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Flammability Characterization of Feather Fiber based Hybrid Composites

Sandesh Kiran. S[1]
[1] Research Scholar,
Department of Mechanical Engineering,
University Visvesvaraya College of Engineering,
Bangalore, India

B. M Rajaprakash[2]
[2] Professor,
Department of Mechanical Engineering,
University Visvesvaraya College of Engineering,
Bangalore, India

***Abstract*:- Natural fiber based hybrid composites are gaining popularity in commercial and industrial application due to advantages of natural fibers, environmental concerns with polymer based fibers including pollution and dependency on crude oil. Usually, all natural fibers are available in abundance, very cost effective and possess reasonable mechanical properties. One of the important requirement for natural fiber based composites to be used in commercial and industrial application is compliance to flammability requirements. Most of the natural fibers are sensitive to flame and heat. Hence, it is important to review the effect of flame on natural hybrid composites. This paper reviews the flammability aspects of Feather Fiber based Hybrid Sandwich Composites. The test panels were tested as per flammability test mentioned in ASTM D 3014 standards. The results from the tests were analyzed and interpreted.**

Keywords: Natural fibers, Poultry Feather Fiber, Feather Fiber based Hybrid Composites, Flammability of Feather Fiber based Hybrid Composites, Flame height, ASTM D 3014

1. INTRODUCTION

Low cost, weight to strength ratio, abundant availability and environmental characteristics of natural fibers based composites are competing against synthetic or polymer based composites which are dependent on petroleum products and causing ecological issues [1]. Natural fibers based hybrid composites are gaining popularity in commercial and industrial applications. Car's interior parts like ceiling and dashboard, false ceiling in construction industry are some of the examples for natural fiber based composites [3, 4]. Cellulose based natural fibers are sensitive to flame and direct heat. Flammability characteristics of hybrid sandwich composites are directly depends on the constituents like core, face sheets and adhesives/resin system.

Natural fiber based composites are inconsistent in there flammability characteristics and there are limited research on flammability review of natural fiber based composites. The emerging field of natural fiber based composites have ample opportunities to understand the flammability mechanism of natural fibers and new techniques to make natural fiber based composites flammability complaint [5-7].

1.1 Firing Order of Testing Requirements

Usually, design engineers tend to initiate testing cycle from mechanical testing of sandwich panel but environmental compliance test like flammability test, smoke & toxicity test, water absorption test are extremely important. If test specimen passes all mechanical testing and fails in environmental compliance tests, than it is not worthwhile to peruse because of the fact that newly developed material may be harmful to human use and for the environment. Thus, it is always advisable to start testing from the compliance stand point of view. Tabulation covered in Table 1 provides details of "Firing order of testing requirements"

Table 1. Firing Order and Priority of Tests for Hybrid Composite Panels [8]

Sl. No	Test Type
1	Flammability Tests
2	Wear and Tear Tests
3	The Impact (Puncture) Test
4	Material Construction Tests
5	Edge Bearing Test
6	Tensile Strength and Modulus Test
7	Water Absorption Test
8	Strength Tests

2. FLAMMABILITY

Flammability testing is a critical part of ensuring safety and trustworthiness of consumer products. Industry applications for flammability test methods include textiles and consumer goods, aerospace and transportation, bedding, and furniture materials. Sandwich composite panels and derived products must satisfy safety requirements and regulations before released to market, including the rate of burning, heat and smoke release criteria.

Sandwich Composite panels used in the generic commercial or industrial application must comply with national and international regulations. Most countries adopt the U.S. Federal Aviation Regulations (FAR) as bench mark for aerospace requirements. These regulations consider that limiting flammability and smoke density will adequately control the toxic fume production. The flammability and smoke density test methods for a given application are largely standardized, based on the FAR 25.853 requirements.

