Phenolic Resin Blended Ablative Composites for High Temperature Applications". International Journal of Advanced Technology in Engineering and Science, November 2014 Vol.02.