Thermal Conductivity and Flammability Analysis on Coconut Sheath Reinforced Polyester Composites

I. Siva

Abstract*: Thermal conductivity is very important study done for the polymer composites towards characterizing the application field in recent days. Present work, thermal conductivity along the thickness is experimented. Flammability for the fabricated composites through accelerated and natural burning is studied and reported. Composites are prepared under compression for varying reinforcement type. Hybrid composite are also produced and compared with the properties of the virgin composites.

***Keywords* : Coconut Sheath, Polyester, Thermal Conductivity, Flammability.**

I. INTRODUCTION

The advantages of natural fibers over glass fibers are their low cost, low density, high strength-to-weight ratio, resistance to breakage during processing, low energy content and recyclability [1]. Specific strength and retaining the same at elevated temperature are good for fiber reinforced polymer composites [2]. Many times their specific strengths can be 10-15 times higher than that of steel, and it is possible to replace conventional metallic, nonmetallic, wood and plastic materials by natural fiber composite for few engineering applications [3].

Coir is a versatile lignocellulosic fiber obtained from coconut trees (Cocos nucifera), which grow extensively in tropical countries [4]. Because of its hardwearing quality, durability and other advantages, it is used for making a wide variety of floor-furnishing materials, yarn, rope, etc. [5,6]. These traditional coir products consume only a small percentage of the total world production of coconut husk. Coir is a cheap fiber, even cheaper than sisal and jute [7].

Even though many researchers have done a variety of works on coir fiber as reinforcement, none of them reported the coconut sheath as reinforcement for polymer matrix composites. Only preliminary studies of coconut leaf sheath fibres were reported in the literature [5]. No other research works reported on the basis of coconut sheath as reinforcement for polymer matrix composites. A lacuna was found in the study of naturally woven coconut sheath. The advantage of coconut sheath over conventional coir fiber is its natural mesh shape.

Ahmeda et al. [8] reported the advantage of woven type reinforcements in the jute/sisal hybrid composite. They reported that the tensile, flexural and inter-laminar shear properties were significantly high when compared with loose fibers reinforced composites. [9] compared mat and loose coir reinforcement. In their result, authors reported that the mat of coir performed well in the mechanical testing than that of the loose coir fibers extracted from the coconut husk. An average of 35 percent enhancement was noted in mechanical properties of mat coir reinforced composite compared with loose coir composites. Integrity between fiber and matrix will be more in woven class reinforcement compared to loose fibers. Mansur et al. [10] investigated the mechanical property enhancement of bamboo mesh reinforced cement mortar. It is one of the most important factors which influence the composites property. Woven fibers bear more loads compared to the loose fibers.

The directional property of the composite regularized if woven fibers were used. Hence this naturally available mat of coconut fibers was studied and hybridization was done in order to enhance the properties. Hybridization was don for the fiber reinforced polymers to achieve more mechanical strength. Sreekala [11] reported the effect of hybridization of glass fiber with oil palm fiber reinforced composites. Gupta et al. [12] studied the hybridization of fly ash in glass fiber epoxy on compressive and impact properties. Velmurugan et al. [13] reported that the mechanical properties of glass/palmyra fiber waste sandwich composites enhance the tensile, flexural and shear strength due to hybridization. Many researchers [14-17] reported the benefit of hybridization. Meanwhile Amico et al. [18] studied the effect of stacking sequence of the mat type sisal and glass fibers on mechanical properties. Authors reported that tensile strength enhanced with placement of sisal and glass fibers in alternative locations. Flexural strength is more when glass fibers stacked at lateral sides of the laminate. And the impact strength was high at placement of sisal fibers at lateral sides.

Thermal conductivity is very important study done for the polymer composites towards characterizing the application field in recent days. Author has already reported the mechanical properties of the less explored coconut sheath reinforced polyester composite [19,20]. Hence, in this work, the thermal conductivity and flammability of the coconut sheath reinforced composites were discussed

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I, Siva , Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil-626 126, India, Email: isiva@klu.com

II. MATERIALS AND METHODS

A. Coconut Sheath

Coconut sheath is a naturally woven material readily available in usable form. Coconut sheath can be obtained from the coconut tree in the bottom portion of the branches of the coconut tree (Fig. 1a). Coconut sheath is grown between the stem and branch at the top of coconut tree. Naturally it will be brown in color

Fig. 1. Coconut tree with sheath (arrow marked) (a), Naturally woven coconut sheath (b)

Coconut sheath has no specific medical or domestic application in general. In villages, coconut sheath is used as scrubber, burning material (fuel) and for few domestic applications. Since coconut sheath has lower calorific value when compared to the wood materials, it cannot be used as fuel for Industrial or large scale applications.