Table 2. Flammability requirement for aerospace application as per FAR 25.853 [9]

Sl.No	Name of the Test	Types of tests	Test's Key findings/Observation	Remarks
1	Flammability Tests	Vertical Flame Test - Type A	materials are subjected to a 60-second exposure to flame	
		Vertical Flame Test - Type B	panels are exposed to only 12 seconds of flame.	
		Burn-Through Resistance Test	measure how well a material will prevent fire from spreading (either in or out)	Smoke Density Test is also conducted on honeycomb
		45° Flame Test		

When detailing the flammability requirements and tests, design engineers and manufactures need to determine the necessary standards required for a particular composite product, perhaps based on its intended end-use. The standards are designed to test specific properties, so that products may be subject to multiple tests that measure or rate various characteristics listed below [10]

- **Resistance to fire** – measurement of a product's ability to resist catching on fire.
- **Ignition rate and/or flame spread** – measurement of a product's characteristics for fire expansion.
- **Reaction to fire** – measurement of a product's response when exposed to fire.
- **Smoke density** – measurement of smoke generated in the presence of flame.
- **Decomposition** – measurement of a product's degradation when exposed to fire.
- **Afterflame** – measurement of length of time for flaming to cease.
- **Afterglow** – measurement of length of time for flaming and glowing to cease.

2.1 Flammability Testing

Flammability test methods measure how easily materials ignite, how quickly they burn and how they react when burned. The materials are placed over a Bunsen burner either vertically or horizontally, depending on the specification. During a vertical flammability test, a material is observed for the length of time it burns after the igniting flame is removed, how much of the specimen burns and whether or not it drips flaming particles. In contrast, horizontal flammability tests observe if the material continues to burn after the test flame is removed, and then calculate the rate at which the specimen burns.

Fig.1 Illustration of horizontal and vertical flame testing setup

Laboratory level flame tests are used to assess a material's flammability using a small Bunsen burner flame with 38mm in length and at 843˚F(450˚C). Fig.2 illustrates the Bunsen burner and flame charactestics. The flame is applied to the lower edge of the specimen for specified tame limit (dependent upon application). In order to be classified as 'self-extinguishing' the material must show limited flame spread and after flaming, and flaming droplets must extinguish within a given time. There are different verities of flame tests based on the application end use and type of materials used for sandwich composites. Most common flame test are listed below.

- Flammability of Cellular Plastics—Vertical Position (ASTM D 3014)
- Flammability of Cellular Plastics—Horizontal Position (ASTM D 1692) withdrawn
- Smoke Generation Tests
- UL 94 Flammability Testing

Table 3. Flammability tests and test parameters

Test Specification No.	Name of test	Specimen size (in.)	Number of specimens	Angle of specimen	Ignition source	Properties measured
ASTM D-3014	Flame height, time of burning, loss of weight : Cellular plastics, Vertical position	10 X 3/4 X 3/4	6	Vertical	Gas burner	Loss of weight and time of extinguishment
UL 94V-0	Flammabilityof plastic materials	1/2 X 5 X thickness	5	Vertical	Bunsen burner	Rate of burning
UL 94 HB	Flammabilityof plastic materials	1/2 X 5 X thickness	3	Horizontal	Bunsen burner	Rate of burning

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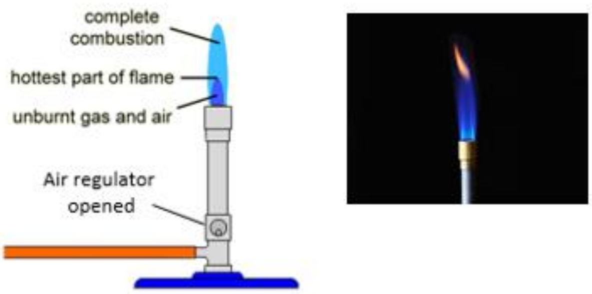

Fig.2 Illustration of Bunsen burner setup and flame characters

2.2 Flammability testing as per ASTM D 3014

The test procedure for Flammability test of sandwich composite panel per ASTM D 3014 standards usually applicable to 0.75in (19mm) thick cellular panels with plastics. The test is carried out by mounting the specimen vertically on a mounting stand and specimen was ignited with a flame 35mm from Bunsen burner for 10 sec. The flame height, time of burning and weight percent retained by the specimen is determined. Fig.3 illustrates the ASTM D3014 and UL 94 test schematics.

