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Use of Banana Peel in the Development of a Less Flammable Polyester Composite

Uporaba bananinega olupka pri razvoju manj vnetljivega poliestrskega kompozita

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Abstract

This study attempted to produce a cheap polyester composite material using an agricultural waste banana peel in the structure. Banana fibre has been used in composites as reinforcements, but banana peel has never been used with polyester before. The possibility of improved thermal and flammability properties of a composite due to increased moisture in the structure, and the char-forming ability of the cellulosic part of banana peel or the production of highly flammable material due to the presence of carbohydrates in the structure were the assumptions. To tackle the second assumption, aluminium trihydrate (ATH) was added. The handmade composites showed a drastic drop in tensile strength from 38.02 MPa to 16.72 MPa due to a lack of chemical bonding between the constituents. The impact and flexural strength showed some improvement with the addition of banana peel, along with ATH, to record results of 10.92 kg/cm and 49 MPa, respectively, after the initial drop that occurred when only ATH was added. However, these results were still inferior to the properties of pure polyester. The results of flammability and thermal resistance matched the second assumption, as flame retardancy was kept under control by the presence of ATH. The absorbency properties remained almost unaffected.

Keywords: tensile strength, viscosity, hydrophobicity, flame retardancy, char

Izvleček

V tej raziskavi je predstavljen poskus izdelati poceni poliestrski kompozit z uporabo bananinega olupka kot kmetijskega odpadka. Bananina vlakna so že bila uporabljena v kompozitih kot ojačitev, bananin olupki pa do zdaj še ni bil uporabljen skupaj s poliestrom. Predvidena je bila možnost za izboljšanje toplotnih lastnosti in vnetljivosti kompozita zaradi povečane vlage v strukturi in sposobnosti pooglenitve celuloznega dela bananinega olupka ali izdelava lahko vnetljivega materiala zaradi prisotnosti ogljikovih hidratov v strukturi. V zvezi z drugo predpostavko je bil dodan aluminijev trihidrat (ATH). Ročno izdelani kompoziti so, ker ni kemičnih vezi med sestavinami, pokazali drastičen padec natezne trdnosti z 38,02 MPa na 16,72 MPa. Udarna in upogibna trdnost sta se nekoliko izboljšali z dodatkom bananinega olupka in ATH skupaj, kjer so bile izmerjene vrednosti 10,92 kg/cm oziroma 49 MPa višje kot na vzorcih, kjer je bil dodan samo ATH. Vendar so bili ti rezultati še vedno slabši od lastnosti čistega poliestra. Rezultati vnetljivosti in toplotnega upora so potrdili drugo predpostavko, saj je bila odpornost proti gorenju pod nadzorom zaradi prisotnosti ATH. Vpojnost je ostala skoraj nespremenjena.

Ključne besede: natezna trdnost, viskoznost, hidrofobnost, negorljivost, zoglenelost

1 Introduction

Bio-composites have recently gained significant popularity because of advantages, such as biodegradability, the reduction of carbon dioxide released into the atmosphere and cost reduction due to the use of cheaper bio-fibres [1]. Natural fibres or fibrous materials from similar sources are the most commonly used component for producing fully or partially biodegradable composite materials. Natural fibre composites are used as a more or less compatible alternative for replacing environmentally harmful synthetic materials, which can be beneficial in terms of controlling pollution problems. In addition, these materials have the advantages of low cost and reasonable mechanical properties. Most importantly, these composites require low-production energy consumption [2–4]. These natural bio-fibres are collected from agro-waste, plants and trees [3]. They also have some significant problems that can affect the properties of final products when used as a reinforcement in composite materials. Bio-fibres are hydrophilic in nature and always tend to absorb water or moisture. This can cause fibre swelling and improper bonding between the fibre and matrix molecules. The different nature of the synthetic matrix and hydrophilic fibres are also responsible for the poor properties of composite materials. In addition, the irregular size, shape, and density of fibres often lead to the poor mechanical properties of the resultant bio-composites [5]. In addition to the above-described drawbacks, the poor flame retardancy or high flammability of bio-fibres can be considered a more significant problem of composites produced using bio-fibres due to the high flammability of those fibres, especially cellulosic fibres.

The main advantage of bio-composites is that, even though these materials can only undergo biodegradation when dumped into the environment, only direct exposure to environmental contents can cause the biodegradation of these materials. For this reason, bio-composites have often been used in various cars in door panels and body parts since 2000 [3]. However, the poor resistance of bio-fibres to ultraviolet (UV) rays limits their uses in the materials that come under less exposure to UV rays. However, the effect of UV rays on degradability is not that significant on cellulosic materials compared with lignin and hemicellulose [6]. The strength of bio-composites is not affected that much, as the strength mainly depends on the crystallinity of cel-

lulose. From that point of view, the choice of fibre is key for producing bio-composites of better strength and durability. Considering all the advantages and disadvantages, bio-fibres and other natural materials are often used only to reduce cost, making the composites lighter and more environment friendly, rather than concentrating on improving any other properties of the composite. According to recent research results, surface modification and the use of additional filler materials to improve or retain the performance of composites are common ways of developing bio-composites [6].

Considering all the facts above, this study aimed to develop a cheap bio-composite (partially degradable) using cellulosic agricultural waste material. Among common agricultural waste, banana peels are produced in large quantities around the world. About 1,200 million tonnes of bananas were produced in 2020 [7], and one-tenth of production was determined to be the waste of bananas in the form of the peel or skin [8]. The huge production of banana peels around the world needs to be utilized more efficiently than the current trend. Banana peels consist of various materials, including a very high proportion of moisture (57–60%), a considerable quantity of cellulosic fibre content (15–25%), carbohydrates (23–35%), some amount of ash (6–9%), different types of sugars (1–3%), etc [9]. The fibre contents in banana peels can be extracted [8] and used in different applications, which can be the subject of future studies. They have not, however, been used in developing composite structures due to the very low amount of fibre in banana peels and the inferior mechanical properties of the fibres compared to other natural fibres [2, 8]. The aim of this study was to use banana peels in a different application, focusing on its contents rather than its properties. Since banana peels are waste products, not much cost is expected for utilizing them in any structure. Expensive polymers such as epoxy, polyester, etc. are used daily in various applications. Using banana peels along with these materials can be a good option for utilizing a waste product that is produced in massive quantities worldwide and reduce the cost of final products. However, the tensile properties of composites are expected to be negatively affected by adding banana peels to the structure. This is because natural hygroscopic contents are known for making no chemical bonds with synthetic resin materials, apart from mechanical bonds [10, 11]. The only way to improve this condition is to use

surface modifying agents, which would increase the cost of the material.

In addition to the last problem, the cellulosic and carbohydrate materials of banana peels are also highly flammable when favourable conditions exist, but this only helps to catch the fire at the beginning relatively quickly and easily. Later, the formed char from the cellulosic material is expected to help reduce flames by absorbing the heat from them [10]. This issue can be solved by using a very small amount flame-retardant filler powder (to keep the cost of the material in check), which can also improve the tensile properties of polyester. Because the addition of powder can increase the viscosity of the resin, which may improve tensile properties to a small degree when used in small amounts [12], it would also reduce the flammability of the composite at the same time. Even though the increased viscosity of the resin is expected to result in a more rigid and less flexible material, adding banana peels is also expected to add pliability to the structure and reduce the rigidity of the material. This would neutralize the adverse effect of the increased viscosity of the resin. On the other hand, the high moisture content of banana peels might be useful in keeping flammability in check and neutralizing the highly flammable nature of the carbohydrate and cellulosic content. The flammability may not be adversely affected at all because cellulosic materials that are known to be easily flammable are expected to produce char that can stop the spread of flames [10, 13]. The effect of banana peels on tensile and especially the flame-retardant properties have not been studied previously, but will be studied in this article.

The resin selected for this study was unsaturated polyester. There were reasons to select polyester as the resin, even though there were other synthetic polymers available on the market that are cheaper than polyester. The superior tensile properties and thermoset characteristics are the reasons why polyester was chosen. Since the addition of banana peel was expected to have a negative effect on tensile properties, a resin of superior tensile properties was required. Polyester is one of the cheapest thermoset resins. For example, a kg of unsaturated polyester resin was available at one-fifth of the price of epoxy resin. Although epoxy has superior tensile and flexural properties, and its thermal properties are also quite good [10, 14, 15], polyester was chosen instead due to the high price of epoxy.

