Machinability and flammability properties of sisal fiber reinforced polymer composites

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Abstract. Nowadays Natural fiber reinforcement polymer composites (NFCs) are conventionally used materials and they are the replacement for the synthetic and other non-degradable fibers. NFCs are considered as environmental friendly materials and it will not cause any hazard to the environment as they are biodegradable. Flaming property of material is based on fire triangle (oxygen, ignition source and fuel). When fire triangle is controlled, then the flammability of materials are controlled. This work is on delay the ignition time and the reducing flammability on NFCs material. According to this, flame retardants are added to the reinforcement because flammability of NFCs is quite high when comparing to the other composite materials. So, flame retardant will delay the time of flame penetration in the material and it acts as a flame restrictor. Sisal fiber with Polypropylene (PP) matrix is used and to reduce the flammability ammonium polyphosphate (APP), magnesium hydroxide (Mg (OH)2), zinc borate (Zb) and graphite added. APP when react with flame the char layer is produced and it will insulate the material to stop further flaming, Mg (OH)2 realises water molecules when react with flame at 135°C and its also helps to delay the further flame. 3 composites are fabricated by varying the composition material. According ASTM D638 and UL-94 test standards by horizontal and vertical burning testing flammability timing is recorded, drilling operation were carried out to find the force of composite material by varying the cutting tool material with 5mm dia.

Keywords. Polyester resin, sisal fiber, flame retardant, flammability testing, drilling operation

1. Introduction

A composite is combination of two or more material. Natural fiber reinforced polymer composite (NFCs) have received much interest in industrial applications due to their environmental and economic concerns. Natural fibers have many advantages like they are biodegradable, low cost, absence of toxic when compare to synthetic fibers [1]. Sisal fibre has been described as a promising reinforcement for use in composites due to its low cost, low density, high specific strength and modulus, no health risk, easy availability in some countries and renewability. It has been used to reinforce thermoplastics, thermosets, gums and cement.

Flammability of NFCs is to be considered as important factor because flaming properties of polymers and natural fibers is quite high when comparing other materials. Though flammability is in high then the burning rate of material also will in high range. So, to reduce that chemicals are added to the reinforcement [2-3]. The flammable property of sisal fiber is poor. So to increase the flammability, flame retardants are added, they are Ammonium polyphosphate (APP), Magnesium hydroxide (Mg (OH)2) and Zinc borate (Zb) [4-5]. Magnesium hydroxide (Mg(OH)2) is widely used metal hydroxide...
flame retardants. They provide effective flame retarding effects by producing char insulating layer and releasing water at about 360°C [6]. Boron compounds such as zinc borate (Zb) decompose endothermically and releases water at about 320°C. The combination of APP and Zb in Polyester leads to an improvement of the fire behaviour [7]. The addition of boron compounds enhances the flame-retardant properties of intumescent Polyester composites [8]. Graphite is as intumescent flame-retardant additive and it is mainly depending on its ability to expand during heating [9-11]. Graphite particles can increase the char layer and thermal stability is also increased. According to Murariu et al the char can also swell and it can reduce the flame extension and the author observed that with 3-6 wt% of graphite will form a porous char swollen layer during flammability testing [12]. The objective this study is to investigate the behaviour of APP, Mg(OH)$_2$, Zb and Graphite in the polyester composite with the reinforcement of sisal fiber. Flammability of the materials was analysed by according to the standard of UL-94 testing methods and to analysis the mechanical properties tensile and impact strength are tested according to ASTM D 3039 and ASTM D 4812 standards.

2. Experimental

2.1 Materials

Polyester is used as matrix and Cobalt octoate 6, Methyl ethyl ketone peroxide catalyst are the curing agent was purchased from Covai Seenu & Company (Coimbatore). According to the manufacturing data the principal characteristics of the specific used for ratio mixing in resin with the hardener. Sisal fiber is used for reinforcement with the density of 1.33 g/cm$^3$ was purchased from Agro products, (Coimbatore). Ammonium polyphosphate (APP) with the density of 1.99 g/cm$^3$, Magnesium hydroxide (Mg(OH)$_2$) with the density of 2.34 g/cm$^3$, Zinc borate (Zb) with the density 3.64 g/cm$^3$ of and Graphite with the density of 2.34 g/cm$^3$ are used as a flame retardant. All the flame retardants are in powder form and these are purchased from GO Green products, (Chennai).

2.2 Composite preparation

Composites are prepared by hand lay-up method and it is made as a flat shape plate with the dimension of 300*300*3 mm in size. According to the dimension the mold arranged as shown in Figure 1.