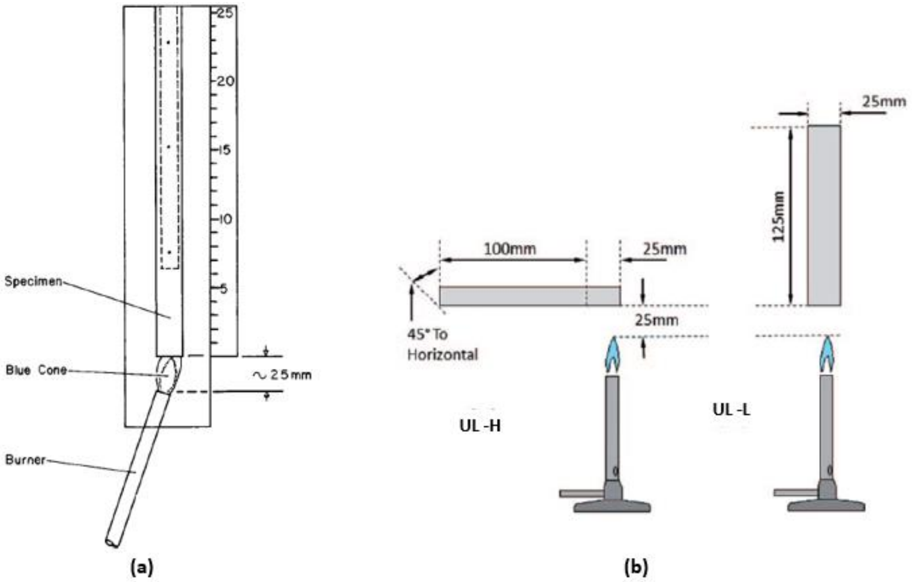

Fig.3 Illustration of flame tests (a) as per ASTM D 3014 [11] (b) UL 94 Horizontal and Vertical Test

2.3 Flammability testing as per UL 94

Sandwich composite panels are also tested as per UL94 procedure as a preliminary indication of acceptability for use as part of a device or appliance with respect to its flammability. It is not intended to reflect the hazards of a material under actual fire conditions The test procedure for the flammability test of composite laminates in vertical and horizontal direction is illustrated in Fig.3 (b).

2.3.1 UL94V (Vertical direction)

A small 3/4th inch high blue flame is applied to the bottom of the specimen for 10 sec, withdrawn, then reapplied for an additional 10 sec, the duration of flaming and glowing is noted as soon as the specimen is extinguished. A layer of cotton is placed beneath specimen to determine whether dripping material will ignite it during the test period.

2.3.2 UL 94 H (Horizontal direction)

Burner ignited to produce 1 inch high blue flame. A depth of 1/4th inch flame applied to specimen for 30 sec without changing the position of the burner and is removed from the burner. If the specimen burns to the 1 inch mark before 30sec the flame is withdrawn. If the specimen continues to burn after removal of the flame, the time for the flame front to travel from the mark 1 inch from the free end to the mark 4.0 inch from the free-end is determined and rate of burning is calculated.

3. BURNING CHARACTERISTICS OF POULTRY FEATHERS FRACTION

From various literature survey, it is evident that feather fibers are sensitive to heat and flame but when they are exposed to fire, they retard the fire propagation. Below table illustrate the properties and characteristics of feathers and its constituents exposed to fire.

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Table 4. Burning characteristics of poultry feathers [12]

Flame position and properties	Barbs/Rachis/Whole feather
Approaching flame	Smoulders and curls away from flame; ignites slowly
In the flame	Burns slowly /orange flame; sizzles and curls, no smoke
Away from the flame	Supports combustion with difficulty for short time
Odour	Burning rubber
Residue	Easy crushable black soft ash

4. FACTORS FOR FLAMMABILITY OF NATURAL FIBER BASED COMPOSITES

As per famous flame triangle, fuel, heat and oxygen are the three important elements in a combustion process. Once the flame is ignited then stopping any of the above three elements may stop (or reduce) the propagation of flame. Natural fibers rapidly decompose under heat sources while polymer matrices melt. The hemicellulose decomposition starts first in the beginning of flame and with the increase in temperature lignin also gets decomposed. Mass is lost continuously during the decomposition process because of the evaporating gases.