In addition, a flame-retardant filler was intended for the composite in small quantities to avoid or neutralize the banana peels' negative effect on the polyester composite's flammability. Fillers are generally small particles that can be used for almost any function, but these mainly add special specific properties according to requirements [12]. Using a thermoset resin actually helps the cause of using filler in the composite structure because the polyester resin can be cured using an agent at room temperature [10], and it helps the filler to keep its original chemical structure, which is essential for performing its specific role in the structure. A flame-retardant filler was intended to be used in this study. There are many flame-retardant filler materials available on the market. For example, metal hydroxides work by absorbing heat, boron-based materials form an insulating layer, halogen-based materials produce gases that help to reduce flames, and phosphorus-based materials produce a high percentage of char [10, 14, 16–19]. The most commonly used flame-retardant filler materials are boric acid, ammonium chloride, zinc chloride, borate, phosphoric acid, aluminium trihydrate, etc. [10, 14, 20, 21]. Among these, many researchers have suggested that metallic hydroxides, such as aluminium trihydrate and magnesium hydroxide, are the most environment-friendly filler materials [10, 14, 16, 22]. These are also not so costly. These chemicals absorb heat in an endothermic type of reaction and produce water when decomposed as a by-product [17]. Among these, aluminium trihydrate, also known as ATH, was preferred for this study over magnesium hydroxide because it is the cheaper of the two, and ATH starts to decompose at about 180°C, which is important when used with polyester, which offers the least resistance to high temperature. ATH can produce a reasonable amount of char, which can help prevent flames from spreading too quickly [23]. A flame retardant material such ATH works at a relatively lower temperature than other commonly used flame-retardant filler materials. This might help banana peels keep their limitations hidden if used in small quantities by keeping the cost of the material in mind.

Thus, this study used dried and ground banana peels in unsaturated polyester resin to produce a composite structure. An additional filler material, ATH, was also used to control the flammable nature of the composite or, more specifically, to control the possibility of increased flammability of the composite due to the addition of banana peels

in the structure. The aim of this study was to find an industrial application of banana peels in composite materials. For that purpose, the mechanical properties of the composite were also checked, together with absorbency and flammability, to determine the suitability of the produced material for any real-life application.

2 Materials and methods

This study did not require too many chemicals. Only unsaturated polyester resin, crystalizing or hardening agents, and filler materials were required as chemicals. Other required materials were used for making the composite, such as a mould, beakers, weights, non-sticky paper, and a stirrer. The final products were subject to several tests.

2.1 Materials

Unsaturated polyester resin (density: 1.12 g/cm³, gel time: 8–11 minutes at 25°C (use of a 2% hardener)) of the Polynt brand, methyl ethyl ketone peroxide (MEKP: active oxygen: 8–9%, density: 1.17 g/cm³) of a local brand, and ATH in powder form (density: 2.42 g/cm³, molar mass: 78 gm/mol) of the Qualikems brand was used. Banana peels were collected from the local market, and then dried and ground using a domestic grinder. The banana peels were used in a small particle form where the particle sizes were about 1 mm in length. All the chemicals were bought from the local market. All other materials were also collected from the local market.

2.2 Methods

Composite samples were made using varying percentages of ATH and banana peels (in terms of weight). One sample of pure polyester was made as the standard for comparison. The prepared samples were conditioned at 25°C and 65% relative humidity for several days, and all tests were performed under

the same conditions. Average values were recorded for all the tests.

2.2.1 Composite preparation

Banana peels and polyester were mixed by vigorous stirring for about 30 minutes in different combinations, as shown below. Composite boards of 8 mm in thickness were made. The prepared mixtures were poured into the mould by hand. A 2.0% hardener was added to the mixtures for curing action, just before the mixture was poured into the mould. Non-sticky plastic paper was used to cover the mixtures in the mould, and a glass rod was used to roll the mixture softly to remove any air bubbles. A 10 kg or 98 N load was applied to the mould during the curing process. The curing took place at room temperature for two hours afterwards. When ATH was added, the same process was followed while the ATH was added to the mixture along with banana peels and polyester resin. The combinations were calculated according to equations 1, 2 and 3 [24].

The weight fraction of ATH:

$$W_{\text{ATH}} = \frac{W_a}{W_a + W_b + W_m} \times 100 \quad (1)$$

The weight fraction of banana peels:

$$W_{\text{BP}} = \frac{W_f}{W_a + W_b + W_m} \times 100 \quad (2)$$

The weight fraction of polyester:

$$W_{\text{POL}} = \frac{W_m}{W_a + W_b + W_m} \times 100 \quad (3)$$

where W_a represents the weight of ATH, W_b represents the weight of banana peels and W_m represents the weight of the polyester matrix

A list of samples is presented in Table 1.

Table 1: List of samples

Sample no.	Weight fraction			Actual weight of components for 300 g of composite		
	ATH (%)	Banana peel (%)	Polyester (%)	W_a (g)	W_b (g)	W_m (g)
1	0	0	100	0	0	300
2	4	0	96	12	0	288
3	6	0	94	18	0	282
4	4	2	94	12	6	282
5	4	5	91	12	15	273
6	4	10	86	12	30	258

2.2.2 FTIR analysis

Fourier transform infrared spectroscopy (FTIR) was used to determine the presence of different functional groups using an infrared spectrum of absorption, emission and photoconductivity [25]. FTIR spectrum analysis was performed within the range of $4,000\text{ cm}^{-1}$ and 400 cm^{-1} . This range is generally known as the mid-range of the FTIR spectrum. A Shimadzu FTIR Spectrometer (Shimadzu, Japan) was used for this study. The machine works by passing infrared rays through a specimen to a detector screen. Different functional groups absorb the infrared rays at different points of the wavenumber. The detector screen detects the percentage of absorbance of the infrared rays by a specimen. The degree of absorbance and the wave number at which the absorption occurs is analysed to determine the specimen's chemical specification. In this study, FTIR was used to determine if any newly created bonds were in the composite containing polyester, ATH and banana peel.

2.2.3 Tensile strength test

The tensile strength of a material can be defined as a material's ability to resist forces that are applied to pull it apart and its ability to stretch when put under stress. It is determined by measuring the required force to break a sample, and the modulus and elongation percentage of a material before it is broken. The calculation is performed based on the relation between the required force to break a samples with respect to the thickness and width thereof. For this study, the tensile strength was measured using a universal testing machine (UTM, Hounsfield, England) according to the ASTM D638 standard method.

2.2.4 Impact strength test

The impact strength of a material its resistance to any specific impact. This test was performed using the Izod impact testing method according to the ASTM D256 test standard. A universal impact tester (Qualitest, USA) was used for the test. The specimens were placed against a pendulum weighing 634 kg. The initial angle of the pendulum was 150° . The degree to which the specimen breaks when hit by the pendulum was calculated. Impact strength was then calculated from the resistance of the specimen. The lower the degree to which the pendulum breaks the specimen, the better the impact strength. The pendulum hits the specimen and then tries to

reach the opposite end through the force (torque) created by movement of the pendulum itself. If the specimen offers high resistance, the pendulum fails to reach the opposite end; instead, it reaches a mark on the other end. That point is checked, and the angle at which the pendulum reaches the mark indicates the specimen's impact strength.

2.2.5 Flexural strength test

Flexural strength is defined as the stress in a material just before it breaks when being bent [26]. This test was performed according to ASTM D790 method using a UTM (Hounsfield, England). A three-point bending system was used for this study. The distance between the lower two points was set to 100 mm. In this method, the two ends of the specimen were bent upwards by applying pressure at the middle of the specimen using the third point that forced the midpoint to go down and eventually break the specimen [27].

2.2.6 Flame retardancy test

Flame retardancy or resistance is the measure of a material's burning rate or its behaviour when exposed to fire. This property was tested using three methods: two burning behaviour tests and an oxygen index test. The burn tests were performed according to the ASTM D3801 and ASTM D635 standards using vertical and horizontal burning method instruments. The oxygen index measurement test was performed according to the ASTM D2863-19 standard.

