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Structural Integrity and Elasticity of Banana Fibre Effect of Blast Pressure: Understandings from Strain Test Comparisons Before and After Blast Test

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ABSTRACT

The purpose of this study is to analyse the structural integrity and elasticity of banana fibre that has been subjected to the blast effect. To accomplish this evaluation, strain tests are done before and after the blast test. The finding that the material's tensile strength was greatly enhanced was one of the most important findings that was made. As a result of being treated with a 400g blast, the pressure reached 12,482.57 MPa, but when 800 g blast, the pressure reached 24,965.15 MPa. During the tensile tests, for the sample 400 g, the maximum force was 64.81 N, and the stress was 2.16 N/mm^2. Sample 400 g had a maximum force of 137.61 N and a stress of 4.59 N/mm^2. The strain test results showed that 400 g had a maximum stroke of 1.59 mm and a strain value of 2.45%. Besides, 800 g has a maximum stroke of 0.83 mm and a strain value of 1.27%. The data thermocouple indicates that the temperature sample is 400 g, reaching a maximum temperature of 39.68°C. When it reached its greatest point, the temperature of 800 g was 38.12 °C. Based on the results of this experiment, it can be concluded that the fibre exhibited higher levels of strength and resilience when it was subjected to conditions that needed a greater amount of blasting.

Keywords: Structural Integrity, Elasticity, Banana Fibre, Blast Effect, Strain.

1. INTRODUCTION

In recent years, the study of natural fibres has gained considerable attention due to their potential in various engineering applications. Banana fibre is unique among natural fibres because of its excellent mechanical qualities, favourable effects on the environment and cost-effectiveness [1]. However, the exploration of banana fibre performance under extreme conditions, such as blast pressure, has been demonstrated and can be explored more extensively [2]. It is necessary to research the elasticity and structural integrity of banana fibre under such circumstances to promote its use in safety and defence-related fields [3]. Understanding how banana fibre performs under blast pressure can lead to the development of lightweight, sustainable, and highly effective blast-resistant materials, offering significant benefits in both civilian and military contexts.

Natural fibres are abundant, renewable, and biodegradable, typically sourced from plants, animals, or minerals, and have been used for years in a variety of applications [4]. Common natural fibres include cotton, jute, hemp, flax, and sisal, each known for specific properties that make this fibre suitable for different uses [5]. Natural fibres have seen an increase in popularity recently as industries look for environmentally friendly replacements for synthetic materials [6].

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Nowadays, textiles, automobile parts, building supplies, and composite manufacturing all utilize these fibres [7].

One of the most capable areas of research is the use of natural fibres in the development of blast-resistant materials. Traditional polyester materials are often heavy and non-biodegradable, presenting significant environmental challenges [8]. Natural fibres, however, such as banana fibre, provide a more sustainable and lightweight alternative [9]. Banana fibre extracted from the pseudo stems of banana plants is particularly important due to its high tensile strength, low density, and flexibility [10]. These properties propose that banana fibre has 529 – 914 Tensile Strength (MPa) is an excellent choice for strengthening materials that can be a protection from explosive forces theoretically important, more environmentally friendly, and efficient solution for blast protection and mechanical properties of sisal, jute, and banana fibres as shown in Table 1.

Table 1: Mechanical properties of sisal, jute and banana fibre [11].

Fibre Type	Tensile Strength (MPa)	Specific Tensile Strength (MPa)	Young's Modulus (GPa)	Specific Young's Modulus (GPa)	Failure Strain (%)
Sisal	347 -378	-	15	-	-
Jute	200 - 450	140-320	20-55	14-39	2-3
Banana	529-914	392-677	27-32	20-24	1-3

The primary objective of this research is to evaluate the structural integrity and elasticity of banana fibre when subjected to blast pressure. This involves three objectives: characterizing the mechanical properties of banana fibre, conducting experiments in blast situations to assess the fibre's performance, and analyzing the data to determine the fibre's suitability for use in blast-resistant applications.