![Figure 1. Mold setup for fabricating composite plate](image_url)
The composites are with various compositions and they are varied according to the wt% of both matrix and reinforcements. For example, composition for first plate are with 70 wt% of polyester resin, 26 wt% of sisal fiber, 2 wt% of ammonium polyphosphate (APP), 1 wt% of magnesium hydroxide (Mg(OH)$_2$), 0.7 wt% of zinc borate (Zb) and 0.3 wt% of graphite. Accordingly, the composites are varied as shown in Table 1.

| S.No | Polyester (%) | Sisal (%) | APP (%) | Mg(OH)$_2$ (%) | Zb (%) | Graphite (%) |
|------|---------------|-----------|---------|----------------|--------|--------------|
| 1    | 87            | 3         | 4       | 3              | 2      | 1            |
| 2    | 82.5          | 10        | 4       | 2              | 1      | 0.5          |
| 3    | 77.5          | 15        | 4       | 2              | 1      | 0.5          |

According to the Table 1 the composite materials are fabricated.

2.3 Characterization

2.3.1 Flammability

Flammability of Polymer composites were studied by a horizontal burning test and a vertical burning test according to UL-94 testing standards.

Flammability of plastic material are used in parts for plastic appliances is commonly known as UL-94. It is a flammability specification issued by the Underwriters Laboratories Inc. Underwriters Laboratories is a non-profit organization which operates the laboratories around the world for examination and testing of devices, systems and other materials. They also define and publish specifications that provide procedures for testing each material. The flammability specification UL-94, incorporates several small-scale flame tests procedures that defines parameters for flame testing of plastic polymers. In here, the behaviour of plastic when exposed to fire is expressed quantitatively. These numbers are obtained from measurements of the after-flame time or from the amount of material burned in a specific length of time. After flame time refers to the length of time, in seconds and minutes are noted for a material continues to burn after removal of the ignition source. The amount of material burned refers to the length of sample that burns in a specified period of time. According to UL-94 standard the composite materials are cut into required dimension (125 mm * 13 mm * 3 mm) as shown in figure 2. The cutting process are done through switchboard cutting machine.
2.3.1.1 Ignition sources

The portable gas cartridge burner with a methane fuel is used as ignition source. The gas flow is controlled with a suitable regulator. The typical flame testing set up is shown in figure 3.

Figure 3. Flammability testing setup

2.3.2 Drilling equipment and tools

The drilling was performed by using commercially available high speed steel drill bit of diameters 5mm, point angle of 118 degree each and flute length of 50 mm in CNC drilling machine. Drilling was carried out for entire thickness of the work piece (3mm through hole). Conducted an experimental study on the effect of process parameter while drilling NFCs composites using Taguchi method [14]
Here HSS and Carbide dill bit are used according to the drilling parameter of as shown in Table 2.

**Table 2. Parameters of drilling operation**

| Runs | Speed (mm/s) | Feed (mm/s) | DOC (mm) |
|------|--------------|-------------|----------|
| 1    | 50           | 3           |          |
| 2    | 1000         | 100         | 3        |
| 3    | 150          | 3           |          |
| 4    | 50           | 3           |          |
| 5    | 2000         | 100         | 3        |
| 6    | 150          | 3           |          |
| 7    | 50           | 3           |          |
| 8    | 3000         | 100         | 3        |
| 9    | 150          | 3           |          |

Composite material for drilling operation was cut into required dimensions of 75*75 mm and total no
of drills are 9 (3*3) with the distance of 20 mm for each drills as shown in figure 4.

**Figure 4.** (a) The 1st composite specimen (as shown in table 1) before drilling operation and (b) After drilling operation with 5mm drill bit.
3. Results and discussion

3.1 Flammability testing results according to UL-94 standard

Here both vertical and horizontal testing are carried out. The UL flammability rating chart shown below for the UL 94 testing.

Table 3. Flammability UL 94 (Vertical Burning testing)

| Test criteria                              | V-0 | V-1 | V-3 |
|--------------------------------------------|-----|-----|-----|
| Burning time of each specimen (s)          | 20  | 26  | 27  |
| Total combustion time (min)                | 3.50| 6.16| 4.4 |
| Dripping of burning specimens             | No  | No  | No  |
| (specimen completely burned)              |     |     |     |
| Combustion up to holding clamp            | Yes | No  | No  |

Here V (0, 1, and 2) are the composite material with various compositions as shown in table 1.