Vertical burning method

The burning rates of the materials and dripping tendency were checked based on this test, which was performed using a Horizontal and Vertical Flame Test Apparatus (Testech, China). For the vertical test, the sample size to be chosen was $13\text{ mm} \times 125\text{ mm}$, with 6 mm of the sample clamped inside the clamp that held the sample vertically. A cotton layer measuring $50\text{ mm} \times 50\text{ mm}$ was placed 300 mm below the sample to detect any dripping of the sample during burning. The specimen was initially exposed to a 20 mm high blue flame from a gas burner for a maximum of 10 seconds. The specimen was then removed from the flame and the self-extinguishing time of the specimen was measured, if self-extinguishing occurred. In the case of self-extinguishing, the specimen was re-exposed to flames according to the previous step and the duration of

Table 2: Classification of materials in terms of flame retardancy in the vertical burning test

Criteria	Rating			
	V-0	V-1	V-2	V-HB
Required time for burning of each individual test specimen (In seconds after first and second application of flames)	≤ 10	≤ 30	≤ 30	N/A
Total required time for burning (In seconds)	≤ 50	≤ 250	≤ 250	N/A
Time of burning and afterglow after second flame application (In seconds)	≤ 30	≤ 60	≤ 60	N/A
Dripping from burning specimens (Ignition of the cotton layer)	No	No	Yes	N/A
Combustion up to the holding clamp (In case of the specimens being completely burned)	No	No	No	Yes

self-extinguishing was again calculated. If self-extinguishing did not occur again, the material was put subject to the recommended horizontal burning test. The cotton layer placed below the specimen was checked to detect dripping. All of the results were then compared with the material rating Table 2 to categorize the specimen. The test was performed inside a closed box.

Horizontal burning method

The burning rate of the material in mm per minute was calculated based on this test. The higher burning rate of a specimen means higher material flammability and vice versa. The sample size for this test was 125 mm × 12.5 mm. The samples needed to be marked at 25mm and 100mm from one end. The specimen was clamped horizontally at an unmarked end. A 100 mm square wire gauze screen was placed beside the specimen to check burning behaviour. The marked end of a specimen was exposed to a 20 mm high blue flame from a gas burner for a maximum of 30 seconds or until the flame reached the 25 mm mark of the specimen, whichever occurred first. The time required for the flame to travel from one end to the opposite end where a mark was made at a distance of 100 mm was measured [13]. The behaviour of specimens was then compared with the following ratings shown in Table 3 for the purpose

of categorization. A Horizontal and Vertical Flame Test Apparatus (Testech, China) was used for this test.

Limited oxygen index test

A limited oxygen index test (LOI) was performed to determine the required minimum oxygen level to burn a material [28]. There is about 21% of oxygen on average in the earth's atmosphere. Thus, if a material requires more than 21% of oxygen to burn continuously, that material will not catch fire or extinguish a fire itself, and can be labelled self-extinguishable. Moreover, a material can be labelled as non-ignitable if it requires more than 21% of oxygen to ignite [10, 28]. A higher LOI value is therefore better [29]. The materials were exposed to vertical flames under the combined flow of oxygen and nitrogen. The required concentration of oxygen to burn the material was then calculated as a volume percentage. A Testech Limited Oxygen Index Tester (Testech, China) was used for the test. The specimen size was 100 mm × 10 mm. The specimen was ignited manually after being placed in a specimen holder. The burning took place using a nitrogen and oxygen gas flow. The fractional value of required oxygen was calculated from the machine reading.

Table 3: Rating of flame retardancy in the horizontal burning test

Rating	Criteria
1	No signs of combustion were visible after removing the ignition source.
2	The flame did not go beyond the 25 mm reference mark.
3	The flame went beyond the 25 mm reference mark but did not reach the 100 mm reference mark.
4	The flame reached the 100 mm reference mark, but the calculated linear burning rate did not exceed 40 mm/min for specimens having a thickness of 3–13 mm or 75 mm/min for specimens having a thickness of less than 3 mm.

2.2.7 Thermal degradation test

Thermogravimetric (TG) analysis is a technique used to monitor the mass of a substance as a function of temperature or time. In this method, the specimen is subjected to a controlled temperature regime in a controlled atmosphere to check mass loss as the result of an increase in temperature. For this study, this test was performed using a SII Exstar 6000 TG/DTA instrument (Seiko Instruments Inc., Japan). The maximum temperature range was set to 600°C at increments of 20°C/min. The temperature was applied using a nitrogen gas flow. Aluminium was used as reference material. Another thermal property tested in this study was differential thermal analysis (DTA), which is the ratio of the temperature difference of the specimen and reference material relative to time or temperature. This test is an indicator of heat or energy absorption (endothermic) or production (exothermic) during a specimen's heat treatment. A flame-retardant material will always need to show an endothermic or heat-absorbing ability, which was checked using this test method. Derivative thermogravimetric (DTG) analysis is another measurement technique that determines a material's weight change rate relative to temperature [30]. The rate of weight change increases at a brisk rate when the decomposition of the main components takes place. This measure also indicates the rate of decomposition and the range of temperatures at which the materials decompose under heat.

3 Results and discussion

The samples were subjected to several tests. The main concern was a composite's mechanical properties after incorporating in the polyester resin two foreign materials that do not match the polyester polymer. First, a composite containing both ATH and banana peels, together with polyester, was compared with a pure polyester board to determine if any new bonds were created during the curing process of polyester using the FTIR method. The materials were then subjected to mechanical tests to determine the possible ratios used without deteriorating the material's mechanical properties too much. Lastly, the materials were subjected to a flame retardancy test to determine if the combinations chosen from the previous test could maintain the flame-retardant property within an acceptable range. The final composite sample's thermal properties were also compared to the pure polyester

sample to see if the incorporation made any changes to the two new materials.

3.1 FTIR analysis

Sample 1 (100% polyester) and Sample 6 (85% polyester, 4% ATH and 8% banana peels) underwent FTIR analysis in this test. The FTIR spectrum from the tests is shown in Figure 1.

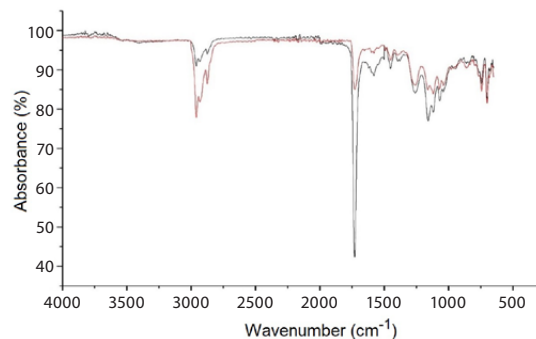


Figure 1: Spectrum of FTIR analysis

Here, the black line in the the FTIR spectrum refers to Sample 1 and the red line refers to Sample 6. The spectrum of Sample 6 showed no new bonds formed between the polyester, ATH and banana peels. The peaks were almost the same in the two graphs. The peaks around 3000 cm^{-1} indicate the presence of hydrogen bonds or, more specifically, the presence of -H and -OH functional groups. The presence of both cellulose and aluminium trihydrate affected this peak's rise, as both contain a high percentage of -OH in the structure. A peak in the range of 1700–1750 cm^{-1} indicates the presence of ester bonds or groups. The few peaks in the fingerprint range (below 1500 cm^{-1}) are also almost the same in the two graphs. The main differences between the two samples are the intensity of peaks, especially the ester bond's peak. The significant reduction of the peak in Sample 6 was because the newly included ATH and banana peel materials resisted polyester molecules to form bonds in between them. Some other peaks were also identified at a lesser intensity, reducing the bonds between the polyester molecules. This means the resulting materials are expected to show deteriorated mechanical properties. Another point can be made: there are no new bonds in the new material. This means that the ATH and banana peels have remained more or less unaffected in terms of chemical properties. As a rule, this will allow both the ATH and banana peels to resist flames.

3.2 Effect of ATH loading on the tensile properties of composites

ATH and banana peels were mixed in the polyester in powder form and ground matter form, respectively. Neither of the materials were dissolved in polyester. Instead, they helped to produce a dispersion-like mixture. The viscosity of the solution was increased with the increasing amount of ATH powder. The tensile test results are shown below in Figures 2, 3 and 4.