The amount of fiber content, matrix type, surface treatment and filler concentration are the factors which affect the final properties of the NFRP. The flammability and thermal behavior of the composites are also affected by these factors. Different authors have studied the effects these factors on the flammability of composites.

5. FECORE

FECORE is a proprietary feather fiber based circular celled honeycomb core. Honeycomb core is feather fiber filled and core comes in different cell size and wall thickness. An example of FECORE of size 48mm x 48mm and thickness 12mm is shown in Fig 3. Surface of the core is provided with thin layer of feather fiber based mat which is sensitive enough to bond with any polymer based scrim. Core comes with cell diameter 4mm, 6mm, 8mm, 10mm and 12mm. Core also comes with reinforcement of quill at the center of the cell with various size of quill diameter from 3 mm to 5mm. Thickness of the core ranges from 5mm to 23mm. FECORE is ready to use core and do not need any fixtures or utilities to expand the core [8].

Figure 4: FECORE - Feather fiber based hybrid honeycomb core [8]

6. MATERIAL AND METHODS

Low-density polyethylene (LDPE)-coated glass fiber prepreg and Poultry feather fiber based honeycomb core “FECORE” were used for the fabrication of sandwich panel. SR 998 adhesive which is a synthetic rubber based solvent containing contact adhesive was used to fabricate the sandwich panel. Adhesive can be applied on the coating surfaces by roller or brush. Core of thickness is 0.5inch (12.7mm) and 0.75in (19mm) with the cell size ranging from 4mm to 12.7mm with variation of quill reinforcement size was used for sandwich panel construction. To test the flammability properties of sandwich panel specimen, the feather fiber based panels were cured in a standard autoclave at a predefined pressure and temperature based in type of base material used on core, face sheet and adhesive system. .

Direction of the fiber reinforcements on prepeg plays very important role in strength aspects of the face sheet. Usually fiber reinforcements are parallel to the length of the prepeg and this pattern is called warp direction. Face sheets were cut to size considering the warp direction of the prepreg. FECORE is available in running lengths and was cut along the ribbon direction of the core. Precut and sized FECORE was cleaned with pressurized dry air and acetone to keep the core surface free from dust and impurities. After cleaning, FECORE was normalized in climate controlled chamber which was maintained at 27^{0}C and 45% Humidity. Precut buildups of sandwich panels were provided with one

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layer of perforated release film at the top with a breather layer (N10). Then entire buildup was placed in the utility and vacuum bagged. Vacuum bag was maintained with vacuum of min 0.65bar which will make compaction of the core easier and the vacuum leak checked periodically.

The pre-fabricated sandwich panels were thermally cured in an industrial autoclave which has a capability of heat up rate between 0.5°C/min – 1.5°C/min. During the curing process of the sandwich panels, two stages of thermal ramp ups were maintained. First stage is to maintain the panels at 65°C for 30-35min and second stage is to maintain the panels at 125°C for 60-90min. The total duration of thermal curing is roughly around 8hrs including cooling down process. Sandwich panels were cooled down with a rate of 3°C/min to a temperature of 35˚C. Once panels reach the lower limit of the cooling cycle, panels will be stored in climate controlled chambers to protect them from moisture entrapment. The thermal curing process and cycle is illustrated in Fig.5.

Flammability test specimens of various sizes listed in Table -3 were cut from the normalized cured hybrid panels using a general purpose band saw. Test sample length of the panel were maintained in such a way that warp direction of the prepreg parallel to sample length.