The first objective, characterizing the mechanical properties of banana fibre is essential to understand its potential for use in composite materials. This characterization includes measuring tensile strength, which is the maximum tensile stress that the fibre can survive before failure. Understanding tensile strength is crucial for predicting the fibre's ability to hold up under stretching forces, which is vital for its performance in blast-resistant applications. Tensile testing involves stretching fibre samples at a constant rate until they break, measuring stress and strain during the process. Additionally, the elastic modulus, or Young's modulus, measures the stiffness of the material, indicating how much it will deform under a given load. A high elastic modulus means the fibre resists deformation, maintaining structural integrity under blast pressure. This is calculated from the initial, linear portion of the stress-strain curve obtained during tensile testing. Impact resistance, the ability to absorb energy and withstand sudden, forceful impacts without fracturing, is also critical.

The second objective is to conduct experiments by blasting conditions and assess the fibre's performance, which involves creating a controlled environment that replicates high-pressure waves and rapid deformation forces typical of a blast. This includes using Pentaerythritol tetranitrate (PETN) detonator No.8, explosive charges (Emulsion), and thermocouples to capture real-time temperature data during blast testing. Preparing banana fibre samples in various forms is necessary for testing under these conditions. The testing procedure involves subjecting these prepared samples to controlled explosive events or high-pressure blasts, recording deformation, breakage patterns, and energy absorption to assess fibre performance.

The third objective, analyzing the data to determine the fibre's suitability for use in blast-resistant applications, involves collecting and examining both quantitative and qualitative data. This includes analyzing microstructure fibre in the microscope and observing failure modes, deformation patterns, and structural integrity post-blast. The suitability assessment determines whether banana fibre meets the necessary criteria for blast-resistant materials, including mechanical strength, weight efficiency, cost-effectiveness, and environmental sustainability. Based on the findings, recommendations for potential improvements or applications are provided along with suggestions for future research way forwards.

2. MATERIAL AND METHODS

Initially, banana fibres were made and put through blast testing to achieve this experiment's objectives. The preparation phase included cleaning and drying the fibres before the experiment was conduct. This action was taken to confirm that the samples provided were consistent. To achieve the objective of applying a range of blast pressures, explosive charges weighing 400g and 800g were utilized. The thermocouples of type K were employed to monitor the temperature changes throughout the testing. The banana fibres were tested for strain before and after exposure to the explosions. The results of these tests were analyzed. An environment that was both predefined and regulated was used for the execution of these studies. Within this environment, the banana fibres were fastened and placed as a component of the testing apparatus. The employment of this apparatus allowed us to get precise measurements of the fibers' structural integrity, elasticity, and failure sites in response to the various blast circumstances.

2.1 Banana Fibre Preparation

Banana fibre has been chosen because one of the most reliable research studies is on the use of natural fibres in the development of blast-resistant materials. Banana fibre extracted from the pseudo stems of banana plants is particularly important due to its high tensile strength, low density, and flexibility [12]. These properties propose that banana fibre could be an excellent choice for strengthening materials that can be used for protection from explosive forces. It is theoretically important, more environmentally friendly, and efficient solution for blast protection. Preparation of Banana Fiber cutting the trunk of a matured banana into a scale 90 cm × 14.2 cm approximately in size targeting focus on the impact to blast at the centre of the trunk approximately target size at 30.48 cm or 1ft as shown in Figure 1.