The coconut sheath is a bi-directional fibers formed as mesh like mat. It has a strong big main fiber which is linked by lean fine fibers. The fig. 1b. shows a portion of coconut sheath. This naturally woven material falls under the category of non-woven fabric reinforcement. Since the arrangement of the main and linked fibers happen naturally, these fiber fabrics are called naturally woven coconut sheath fibers. This material is used in this investigation as a main and novel reinforcement.

Unlike the conventionally used coir fiber reinforcement which is obtained from the coconut husks, this newly identified application of coconut sheath has enhanced physical properties. The table 1 shows the comparison of properties of coconut sheath with conventionally used coir fiber in polymer composites. It can be noted that the novel coconut sheath has higher cellulose content which promotes more crystallinity of the fiber and expected improved performance in engineering aspect.

Table 1. Mechanical Properties for Coconut Sheath

Properties	Coir Fiber [9]	Coconut Sheath
Wax content (%)	-	
Density (g/cc)	1.15	1.38
Cellulose (%)	32	68
Lignin (%)	28.23	20.63
Moisture (%)	8	8.79
Ash (%)	1.5	1.0

B. Thermal Conductivity Study

In this research work a similar setup of Guarded Heat Flow Meter was fabricated and used for measuring the thermal conductivity of the prepared composites. This method is based on two dimensional steady state techniques and is used to measure and compare thermal properties of materials under controlled conditions and their ability to maintain required thermal conductance levels. The specimen and a heat flux transducer are sandwiched between two flat plates controlled at different temperatures to produce a heat flow through the stack. A cylindrical guard surrounds the test stack and is maintained at a uniform mean temperature of the two plates, in order to minimize the lateral leak of heat. At steady state, the difference in temperature between the surfaces contacting the specimen is measured with temperature sensors embedded in the surfaces, together with the electrical output. The output voltage is proportional to the heat flow through the specimen and it interfaces between the specimen and the apparatus. The coefficient of thermal conductivity can be obtained by prior calibration of system with the specimens of known thermal conductivity.

C. Flammability Testing

This chapter deals with the flammability properties of the untreated, alkali and silane treated coconut sheath reinforced composite and its hybrid. Pilot and natural ignition were estimated and reported as the function of chemical treatments and hybrid. The UL-94 test is performed on a plastic sample (125×13×3mm) hanged horizontally above a steel patch. The composite is subjected to a flame exposure for 10 seconds with a calibrated flame in a unit, which is free from the effect of external currents. After the first 10 seconds exposure, the flame is removed and the time for the sample to self-extinguishing is recorded.

III. RESULTS AND DISCUSSION

Fig. 2. shows the thermal conductivity of the fabricated non-hybrid and hybrid composites. Non-hybrid and hybrid composites were prepared with fibers in as received condition. NNN reinforced composite shows the lower thermal conductivity among the others. Generally, natural materials have lower thermal expansion compared to the synthetic fibers [21,22]. GGG synthetic fiber reinforced composite showed higher thermal conductivity compared to all. Incorporation of the glass fiber as hybrid in coconut sheath composite improves the thermal conductivity. An increasing trend of thermal conductivity when increasing the glass fiber content was noted in the fig. 2.

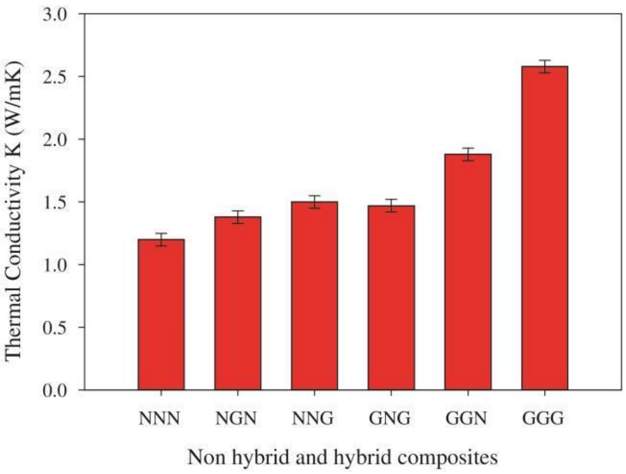

Fig. 2. Thermal conductivity of non-hybrid and hybrid composites

In addition, the stacking sequence significantly influencing the thermal conductivity of the hybrid composites. Thermal conductivity was increased when glass fibers were stacked adjacent to each other. Compared with NGN, hybrid composite NNG composite showed higher thermal conductivity. When glass fiber was stacked inside, natural fibers resist more conductance of heat through the thickness. Similarly, GGN composite has much higher thermal conductivity compared to GNG hybrid composite. Core coconut sheath weakens the conductivity of the GNG composite.