According to vertical flammability testing the composition of 87% polyester resin, 3% of sisal fiber, 3% of Mg(OH)₂, 4% of APP, 1% of Zb and 1% of graphite has more char layer (shown in Fig 6) when compare to other compositions.
Figure 5. (a) Process of vertical flammability testing (b) combustion of vertical flammability testing and (c) image of specimen 1 which formed more char layer when compare to other specimens.

Table 4. Flammability UL 94 HB (Horizontal Burning testing)

| Test criteria                        | H-0  | H-2  | H-3  |
|--------------------------------------|------|------|------|
| Maximum flaming time (s)             | 53   | 30   | 42   |
| Maximum glowing time (min)           | 6.10 | 12.23| 12   |
| Dripping particle at the time of ignition | No   | Yes  | Yes  |

Whereas H (0, 1, 2) are the composite material with various compositions as shown in Table 1.
In horizontal burning testing during burning the specimen starts to bend like C shape and the 2\textsuperscript{nd} and 3\textsuperscript{rd} composition as shown in Table 1 has a dripping particles during the combustion. The C shape is shown in figure 6.

![Image of horizontal burning testing](image1)

![Image of C shape during combustion](image2)

**Figure 6.** (a) Process of horizontal burning testing (b) Formation C shape while combustion in horizontal burning testing

3.2 \textit{Effect of machining parameters on the composite material}

To study and compare the thrust force while drilling efficiently polyester composite specimen was loaded initially for the drilling operation. The operation was initiated with drilling parameters which are planned earlier as cutting speed of 1000, 2000 & 3000 rpm, a feed rate of 50, 100, 150 mm/sec and the depth of cut of 5mm. The hole was set to drill with the offset of 15mm each in 3 x 3. The observed thrust force was recorded with the help of dynamometer and plotted as a graph which is listed in Fig 4. It was observed that thrust force shows increasing trend with an increase in feed rate and decreases with increase in cutting speed.
According to the machinability parameters the by using L9 orthogonal array the nominal thrust force are analysed in the Design of Experimental by using Taguchi method and progress are discussed below.

The effect of influencing data as per the various machining parameters in the taguchi method

Table 5. S/N ratio according to the drilling parameters and Fz for HSS tool

| S.no | Speed(rpm) | Feed(mm/sec) | Fz (N) | S/N ratio |
|------|------------|--------------|--------|-----------|
| 1    | 1000       | 50           | 29.66  | -29.4434  |
| 2    | 1000       | 100          | 46.50  | -33.3491  |
| 3    | 1000       | 150          | 61.33  | -35.7535  |
| 4    | 2000       | 50           | 21.53  | -26.6609  |
| 5    | 2000       | 100          | 27.47  | -28.7772  |
| 6    | 2000       | 150          | 35.45  | -30.9923  |
| 7    | 3000       | 50           | 21.09  | -26.4815  |
| 8    | 3000       | 100          | 25.12  | -28.0004  |
| 9    | 3000       | 150          | 29.00  | -29.2480  |

Fz is force acting towards the z-axis. Though work is on driling operation the force will act on Z-axis only. So we are considering only Fz for the analyse.

The result for the carbide tool drilling operations are shown in the Table 6 with the S/N ration for the parameters and Fz result.

Table 6. S/N ratio according to the drilling parameters and Fz for Carbide tool

| S.no | Speed(rpm) | Feed(mm/sec) | Fz(N) | S/N ratio |
|------|------------|--------------|-------|-----------|
| 1    | 1000       | 50           | 20.87 | -26.3904  |
| 2    | 1000       | 100          | 33.39 | -30.4723  |
| 3    | 1000       | 150          | 47.82 | -33.5922  |
| 4    | 2000       | 50           | 15.45 | -23.7786  |
| 5    | 2000       | 100          | 24.16 | -27.6619  |
| 6    | 2000       | 150          | 32.15 | -30.1436  |
| 7    | 3000       | 50           | 11.71 | -21.3711  |
| 8    | 3000       | 100          | 16.60 | -24.4022  |
| 9    | 3000       | 150          | 23.07 | -27.2610  |

The influence of cutting speed on force in the drilling of sisal fiber composites are shown in figure 7.
Figure 7. (a) Main effect plot for mean of force and speed in carbide drill bit and (b) Main effect plot for mean of force and speed in HSS drill bit
Machinability in natural reinforced polymer composite are developing now-a-days and this work is on the drilling operation with two various tools HSS and Carbide with 5mm tool diameter. The work is to find the nominal thrust force in the composite material by varying two machining parameter speed and feed they are in three level speed in 1000rpm, 2000rpm and 3000rpm. Feed in 50, 100, 150 mm/sec. According to the parameters the results of Fz are incorporated in the Minitab 17 software to perform Taguchi Design in L9 orthogonal array. As a result the nominal are the better for HSS tool Fz = 46.50 N in 1000rpm and 100mm/sec is nominal for the composite material. For Carbide tool Fz = 33.39 is nominal for in 1000rpm and 100mm/sec.