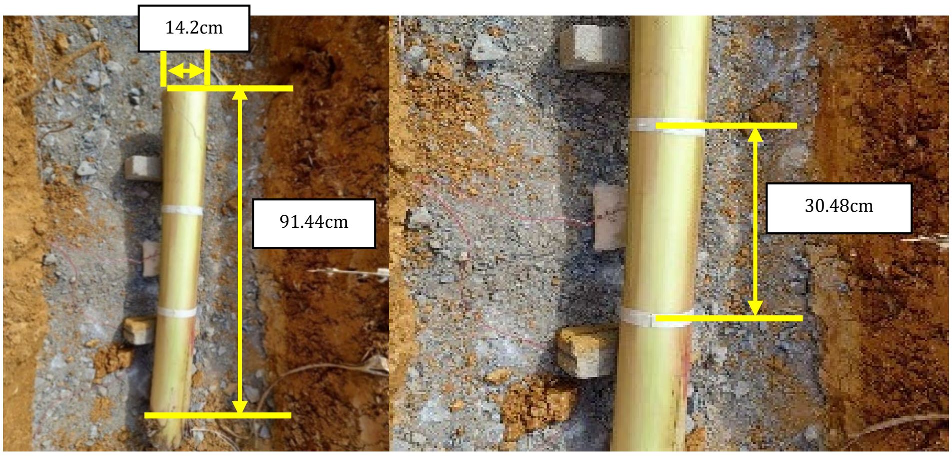

Figure 1: Banana trunk in size and placing to an explosive charge.

2.2 Explosive Charge

The blast test in this experiment was conducted by detonating the mass of amounts 400g, 600g, 800g, and 1000g. Emulsion High Explosive commercial grade with Velocity of Detonation (VOD) 4500m/s to 5700m/s, Explosive energy 4.17 MJ/kg, density 1.13g/cc to 1.21g/cc is shown in

Figure 2. Detonator No.8 was used for initiation, as shown in Figure 3. The equivalent of the total charge mass for 400g is 399g of trinitrotoluene (TNT), 600g is 599g of TNT, 800 is 799 of TNT, and 1000g is 999g of TNT. This was based on the TNT Equivalent [13].

Figure 2: Emulex®180 (Surface & Underground Blasting).

Figure 3: Detonator No.8.

An explosive charge was spherical moulded into a plastic with a weighed amount of 400g and 800g, as shown in Figure 4, which is described in AEP-55 Technical Detail of Level 1 Surrogate where Explosive mass above > 300g. The preparation assembly of the explosive charge is shown in Figure 5.

Figure 4: Weighing amount and spherical mould of explosive.

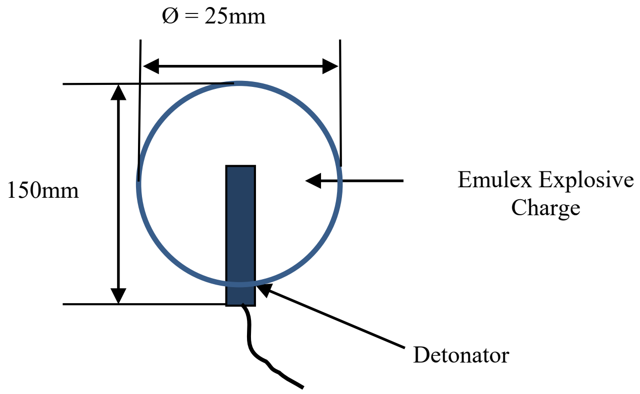

Figure 5: Assembly of explosive.

2.3 Thermocouple Type K

Type K thermocouples can measure temperatures ranging from -200 degrees Celsius to 1372 degrees Celsius and allow the monitoring of temperatures in a wide range of temperatures, as shown in Figure 6. The scope of this concept comprises a wide variety of possible selections. To accurately monitor and measure temperatures, the type has a sufficient degree of sensitivity, which enables the measure of specific ranging temperatures of the blast. Test apparatus is mounted on the target banana fibre frame impact to blast.

Figure 6: Thermocouple type K [14].

2.4 Test Setup

The blast test was conducted using this apparatus, and the procedure is an air blast setup. The air blast setup was selected because the test will repeatedly be conducted by enhancing the banana trunk fibre to show blast output. The test apparatus for the Air Blast Test was placed in an adjustable position with a concrete block as a stand. To prevent the possibility of the ground reflecting the blast wave, the height between the ground surface and the surface of the target is set at 30.48cm (Figure 7). With a constant stand-off distance and a constant mass of explosive charge, a detonation in the air will give a similar blast output as the experiment setup shown in Figure 8.