The reason could be the due to the poor compatibility of the untreated coconut sheath fiber with the polyester matrix, which could be observed as a notable separation between the fiber and the matrix. Thermal conductivity could be increased with level of mechanical contact between two adjacent bodies [23].

A. Effect of Chemical Treatment on Thermal Conductivity

Effect of alkali and silane treatment on thermal conductivity is shown in fig. 3. It could be observed from the NNN fiber reinforced composite that the alkali treatment improves the thermal conductivity. This could be due to the enhanced interlocking between fiber and the matrix, after the alkali treatment of coconut sheath fibers. Thus heat conduction was promoted more in that composite. Coat of silane, which is poor thermal conductor in nature made a thin layer between fiber and matrix. Obviously, polyester matrix is a poor thermal conductor, hence the integral unit (composite) become weak in thermal conductance once silane treated fibers were used.

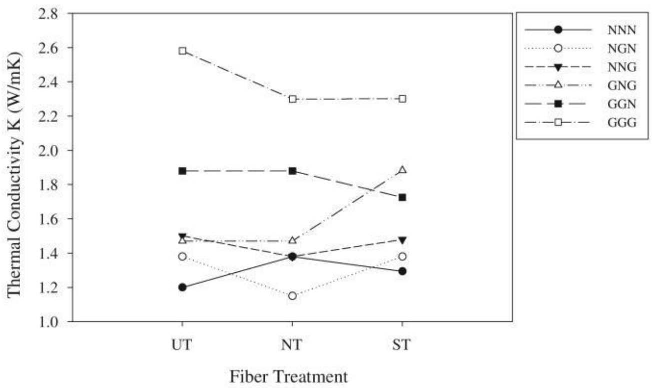

Fig. 3. Effect of chemical treatment on Thermal conductivity of non-hybrid and hybrid composites

Drastic loss of thermal conductivity was observed in GGG composite after alkali fiber reinforcement. Alkali treatment of the coconut sheath fibers made the surface rougher and wax free. In the meantime, this treatment damaged the glass fiber also. Hence, the same was expected in hybrid also. A little improvement was noted in GGG-USP composite after silane treated fibers were reinforced.NGN and GNG hybrid composites significantly improved after the chemical treatments. Though the alkali treatment improves mechanical interlocking and shorten the gap, the glass fibers become weaken after the alkali treatment. Thus, the thermal conductivity of the total composite falls. Silane treatment further enhances the contact of adjacent fibers as well as matrix; better improvement in the thermal conductivity was achieved. This could be understood as the effect of stack sequence. Other sequenced hybrid composites uniformly lost their thermal conductivity after the chemical treatments.

B. Flammability of the Composite

The organic resin like polyesters can ignite within a very short time of being exposed to a hot fire. Following ignition, composites often burn with large, high-temperature flames that contribute to the rapid spread of fire. For this reason, ignition is an important property in describing the fire hazard of composite materials. Ignition usually occurs when the surface of a composite was exposed to fire when heated to about the endothermic decomposition temperature of the polymer matrix. The thermal decomposition reaction of the matrix produces flammable volatile gases that flow from the composite into the fire. When the amount of volatile at the composite/fire interface reaches a critical concentration and then ignition and combustion flaming would be occurring. Most of the volatile are generated by the endothermic decomposition of the polymer matrix. Smaller quantities of volatile can be produced by the decomposition of organic sizing and binding agents that coat the fiber reinforcement.