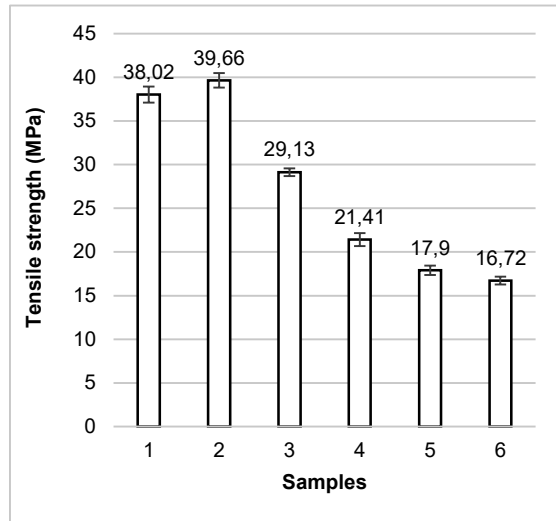


Figure 2: Effect of the addition of ATH and banana peels on tensile strength

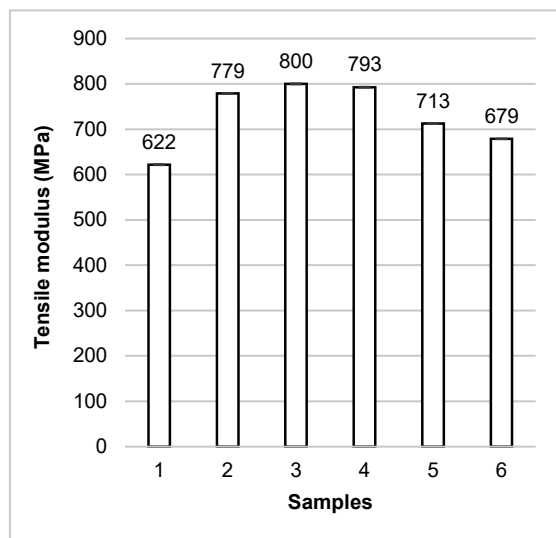


Figure 3: Effect of addition of ATH and banana peels on tensile modulus

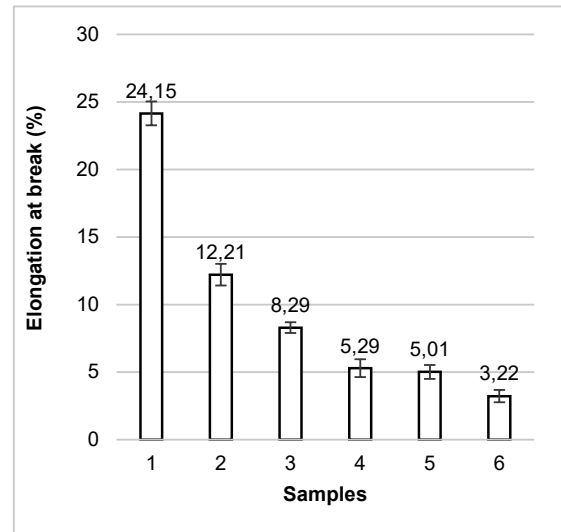


Figure 4: Effect of the addition of ATH and banana peels on elongation property

The results in Figure 2 show that using ATH with polyester improved the tensile properties of the samples at the beginning, only to see a deterioration with the further addition of ATH. At the same time, the introduction of ground dry banana peels reduced the tensile strength further. Polyester resin became viscous with the addition of ATH. The formation of a homogenous dispersion of polyester and ATH made the material viscous and presented a more uniform and compact structure at the beginning, which helped increase the tensile strength. The dispersion was able to be cured quickly into a hard and brittle material [21, 31]. The improved rigidity can also be confirmed by the tensile modulus results of Figure 3, where Sample 2 (containing 4% ATH) and Sample 3 (containing 6% ATH) showed superior tensile modulus. The material's hardness also improved the tensile strength of the composite at the beginning with the addition of 4% ATH. Later, however, the too-high brittleness and reduced extensibility of the material caused quicker breakage under stress because in the test of tensile properties, stress is applied uniformly onto the whole cross-section of the structure, and every pore or impurity within the cross-section affects the tensile properties of the material. As a result, the tensile modulus increased. The same trend can also be seen in the elongation property of the material in Figure 4, where a gradual decrement of elongation property can be seen due to the addition of ATH. However, when the granules of banana peels were intro-

duced, the tensile strength fell further due to the presence of more impurities within the cross-section. The banana peels actually worked more like a filler than a reinforcing fibre. However, the banana peels were not expected to improve mechanical properties because fibres with a high lignin content in their structure generally struggle to make mechanically bonds with hydrophobic polyester, which cannot impregnate fibres or fillers containing lignin [32]. Although banana peels do not contain that much lignin, dried banana peels presented a surface that was difficult to be impregnated with polyester. Moreover, when there were no chemical bonds (as found in the FTIR analysis) and strong mechanical bonds between the filler and resin, the increased number of pores within the structure due to the presence of banana peel instead reduced the close bonds between polyester molecules. As a result, the composite gradually became fragile. However, nature of the materials did not help the tensile strength thereof. For this reason, the tensile strength decreased with the addition of banana peels to the structure.

Tensile modulus and elongation properties followed the same trend as tensile strength. Tensile modulus depends on the stress and strain on a material. Stress mainly depends on the required load to break a material, while strain is an indicator of a material's extensibility or elongation property. The strength of the samples increased with the addition of ATH, while the elongation property deteriorated from the beginning to the end due to increased hardness when ATH was added and then due to a lack of bonds between polyester molecules when banana peels were added together with ATH. As mentioned earlier, the addition of banana peels made the polyester a bit fragile due to a lack of bonding action between the polyester molecules. It caused the early breakage of materials when put under stress. The modulus decreased gradually as a result. On the other hand, the elongation property also deteriorated gradually and at a higher rate than tensile strength.

3.3 Impact strength test

The impact strength of a composite depends heavily on the aspect ratio of the reinforcing fibre and filler. The bonding between the additional materials and the resin is also essential. The results of the impact strength test of the samples are shown in Figure 5 below.

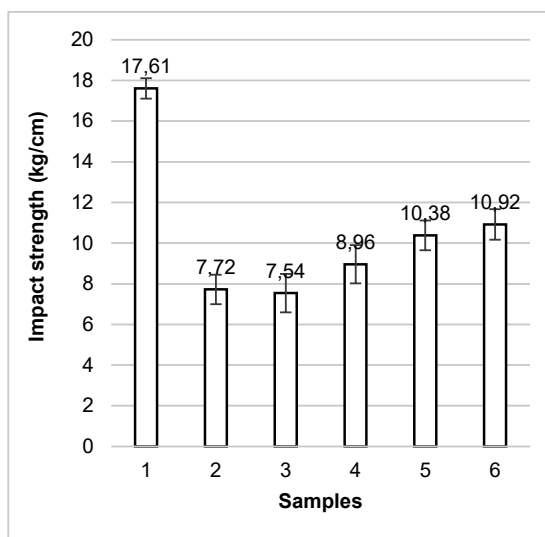


Figure 5: Effect of addition of ATH and banana peels on the impact strength of composites

The impact strength of the composites was affected significantly by the addition of ATH and banana peels. Results show that the impact strength decreased with the addition of ATH and improved again when banana peels were added. Impact strength is greatly affected by the bonding between matrix molecules and a matrix's fracture property [33]. The addition of ATH and banana peels reduced the bonds between the polyester molecules, but ATH had the most negative effect. When ATH was mixed with polyester at the beginning, it formed a homogenous dispersion with increased polyester viscosity, making the resulting composite material harder and slightly brittle. It also affected the fracture property of the composite negatively and resulted in a gradual decrease in the impact strength of the composites. When banana peels were added, however, the strength improved. Both ATH and banana peels worked more like filler materials in the composites. The fibrous materials helped reduce the impact of ATH powder on the structure. The impact strength test does not cover the full cross section of the material, but instead depends more on the specific positions of the composite that comes under the impact. The addition of rough fibrous materials of various lengths resisted the production of homogeneous dispersion similar to the samples that contained only ATH. The tendency of the powder to adhere to the rough fibrous surfaces also helped keep the ATH powder around the fibrous materials more than powder uniformly throughout the polyester [34]. It allowed the polyester molecules to come

closer to form stronger bonds. Moreover, an impact test generally focuses on the surface of a material where the initial impact is made, where the presence of fibrous materials allows the polyester molecules to cover the full surface. Since the entire test does not depend on the whole cross-section of the material, the number of possible pores per unit area on average created by the presence of ATH fell. Instead, the adherence of ATH powder to the surface of the fibrous materials allowed the formation of typical bonds between the polyester molecules that would be suffice to increase the impact strength of the materials. The gradual increase in fibrous materials helped increase impact strength for the above-stated reasons. The addition of banana peels improved the impact strength of the composites. The same trend was recorded for the addition of 10% fibre, where the impact strength increased slightly. The ability of the filler or fibre to absorb impact also helps the process, as the low-density banana peel materials covered more spaces and were able to absorb the impact better than the brittle polyester resin. The soft nature achieved by the addition of banana peels was also played a role in this regard.