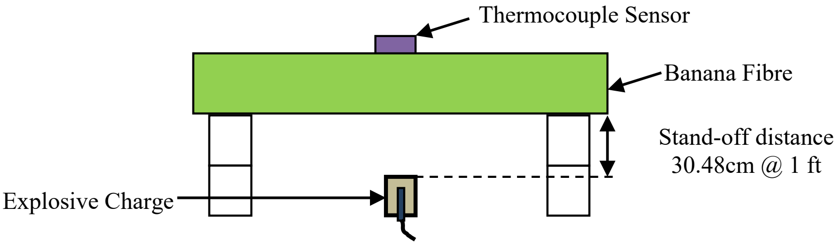

Figure 7: Explosive charge facing to the target and thermocouple on top.

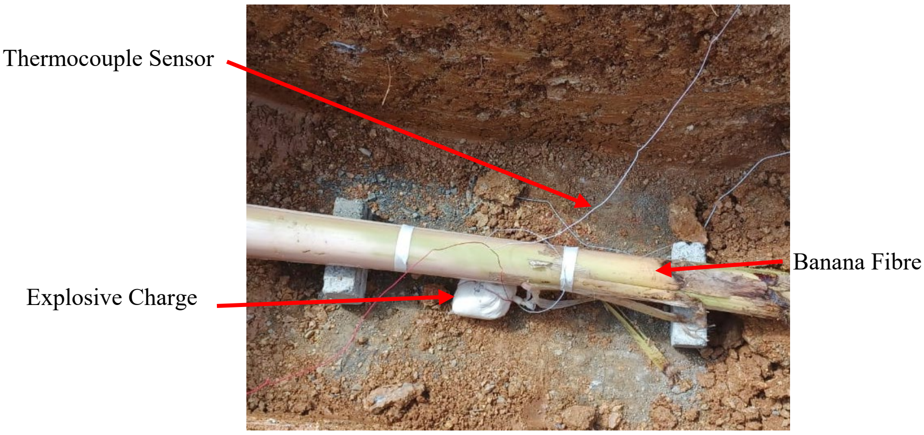

Figure 8: Experiment setup for air blast.

2.4.1 Equations

TNT equivalence was based on the conversion Hopkinson scaling law, which is given in equation (1), where the heat of detonation d = 0.76862 and m = 0.7341.

$$\text{TNT equivalent (by Q)} = Q_{EXP} \,/\, (Q_{TNT}\ (1 - \text{d}) + \text{m}.\ Q_{TNT} \qquad (1)$$

The expected tensile strength of the banana fibre is related to the linear regression equation [15], that the tensile strength decreases linearly with explosive weight as equation (2).

$$\text{T} = T_0 - \text{k (W)} \qquad (2)$$

Where;

T is the tensile strength after blast (MPa)
T_0 is the initial tensile strength before the blast test (31.21MPa).
K is a rate of reduction in tensile strength per gram of explosive (MPa/g)
W is the weight of explosive (g)
Final equation,

$$\text{T} = 31.21 - 0.0035625\ \text{(W)} \qquad (3)$$

Using this equation can estimate tensile strength after a blast test with different explosive weights.

3 RESULTS AND DISCUSSION

3.1 Tensile Test

The findings of the tensile tests that were carried out on banana fibres that were subjected to a variety of blast pressures show a consistent pattern of decreased tensile strength as the concentration of the blast increases. Observation on subjected blast to banana fibre is relatively strong when they are exposed to lower blast pressures of 400g using a tensile test machine, as per shown in Figure 9. This reveals that the banana fibres are durable and have only suffered modest damage. When the blast pressure is increased to 800g, there is a significant loss in the ductile strength of the material, as shown in Figure 10.