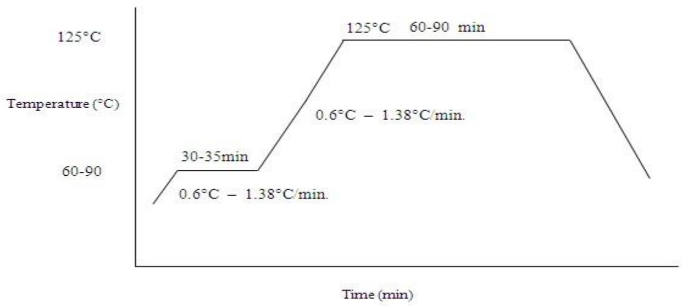
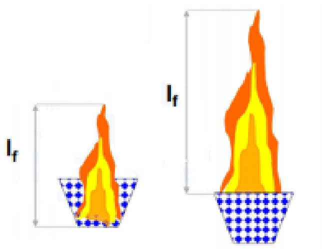


Figure. 5: Sandwich Panel's Thermal Curing Cycle

7. FLAME HEIGHT CALCULATIONS

Flame height calculation is very output data from the test and very important factor for the evaluation of Flammability of sandwich composite panels. Actual flame height will be calculated based on the heat release rate of flame using McCaffrey equation. Thermal sensors mounted with in the chimney at designated location provides the data for heat release rate in kilowatts.



Flame height measured from base of flame

McCaffrey Equation for Flame Height Calculation

$$Z_c = 0.08\dot{Q}^{2/5} \quad and \quad Z_i = 0.20\,\dot{Q}^{2/5}$$

Where:

Z_c = Consistent Height of Flame in Meters

Z_i = Intermittent Height of Flame in Meters

0.08 = Consistent Flame Variable in m/kW

0.20 = Intermittent Flame Variable in m/kW

$\dot{Q}$ = Heat Release Rate of Fire in Kilowatts

Fig.6 Flame height calculation methodology [13]

8. EXPERIMENTAL DETAILS RESULTS AND DISCUSSION

8.1 Flammability test as per ASTM D3014

Flammability test was carried out by mounting a 0.8in(20.3mm) thick FECORE based sandwich specimen vertically on vertical stand inside a closed glass chimney. Fig-3 illustrates the experiment setup with dimensional details. Bunsen burner with flame of >35mm was placed under the specimen with a gap of 25mm between the tips of the flame to the bottom surface of the sample. The ignition time is 10 sec and after the ignition time, burner was switched off. The flame height, time of burning and weight percent retained by the specimen was determined for each specimen. Total of 6 samples were tested as per the test procedure requirement.

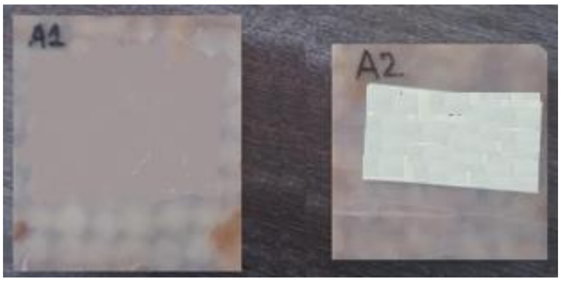


Fig.6 samples for testing (before precut)

Table 5. Test specimen identification and details

Sl. No	Specimen ID	Cell Size(mm)	Quill Reinforcement	Quill Size(mm)
1	S1	4	No	0
2	S2	6	Yes	1.5
3	S3	6.35	Yes	2
4	S4	8	Yes	2.5
5	S5	10	Yes	3
6	S6	12.7	Yes	4

Thickness of the panel =0.8in(20.32mm)

Table 6. Test results as per ASTM D3014

Speciman ID	Flame height (mm)	Extinguish time (sec)	Loss of weight (grams)
S1	34	45	2.7
S2	36	50	2.55
S3	41	68	3.48
S4	49	81	4.55
S5	46	97	5.03
S6	63	110	6.81