3.4 Flexural strength test

The flexural strengths of composites are shown in Figure 6.

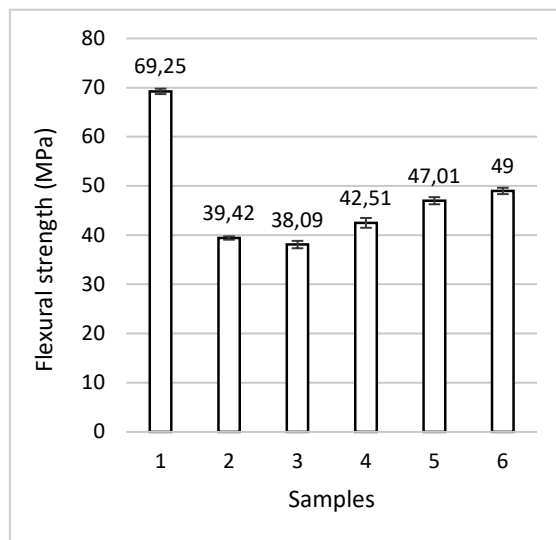


Figure 6: Effect of the addition of ATH and banana peels on the flexural strength of composites

The results show that flexural properties were very significantly affected by the addition of ATH and banana peels. The flexural strength was reduced

drastically by the addition of ATH. On the other hand, flexural strength improved a bit gradually when the banana peels were added, together with the ATH. The ATH and banana peels both acted as foreign materials in polyester resin, which could not impregnate the materials; both acted as filler materials instead. These materials thus reduced some bonds between polyester molecules. To improve the flexural property, the composite had to become softer rather than hard and brittle. The addition of the ATH, however, resulted in the formation of a more homogeneous dispersion, where the disruption in bonds of polyester molecules took place uniformly. On the other hand, adding banana peels made the ATH adhere to its surfaces more than in a uniform dispersion in the mixture. It also resulted in an increase in uninterrupted bonds between polyester molecules in places, especially at the surface. The high density of banana peels actually made the materials remain inside the structure rather than at the surface of the composite [35]. A three-point flexural test initially puts the stress onto the surface of a material, and then the stress spreads within the structure. It allows the structure to withstand initial stress due to the presence of intra-bonded polyester molecules, resulting in better flexural resistance and better elastic properties. When the stress spreads within the whole structure gradually, and because the presence of the fillers actually makes the material softer due to a lack of bonds within the structure between polyester, the softness of the banana peels helps to absorb stress put forth in the flexural test better than pure polyester. The percentage of banana peels in this study is quite low, which is also the reason for this type of material characteristic. As a result, the addition of banana peels gradually increased the material's flexural strength, which could not surpass the flexural strength of pure polyester, but showed better results than materials containing only the ATH. The further addition of banana peels could have reduced the flexural strength due to the extension of the molecular bonds of polyester beyond the limit, but this concept was not tested in this study.

3.5 Flame retardancy tests

The results of these tests are shown in four parts. In the first part, the vertical burning behaviour of the materials was checked. The materials that failed the vertical test were then subjected to the horizontal burning test. The first step of this part was

to determine if the materials could be considered flame retardant, even after the modifications made by adding ATH and banana peels. These results are shown in Tables 4 and 5, and in Figure 7. The LOI was then tested for Samples 1, 5 and 6, and the results of that test are given in Table 6.

Since all the samples failed the vertical burning test, the samples had to undergo the horizontal burning test. Table 5 below illustrates the horizontal burning test results.

All the samples self-extinguished within 10 seconds when first exposed to flames. The second time, however, the samples could not self-extinguish, and the entire samples were burned as a result. No dripping occurred, but ashes were produced. Since the materials fell only into the UL 94 HB rating category, all of these materials have the least flame-retardant property, i.e. they were not very flame-retardant. Instead, they burned slowly for quite a long period. The degree of horizontal burn rate varied with the specifications of the composite materials. The horizontal burning rates of the materials during the test are shown in Figure 7.

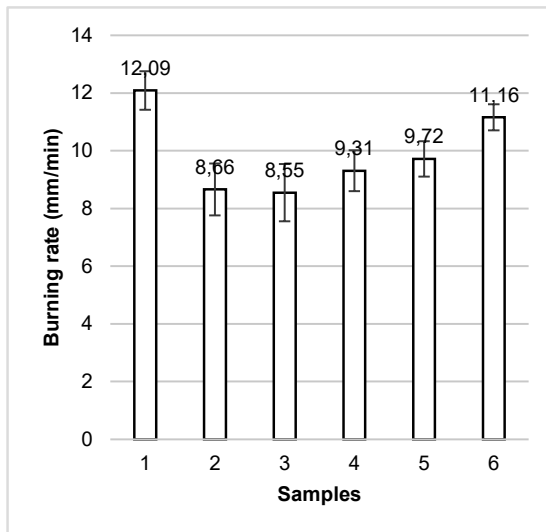


Figure 7: Effect of the addition of ATH and banana peels on the burning rate of composites

The results presented in Table 4 show that all the materials fell into the 4th or last category of flame-retardant materials (because they had a linear burn rate below 40 mm/min). The results in Figure 7

Table 4: Vertical burning behaviour of composites

Sample no.	UL 94 Rating				
	Burning stops within 10 seconds with no dripping	Burning stops within 30 seconds with no dripping	Burning stops within 30 seconds with dripping	Rating of samples	
	UL 94 V-0	UL 94 V-1	UL 94 V-2	Vertical burning rating	Recommended for horizontal burn test
1	No	No	No	UL 94-V	UL 94 HB
2	No	No	No	No	Yes
3	No	No	No	No	Yes
4	No	No	No	No	Yes
5	No	No	No	No	Yes
6	No	No	No	No	Yes

Table 5: Horizontal burning behaviour of composites

Sample no.	Continuous burning of samples (Yes/No)	Flame reached 25 mm mark (Yes/No)	Flame reached 100 mm mark (Yes/No)	Linear burn rate exceeded 40 mm/min mark (Yes/No)	Rating of samples	UL 94 rating
1	Yes	Yes	Yes	No	4	HB
2	Yes	Yes	Yes	No	4	HB
3	Yes	Yes	Yes	No	4	HB
4	Yes	Yes	Yes	No	4	HB
5	Yes	Yes	Yes	No	4	HB
6	Yes	Yes	Yes	No	4	HB

Table 6: Limiting oxygen index (LOI) of composites

Sample no.	ATH (%)	Banana peels (%)	Polyester (%)	LOI (%)
1	0	0	100	19.1
5	4	5	91	19.5
6	4	10	86	19.2

show that the addition of the ATH improved flame-retardant properties, as flame spreading was reduced by the action of the ATH, which resulted in a reduction in the burning speed. However, the addition of banana peels increased the burning rate again gradually. The ATH was expected to improve flame retardancy, as it releases water during combustion and reacts endothermically during the reaction [10]. The samples containing the ATH absorbed the fire's heat and became hot, which resulted in the release of water molecules that delayed the burning rate, as seen in Figure 7. When the banana peels were added, however, the burning rate rose as expected. Even though the presence of cellulose could be useful for producing char and reducing the burning rate, the easily flammable small amount of cellulosic material could not produce a sufficient amount of char to improve the flame retardancy of the materials. The small amount of banana peels caught fire more easily and burned very quickly, as cellulosic materials are expected to be burn easily and quickly by nature. It could only help flame retardancy by producing a high amount of char, which did not happen. At the same time, the presence of moisture in the structure could have helped, but the moisture was dried during the drying of the banana peels and the heat produced during the curing of polyester. Instead, highly flammable carbohydrate parts made the materials more flammable. The percentage of ATH could have been increased to improve flame retardancy, but to do so, the mechanical properties and the composite price had to be sacrificed.