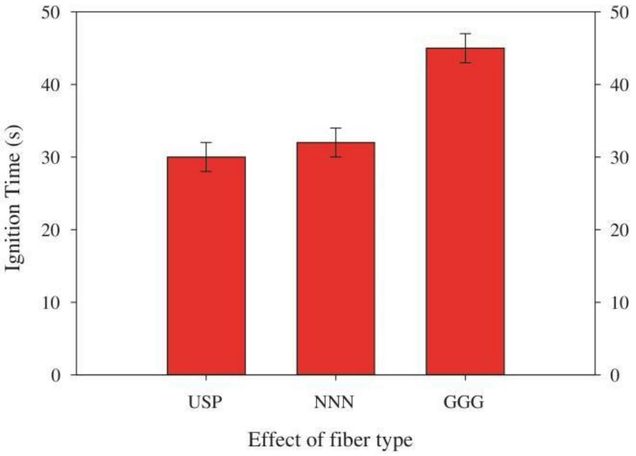

Fig. 4. Effect of fiber type on the pilot ignition time

Ignition is an important fire reaction property of flammable materials because it defines the start of flaming combustion. The time-to-ignition of composites is determined by experimental fire testing using techniques such as UL94 flammability tester. Ignition times can be measured in two conditions called natural and piloted ignition. In natural ignition, flaming propagates from the accelerated flame. Piloted ignition is initiated in an ignition source; such as flame from the LPG burner. The fig. 4. shows the ignition time as a function of type of reinforcements. Ignition time measured for travel of fire from firing end of the composite to 20mm in length. It could be seen that, addition of coconut sheath in polyester significantly increases the pilot ignition time. The addition of the fibers could be lowering the pyrolysis rate and thereby lengthening the ignition time. Meanwhile, lesser the production and flow rates of volatiles to the composite/fire interface when compared with pure polyester, caused longer time-to-ignition [24]. Hence, the start of flaming combustion postponed and the material stand for slightly longer in service. However, this was not up to the level of classically used glass fiber reinforcement. Glass fiber reinforced polyester took much higher time for ignition. Hybridization was made in order to increase the time of ignition of the coconut sheath reinforced composites.

Fig. 5. shows the effect of hybridization on the time-to-ignition. An increase in ignition time was observed with increase in glass fiber content. The ease of ignition is generally characterized by the time-to-ignition, which is the minimum time required to promote ignition and continuous flaming of a combustible material when exposed to an external heat flux. A little influence of stacking sequence was noted in all the hybrid composites. Similar to the all mechanical property testing, in fire properties also, stacking of same type fibers in adjacent could gain more. Among NGN and NNG, the time-to-ignition for NNG hybrid composite is higher. In case of GNG and GGN, the time-to-ignition is high for GGN hybrid composite. This could be because of those same type fibers may resist more degradation to heat and produce less volatiles in composite/fire interface.

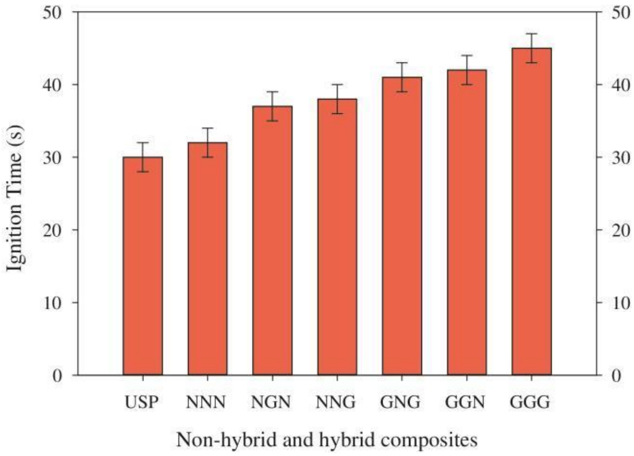

Fig. 5. Effect of hybridization on the pilot ignition time

C. Effect of Chemical Treatment on Ignition Time

Fig. 6. shows the effect of chemical treatment on the pilot ignition time. Pilot ignition of the composites significantly changed after chemical treated fibers were reinforced. At first, alkali treated fibers reinforced composites were fired. Invariably, the alkali treatment shortened the pilot ignition time for all the non-hybrid and hybrid composites. An increase in the production and flow rates of volatiles to the composite/fire interface lowering the time-to-ignition [24].

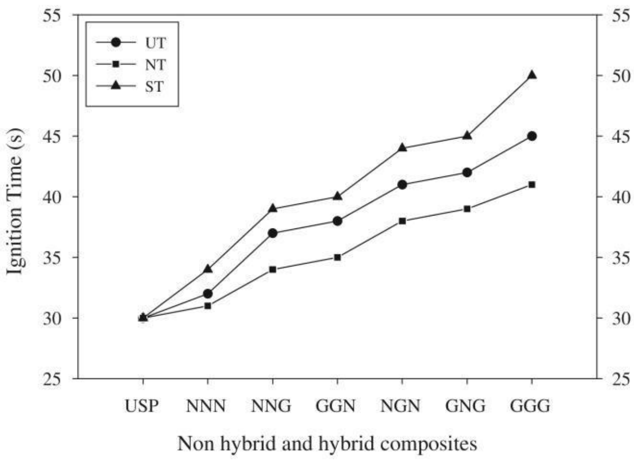

Fig. 6. Effect of chemical treatment on pilot ignition time of non-hybrid and hybrid composites

Compared to NNN/USP composite, GGG/USP composite burnt in very short period. However, hybridization improves the pilot ignition time. Stack sequence showed very less significance. Stacking glass fibers at outer made the pilot ignition time longer. This effect was observed in all the hybrid composites.