8.2 Flammability test as per UL94

FECORE based hybrid sandwich composite specimens of size 125*13*12 mm were tested for flammability behavior according UL94 standard for getting vertical and horizontal burning rates. For horizontal test, a 25mm Bunsen flame was applied to the leading edge of the sample. 6.35mm length of samples is introduced to Bunsen flame for 30 sec without altering place of Bunsen flame and sample. Then the sample is withdrawn from the flame. When the sample burns to the 25.4 mm mark before 30 seconds then the flame is removed. If the sample constantly burns after displacement of the flame, the time for the fire front to travel from the 25.4 mm to the 101.6 mm mark from the free end is noted to calculate the rate of burning. In vertical rate of burning test, a 19.05 mm Bunsen flame is applied to the bottom of the sample for 10 sec, replaced and then reapplied for a supplementary 10 seconds. The time of flaming and glowing is recorded as soon as the sample is replaced. The experimental schematics for burning tests is as shown in figure 3 and setup is shown in figure 7.

Fig.7 (a) Vertical (b) Horizontal flame testing as per UL 94

The figure 8 represents the graphical representation of burning rate of vertical and horizontal burn test as per UL 94 specification. The results indicate that addition of Quill reinforcement increases the flammability. Hence Quill supports fire and is a bad flame retardant due to the generation of a surface layer during pyrolysis of the natural fiber composites which discloses poor fire retardancy. This layer behaves as supporter of fire, which spreads the heat to the un-pyrolysis substance. In vertical burning test, the speed of flame is much faster than in horizontal position due to preheating of the specimen.

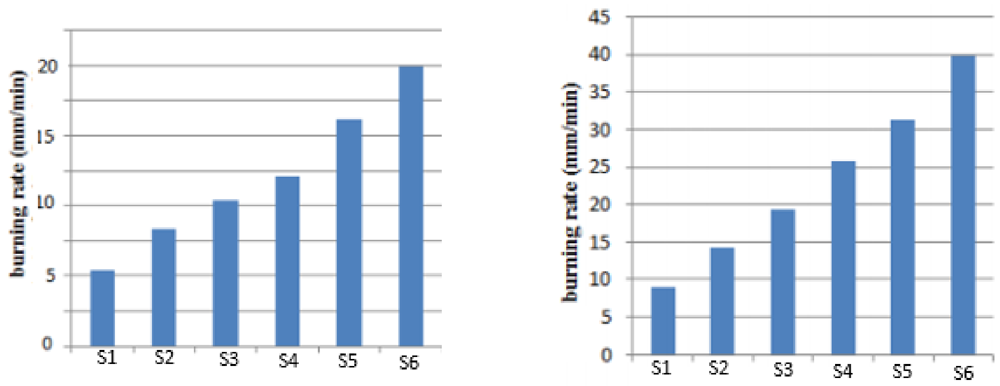


Fig.8 (a) Horizontal (b) Vertical flame testing result plot (as per UL 94)

Table 7. Linear burning rate of Horizontal and Vertical flame test results

Specimen ID	Hor. Linear Burning Rate (mm/min)	Ver. Linear Burning Rate (mm/min)
S1	5	9
S2	8	14
S3	11	19
S4	13	26
S5	17	32
S6	20	39

9. CONCLUSION

FECORE (Feather fiber based honeycomb core) based sandwich composite panels were tested as per ASTM D3014 and UL 94 Horizontal and Vertical conditions. Flame testing results shows the linear pattern in flame burning rate (mm/min) and weight loss rate (gm/mm). Flame testing on the sandwich panel has revealed that the inherent flame retardation characteristics which is attributed to the fire resistance characteristics of the feather fiber. Quill reinforced sandwich panels have shown more flame burning rate compared to non-quill reinforced sandwich panels. The burning rate and the corresponding mass loss rates were found to decrease as the volume fraction of fibers increased. The increase in flame resistance was observed with the decrease in wt% of quill reinforcement in the hybrid composite development.

From the flammability test results, it is evident that feather fibers alone has good fire retardant property and quill is vulnerable to flame and heat due to presence of voids and air pockets in its structure. Despite of the fact that quill impacts the flammability aspects of the hybrid composites, still the flame propagation rate is considerably less when compared to other natural fiber based sandwich composite panels. Thus feather fiber based hybrid composites have bright future in industrial applications.

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