The expected results were thus achieved, as the addition of the ATH reduced flammability slightly, as evident in Figure 7, where the burn rate was found to be a bit lower for Samples 2 and 3. However, the

addition of banana peels increased flammability as expected. If the banana peels had been added alone, flammability would have increased more significantly, but the presence of the ATH kept the flammability of the composite below the original rate of pure polyester. The LOI test results shown in Table 6 also support this concept. The increase in the LOI value indicated the improved flame retardancy of the material. The values are almost identical here for Samples 1, 5 and 6. The LOI increased slightly after the addition of the ATH and 5% banana peel, and it decreased further by increasing the amount of banana peels. Nevertheless, the results were slightly better than pure polyester, but the difference was too small. It can be said instead that the flammability of polyester did not change due to the addition of banana peels in the structure since cellulose and similar materials (such as starch, carbohydrates, hemicellulose, etc.) are generally very flammable and have LOI values of around 18 [10]. This LOI is lower than the polyester used in this study. This means the newly formed composite would become more flammable due to the addition of banana peels in the structure. To stop that trend, a small proportion of ATH was added to the structure, and it successfully maintained flammability within a similar range for the composite.

3.6 Thermal properties test

The thermal properties of TG and DTA were tested for Samples 1 and Sample 3 to compare the results. The TG and DTA analysis results are shown in Table 7 and Figures 8–10.

The results are almost the same in thermogravimetric analysis (TG), as shown in Table 7. The onset and endset temperatures of all the samples were almost same, while the peaks followed the same

Table 7: Thermogravimetric analysis results of the composites

Sample no.	T_{onset} (°C)	T_{endset} (°C)	T_{max} (°C)	Residue at 600°C (%)
1	390.6	430.1	418.4	0
2	388.2	429.5	408.2	0
6	387.2	436.6	415.8	4.19