Silane treatment makes the burn longer and keeps the structure stand for a while. GGG-USP gained more than that of NNN-USP composite. Silane coat over the fibers slightly resists the fire from reaching the core fibers, thus making the pilot burning time longer when compared to untreated. Similar response was observed in hybrid composites also. Glass fiber burnt much longer than coconut fibers. Stacking the glass fibers at outer resists more flame propagation.

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D. Natural Burning of Composites

The ignited fire was allowed to naturally burn up to 70mm long on the fabricated composites. Fig. 7. shows the natural burning time non-hybrid and hybrid composites. Incorporation of coconut sheath increased the natural burning time of the USP. In the meantime, hybridization also increased the burning time in the order of NGN, NNG, GNG and GGN. Glass fiber polyester composite had the longer burning time.

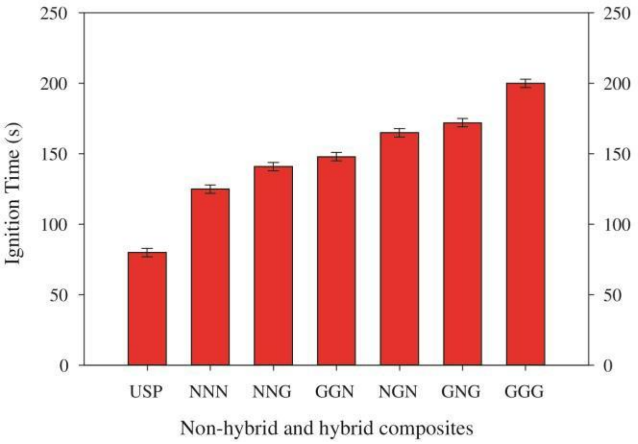

Fig. 7. Natural burning time vs non-hybrid and hybrid composites

E. Effect of Chemical Treatment on Natural Burning Time

Fig. 8. shows the effect of chemical treatment on natural burning time of non-hybrid and hybrid composites. Alkali treated fibers reinforced composites significantly changing the natural burning time of untreated composites. Nearly 15% shortening of natural burning was observed in alkali treated composites. Similar to pilot ignition, natural burning was also becoming longer when silane treated fibers are reinforced.

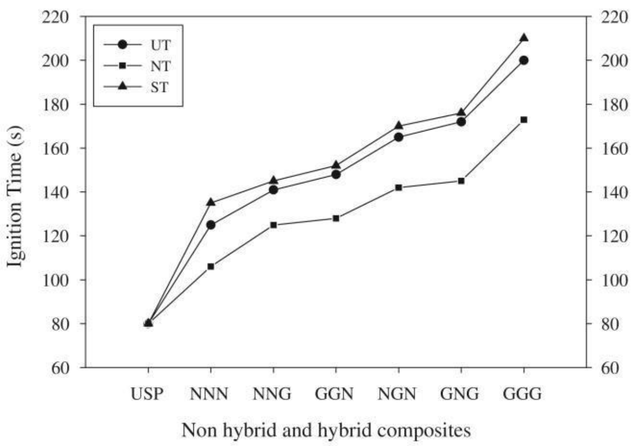

Fig. 8. Effect of chemical treatment on natural burning time of non-hybrid and hybrid composites

IV. CONCLUSION

Composites are fabricated; conductivity and flammability properties are explored as a function of hybrid and fiber treatment. Following are some conclusions drawn based on the experimental results,

- In common, conductivity of the composite become lower after the fiber surface treatment.
- Ignition time is short for the natural fiber composite and longer for synthetic composites.
- Extinguish properties also become stronger upon adding synthetic fibers

Experiment reveals the research possibilities of enhancing the conductivity and fire resistance properties of the less explored coconut sheath composites.

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AUTHOR PROFILE

Dr. I. Siva is currently working as Professor in the Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Anand nagar, Krishnankoil-626126, India He has 15 years teaching as well as research experience. He is a reviewer more than 10 reputed journals He is a Member of Indian Society for Technical Education. His areas of interest are polymer composite, materials characterization, tribology.