4. Feature work recommended

Limited Oxygen Index (LOI) plays a vital role in the flammability of polymer composites materials selection of LOI % in polymer can vary the flammability time. High LOI value gives low flammability and low values gives high flammability.

Other flame retardants like inorganic, inducements and phosphors based flame retardants also can be used based on the area of applications because for example some flame retardants has toxics which are not good for environments.

5. Conclusion

Incorporating flame retardants; i.e. APP, Mg (OH)$_2$, Zb, and Graphite into sisal fiber/Polyester resin composites resulted in the improved flame retardant. The addition of APP or combination of APP with Zb remarkably enhanced flame retardant of sisal fiber/Polyester composites. Here the composite with the composition of 82.5% polyester resin, 10% of sisal fiber, 2% of Mg(OH)$_2$, 4% of APP, 1 % of Zb and 0.5 % of graphite has better flame restricting capacity. Also the thrust force for 1$^{st}$ composite material as shown in table 1 was analysed by carbide and HSS drill bit. The result shows that carbide tool requires 34.5 N force and HSS tool requires 47.3 N for drilling 3mm composite material.

5. References

[1] Jeencham R, Suppakarn N and Jarukumjorn K 2014 Effect of flame retardants on flame retardant, mechanical, and thermal properties of sisal fiber/polypropylene composites, Compos. Part B Eng. 56,249–53
[2] Badia J D, Reig-Rodrigo P, Teruel-Juanes R, Kittikorn T, Strömberg E, Ek M, Karlsson S and Ribes-Greus A 2017 Effect of sisal and hydrothermal ageing on the dielectric behaviour of polylactide/sisal biocomposites, Compos. Sci. Technol. 149, 1–10
[3] Gokul K, Prabhu T R and Rajasekaran T 2017 Processing and Evaluation of Mechanical Properties of Sugarcane Fiber Reinforced Natural Composites, Trans. Indian Inst. Met. 70, 2537–46
[4] Tang H, Zhou X B and Liu X L 2013 Effect of magnesium hydroxide on the flame retardant properties of unsaturated polyester resin, Procedia Eng. 52,336–41
[5] Braun U, Schartel B, Fichera M A and Jäger C 2007 Flame retardancy mechanisms of aluminium phosphinate in combination with melamine polyphosphate and zinc borate in glass-fibre reinforced polyamide, Polym. Degrad. Stab. 92, 1528–45
[6] Sain M, Park S H, Suhara F and Law S 2004 Flame retardant and mechanical properties of natural fibre-PP composites containing magnesium hydroxide, Polym. Degrad. Stab. 83, 363–7
[7] Samyn F, Bourbigot S, Duquesne S and Delobel R 2007 Effect of zinc borate on the thermal degradation of ammonium polyphosphate, Thermochim. Acta. 456, 134–44
[8] Dočan M, Yılmaz A and Bayraml E 2010 Synergistic effect of boron containing substances on flame retardancy and thermal stability of intumescent polypropylene composites, Polym. Degrad. Stab. 95, 2584–8
[9] Huang J, Tang Q, Liao W, Wang G, Wei W and Li C 2017 Green Preparation of Expandable Graphite and Its Application in Flame-Resistance Polymer Elastomer, Ind. Eng. Chem. Res. 56, 5253–61

[10] Wu T C, Tsai K C, Lu M C, Kuan H C, Chen C H, Kuan C F, Chiu S L, Hsu S W and Chiang C L 2012 Synthesis, characterization, and properties of silane-functionalized expandable graphite composites, J. Compos. Mater. 46, 1483–96

[11] Zhang L, Zhang M, Zhou Y and Hu L 2013 The study of mechanical behavior and flame retardancy of castor oil phosphate-based rigid polyurethane foam composites containing expanded graphite and triethyl phosphate, Polym. Degrad. Stab. 98, 2784–94

[12] Murariu M, Dechief A L, Bonnaud L, Paint Y, Gallos A, Fontaine G, Bourbigot S and Dubois P 2010 The production and properties of polylactide composites filled with expanded graphite, Polym. Degrad. Stab. 95, 889–900

[13] Sunny T, Babu J and Philip J 2014 Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP Composites Using Taguchi Method, Procedia Mater. Sci. 6, 1131–42