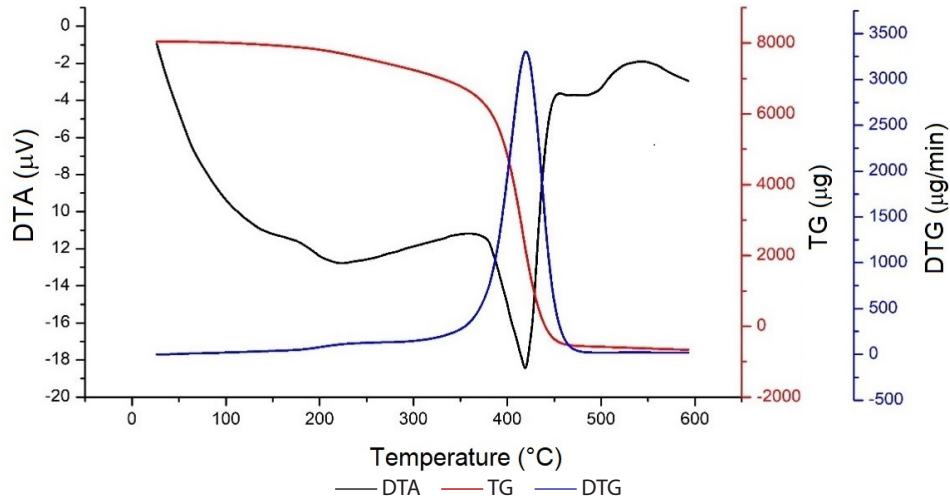


Figure 8: TG-DTA-DTG analysis curves for Sample 1

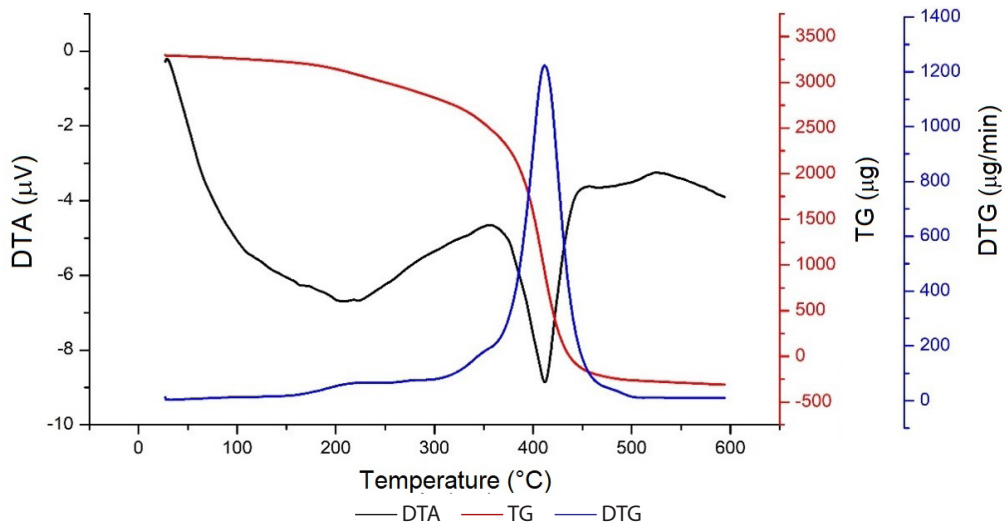


Figure 9: TG-DTA-DTG analysis curves for Sample 5

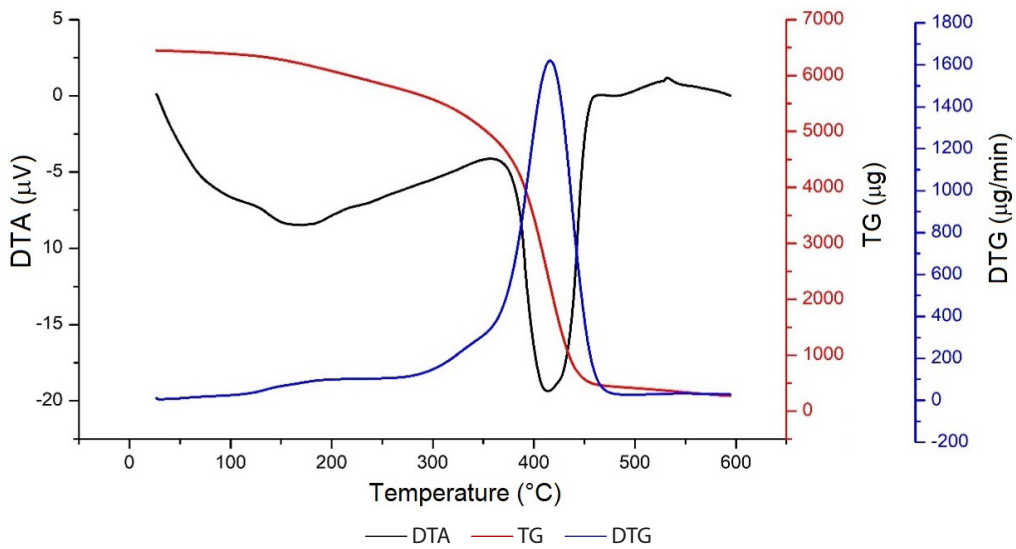


Figure 10: TG-DTA-DTG analysis curves for Sample 6

trend. However, there were a few differences as the onset mark had only about 70% weight of the material for Sample 1, containing polyester only, while Sample 2 and Sample 6, containing polyester, ATH and banana peels, recorded a material weight loss of around 35–38%. The percentage of weight loss increased due to the presence of moisture in the banana peels, which evaporated during heating and resulted in a loss of weight in the samples. In the beginning, moisture drying took place. The thermal degradation of polyester then started at around 390°C for all the samples. The addition of the ATH or banana peels did not affect the onset temperature much, but the weight loss percentage decreased in Sample 2 and Sample 6, as both samples had a smaller amount of filler materials. The ATH was also expected to evaporate by the time the onset temperature was reached because the ATH decomposed at about 180–200°C, resulting in a further decrease in the weight of the composites in Sample 2 and Sample 6. In that sense, both materials should record the same time and range of temperature during decomposition, as both contain a same amount of ATH. In reality, the weight loss in TG curves showed similar trends in all the materials. The onset and endset temperature, and the peak temperature all remained around same. This occurred because the filler percentages were too low to have any significant effect, but the difference between the samples can be assessed by looking closer look at the TG curve. Sample 1 is pure polyester, which showed minimal decomposition until a temperature of around 390°C, while the other two samples contained the ATH and banana peels. Both these materials are expected to decompose before 350°C. If the weight loss is assessed, it can be seen that Sample 1 has undergone very few changes in terms of weight until 350°C, with a weight loss percentage of around just 12%. In the case of Sample 2, however, the weight loss percentage rose to around 20% due to the evaporation of the ATH from the structure. Sample 6 contained banana peels, which increased weight loss to about 22%, indicating the decomposition of the cellulosic contents within the structure. However, the difference between Sample 2 and Sample 6 is less than the percentage of banana peels being added to the structure because of the formation of char, which is also evident in the end of the cycle, as Sample 6 produced about 4% of char. The results of TG thus confirm the presence of all the materials as expected. The DTA curves of

Sample 2 and Sample 6 showed an endothermic reaction in the curve at around 200°C. Interestingly, pure polyester also showed an endothermic curve at the same temperature also later, while the second dip is also an indicator of a more endothermic than exothermic reaction. This means that polyester itself can absorb some heat and may not be too flammable.

Meanwhile, the DTG showed a significant increase in the rate of weight loss within the onset and endset temperatures, as expected, but there was a slight increase in the rate of weight loss near 200°C for Samples 2 and 6 relative to Sample 1 due to the presence of ATH in Samples 2 and 6. The banana peels did not have a significant impact, while the rise in the curve was lost with an increase in the weight loss percentage during the subsequent degradation of the polyester. However, the addition of the ATH and banana peels reduced the rate of weight loss in both samples drastically relative to Sample 1, where the rate of weight loss in terms of time was relatively high (more than 3000 µg/min), while it was around 1200–1500 µg/min in Sample 2 and Sample 6. Thus, the addition of the ATH and banana peels did not significantly affect the final properties of the composite material relative to the pure polyester. At the same time, there was no adverse effect. Instead, the thermal resistance was slightly better in Samples 2 and 6 than in pure polyester. The main aim of this study, which was to maintain unchanged properties of polyester due to the addition of foreign materials in the structure, was successfully achieved in terms of thermal properties.

3.7 Comparative analysis of results

The results of this study indicate that success was achieved to some degree, but there were also some deficiencies. The mechanical properties began to deteriorate drastically when fillers were added to the structure. To maintain the considerable strength of mechanical properties, the amounts of filler materials were compromised. The aim of the study was to use banana peels in a composite with polyester, without not affecting the properties of the polyester. The resulting material of this study showed a significant change in mechanical properties due to the addition of banana peels. However, the thermal and flammability properties of the composites were maintained almost unchanged through the addition of the ATH, together with banana peels. The absorbency property showed a

slight but not significant improvement because the polyester was an absolutely non-absorbent material. The mechanical properties could not be maintained unchanged because of the inability of the process to form any chemical bond between the resin polyester and banana peels. The different natures of the two materials also played a part in this trend. The only way to retain or improve the tensile properties of the composite was the surface modification of the banana peels to make them compatible with polyester. Since this was not done, the results in terms of mechanical properties were more or less expected. However, success was achieved in terms of maintaining the thermal and flammability properties of the composite unchanged relative to the pure polyester. If the results are compared with some previous studies, it is possible to say that this study was successful.

Many researchers have proven that it is very difficult to improve the tensile properties of a natural fibre-reinforced synthetic resin composite because

of the lack of chemical bonding between fibre and matrix molecules. Surface treatment, however, has very often produced positive results [6, 36, 37]. On the other hand, the use of flame-retardant type filler materials also affected the tensile properties of composites according to previous reports. A small comparison has been made in the two Tables (Table 8) below to determine the reliability of these claims. Table 8 compares the mechanical and flame-retardant properties of a few composites. Many researchers have not used banana peels. For this reason, only one similar type of composite by Luthra et al. but made of polypropylene was selected in this comparison part [38]. Another study was done by Sain et al. using a similar product, sawdust powder, and metallic hydroxide magnesium hydroxide as the filler, was used in the comparison [13].

Two other studies were also selected for the effect of flame-retardant filler materials only. He et al. produced unsaturated polyester composites using organic magnesium hydroxide as flame-retardant

Table 8: Comparison of mechanical and flame-retardant properties with other researches

Researches	Sample composition						Properties			
	Type of resin	Resin (%)	Filler or reinforcement (F/R)				Tensile strength (MPa)	Flexural strength (MPa)	UL 94-V rating	LOI
			F/R 1 (%)	F/R 2 (%)	F/R 3 (%)	F/R 4 (%)				
This study	Unsaturated Polyester	100	---	---	---	---	38.02	69.25	HB	19.1
		96	4	---	---	---	39.66	39.42	---	---
		91	4	5	---	---	17.9	47.01	HB	19.5
		86	4	10	---	---	16.72	49	HB	19.2
Sain et al. [12]	Polypropylene	97.5	---	---	---	---	22.6	39.5	---	25
		47.5	25	25	---	---	28.8	56	---	35
		47.5	25	20	5	---	26.4	53.1	---	26
		47.5	25	20	---	5	28.2	55	---	30
Luthra et al. [38]	Polypropylene	100	---	---	---	---	33	37.9	---	---
		90	10	---	---	---	27.8	36	---	---
		80	20	---	---	---	26.3	38.8	---	---
		70	30	---	---	---	24	38.2	---	---
Chen et al. [39]	Unsaturated polyester	100	---	---	---	---	31.9	52.1	HB	19.2
		90	10	---	---	---	27.6	48.6	V-1	22.3
		70	30	---	---	---	20.5	40.4	V-0	27.8
		70	---	7.5	15	7.5	18.7	35.1	V-0	25.7
He et al. [37]	Unsaturated polyester	100	---	---	---	---	---	35	---	20.5
		96	4	---	---	---	---	35	---	20.5
		93	1	6	---	---	---	21	---	26.4
		91	1	8	---	---	---	20	---	28.5

filler and expandable graphite for comparison [37]. Chen et al. produced microencapsulated flame-retardant filler to improve the flame retardancy of unsaturated polyester composites [39]. They used Ammonium polyphosphate (APP), Diatomite (Dia), and Triphenyl phosphate (TPP) as flame retardant fillers. They also produced a microcapsule of TPP filled with APP and Dia, and used that as a flame-retardant filler material with good effect.

The results vary significantly in the studies mentioned above for various reasons. All the researchers used different combinations and contents. The general points that can be made after reviewing the above comparison in Table 8 are as follows:

- i) Mechanical properties are generally affected negatively by the addition of flame-retardant filler materials, except when surface modification of the filler material is performed.
- ii) The percentage of filler must be much higher to significantly impact the flame-retarding property of the composites.
- iii) The type of flame-retardant filler changes the impact on flame retardancy, as not all fillers have a similar flame-retarding or resisting ability.

The addition of both reinforcements and filler materials has a significant impact on the mechanical properties of the composites. Generally, that impact is negative. Associating any material with polyester is always difficult because it does not allow other materials to create chemical bonding with its molecules. This is due to the thermoset nature of the material. Creating any chemical bond requires the application of heat and pressure to a much higher degree. Instead, the thermoset polyester is cured at room temperature or at a maximum of around 80–100°C [39, 40]. This temperature is insufficient to initiate any chemical reaction that can create new bonds with other materials. Moreover, its hydrophobic nature does not allow any materials to enter its structure, while other materials are difficult to associate with it. For this reason, mechanical properties always deteriorate with the addition of reinforcing or filler materials, which are always foreign materials to the polyester molecules. These materials cause a resistance between polyester molecules, which results in the de-bonding of the polyester molecules in the structure. This was the case in this study and in other studies that were discussed earlier [37, 39]. The only way to improve or retain the

mechanical properties of polyester, even after the addition of other materials, is through surface modification or the use of coupling agents, which helps to make the additional materials more similar in terms of surface characteristics [12, 40].

Compared to the other studies, adding a small amount of filler generally found in powder or nanoparticle forms does not have a significant effect on mechanical properties. When higher percentages are introduced, however, mechanical properties deteriorate drastically. The addition of fibrous materials, which are generally more hygroscopic, i.e. the opposite of the characteristics of polyester, has a greater effect on mechanical properties than fillers [32, 41]. It also depends on the size of the fibrous materials, if they are used without being converted into nanomaterials like in this study, where the banana peels were ground but still took the form of large particles because banana peels are not finer materials (particle size varied from 150 to 400 μm), while the aluminium trihydrate particles were much finer (around 5 μm). For this reason, the negative effect was more drastic than the filler materials, while aluminium trihydrate did not have any adverse impact. According to some researchers, particle size is also an essential issue in terms of the flame retardancy of a composite, as some reports suggest that smaller filler particles fared better than larger particles. This was mainly due to the cover effect of smaller particles, which could cover more area in the structure than larger particles and helped to reduce flame resistance [42]. Moreover, the smaller particles could produce a layer within the polyester structure that served as a heat barrier. For this reason, smaller particles are preferred as flame retarding agents for maintaining a composite's mechanical properties.

Another reason for poor mechanical properties is the curing agent used in this study, i.e. methyl ethyl ketone peroxide, which is a powerful agent and performs curing at room temperature within a minimal duration. It helps to create more uniform and stronger bonds between polyester molecules. At the same time, however, this type of curing agent gives very little time to form proper mechanical bonds when foreign materials are inserted between the polyester molecules. On the other hand, benzoyl peroxide is another curing agent used in several studies that require around 80°C. It also requires more than an hour to cure. It gives more time for the foreign materials to settle in the structure. This

problem can still be avoided by using proper pressure during curing. Since the materials were produced using a hand lay-up process, the parameters could not be maintained as well as required, which caused a drastic deterioration in tensile properties when fibrous materials were added to the composites. Nevertheless, due to the use of a small amount of filler and fibrous materials, the mechanical properties remained similar to another research that was within the relevant range.

The LOI obtained in this study was too low, and the composites in this study cannot be deemed flame retardant at all. This is due to the use of a very small amount of flame-retardant filler, while one of the few possible outcomes of the enhanced flame-retarding property of the composite due to the high percentage of moisture trapped in the banana peels or the possible char forming ability of banana peels did not materialize. Instead, the other expected outcome of increased flammability materialized in the composites in this study. However, the presence of ATH as filler resulted in almost unchanged flammability, but did not have any further effect, either. For this reason, the composites in this study could not reach the level of a flame-retardant composite. The studies reduced the polyester percentage by a considerable amount to achieve the best results. Chen et al. used only about 70% resin and introduced about 30% flame-retardant filler materials in the structure of the composites [40]. The resulting materials fared considerably better when higher percentages of flame-retardant fillers were introduced. The composites in this study showed the least flame-retardant property, as all the materials fell into the horizontal burning category in the UL 94-V test. In contrast, other studies recorded a significantly better property, as V-0 and V-1 ratings were achieved by Chen et al. in their respective studies [40]. The minimum amount of filler required to attain a V-1 rating was 10% [39]. For further improvement, about 30% of fillers were required by both Jiang et al. and Chen et al. [40]. They introduced different combinations to achieve that level. Also worth of note is that they showed that combinations of different fillers were required for the best results instead of a single filler. A combination of several fillers can give a synergistic effect and enhance the power of the fillers. Otherwise, more than 30% would have been required to achieve a similar effect if the fillers were used alone, as different studies showed that more than 30% of fillers were required to have

any significant effect on flame-retarding properties [43, 44]. On the other hand, char-forming ability could also significantly improve the flame-retardant property of a material, as shown by Sain et al. [13]. The formation of a non-flammable layer by the char can disrupt the flow of flame and can readily reduce the flame. However, the banana peels used in this study could not produce the amount of char required, possibly due to the low percentage. Sain et al. used surface modification to use a higher percentage of fibre without damaging the mechanical properties of the composites. In this study, however, the fibre percentage could not be increased up to the required level due to the drastic drop in the tensile strength of the composites, which was not a surprise. There was no other option due to the aim of this study to keep the cost of the final material down.

Another critical point to be discussed is the type of filler used in the discussed composites. The ability of the fillers differs from each other. The mechanisms of different fillers likewise differ from each other, as previously mentioned above. The main designated flame-retardant filler used in this study was aluminium trihydrate (ATH), which can be classified as a medium-strength filler. Studies have shown that quite a high percentage of aluminium trihydrate is required (equal to or above 30%) to have a better impact on the flame-retardant properties of a composite [43–46]. The thermal stability of aluminium trihydrate is also on the lower side as the 1st step of decomposition takes place at around 200°C when the water molecules are released [47]. Even though the 2nd step of degradation or the full degree of disintegration takes place much later, at around 500°C, the main flame-resisting process takes place during the 1st step of degradation when aluminium trihydrate absorbs heat and releases water molecules [10, 47]. Similar results in the composites were obtained when another metallic hydroxide, magnesium hydroxide, was used as the filler. It also follows a similar mechanism and gives more or less similar results as aluminium trihydrate [13, 39]. From the above comparisons, it is possible to come to some conclusions regarding this study. First, the objective was to produce a cheap material containing banana peels and ATH. The results achieved in the mechanical properties test showed a significant loss of strength due to these modifications, while in the flame retardancy test, the results were not of a very high standard. However, the flame-resisting

property was still improved to a lesser degree. The reason for this was the use of a very small amount of flame-retardant filler material, and because the lignocellulosic banana peels used in this study did not have the desired effect of a high percentage of char formation, as expected. To improve the property further, the use of a higher percentage of flame-retardant filler material than in this study, or the use of cellulosic material containing a higher percentage of lignin than banana peels, or increasing the amount of the cellulosic material or replacing the filler material with a more effective filler material or materials, is recommended for future research. The true aim of this study was not to produce a flame-retardant composite, but rather to produce a cheap material using banana peels, and to keep the thermal and flammability property of the final material in check, even after modification. The tensile properties were damaged more than expected, but the thermal and flammability properties were kept within the desired range. This study can thus be deemed successful.

4 Conclusion

This study was an attempt to use banana peels to develop a polyester composite. Polyester was accompanied by ATH in different combinations. Due to the absence of newly formed chemical bonds between banana peels and polyester, the mechanical properties deteriorated drastically with the addition of ATH and banana peels. The tensile properties suffered the most with a reduction in strength of more than 50%, while flexural strength was also affected significantly for the same reason. However, the addition of fibre improved the impact and flexural properties to some extent after a drastic deterioration when the composites were made using only ATH and polyester. However, the results were still inferior to the properties of pure polyester. In terms of flame retardancy, the ATH did improve the property to a small degree when added. The small amount of banana peels proved insufficient to improve the flame-retardant properties of the materials because they produced some char. In contrast, they did not worsen flammability significantly because small quantities were used. More banana peels could not be added because of the deteriorating mechanical properties. The thermal properties proved the impact of both fillers on the composite, but no significant changes were identified with the

addition of banana peels or the filler, again due to the presence of a very small quantity. In summary, the addition of banana peels and filler materials caused a deterioration in mechanical properties relative to pure polyester, but flammability was kept in check by incorporating filler material. The cost of the final product has definitely reduced, but that came at the cost of deteriorated mechanical properties. However, the banana peels were added in a small particle form, which acted more like a filler in this study. They can be altered in future studies to determine whether banana peels in the form of a reinforcing fibre can stop the deterioration of mechanical properties or if they can improve any of the mechanical properties instead.

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