Figure 9: Tensile test machine.

Figure 10: Impact of banana fibre after blast test.

As a result, the explosions that are of a higher intensity, which are responsible for producing this, reflect the huge damage caused by the explosions. The increase in tensile strength and the increased survival of the fibres are correlated with rising blast circumstances were correlated to previous work [16]. The result shown in Table 2 is that higher explosive weight strengthens the banana fibre and leads to increased tensile strength based on equation (3). This is how the enormity of the damage was demonstrated and validated [17]. The selection of banana fibres resistant to blast impacts is recommended to increase the survivability of applications that require blast protection.

Table 2: Tensile strength of banana fibre after blast test with different explosive weights.

	400g	800g	Observes
Tensile Strength (MPa)	12,482.57	24,965.15	Higher explosive weights result in greater reinforcement or strengthening of the banana fibre samples, leading to increased tensile strength.

Due to being subjected to blast testing, the banana fibre samples were found to have maintained their mechanical integrity. Banana fibre demonstrated a higher tensile strength than had been discovered earlier. This was confirmed by the showing tensile strength figures, which gave evidence that these values were accurate.

Table 3: Data processing items.

Name	Max_Force	Max_Stress	Max_Stroke	Max_Strain
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Calc. at Entire Areas	Calc. at Entire Areas
Unit	N	N/mm^2	mm	%
1_1 (400g)	64.81	2.16	1.59	2.45
Maximum	64.81	2.16	1.59	2.45
Minimum	64.81	2.16	1.59	2.45
Median	64.81	2.16	1.59	2.45
2_1 (800g)	137.61	4.59	0.83	1.27
Maximum	137.61	4.59	0.83	1.27
Minimum	137.61	4.59	0.83	1.27
Median	137.61	4.59	0.83	1.27
Total maximum	137.61	4.59	1.59	2.45
Total minimum	64.81	2.16	0.83	1.27
Total median	101.21	3.37	1.21	1.86

Table 3 Data Processing Items show Sample 400g has a maximum force of 64.81 N and a stress of 2.16 N/mm^2, which are both much lower than those of Sample 800g, which has a maximum force of 137.61 N and a stress of 4.59 N/mm^2. After comparing Sample 400g and Sample 800g, the findings indicate that Sample 800g holds a significantly higher power level than Sample 400g. When all the information is taken into consideration, it is possible to conclude that Sample 800g can withstand a more significant number of weights before it becomes damaged. Sample 800g has a maximum stroke of 0.83 mm and a strain of roughly 1.27%, whereas Sample 400g has a maximum stroke of 1.59 mm and a strain of 2.45%.

In comparison to the strain found in Sample 800g, which is roughly 1.27%, this is a much more significant percentage. Sample 400g, which is the first sample, provides an additional illustration of the contrast that exists between the two samples. Based on this, Sample 400g is more ductile than Sample 400g. To bring to light the variance that exists between the samples, it is necessary to give more attention to the changes that take place in the mechanical characteristics of the composite material.

The material that is being referred to as sample 400g possesses a higher degree of flexibility and ductility, which makes it more suitable for applications in which these qualities are advantageous when compared to other materials. From the findings of the strain test on the composite material that was made up of banana fibre and blast, it is possible to conclude that the mechanical properties of the samples go through considerable changes [18]. To achieve the objective of optimizing the material for applications, it is essential to have a comprehensive hold of these dissimilarities and a course of action taken to ensure a balance of strength, stiffness, ductility, and flexibility is accomplished simultaneously where it correlated with [19].

Based on the results of the tests, it has been determined that the values assigned to each characteristic are separate. It is possible to estimate the maximum force and stress the material can withstand to ascertain its strength before it completely breaks. The maximum stroke and strain are evaluated on the material to determine the amount to which the material can stretch or deform before it breaks. One can discover potential applications for the material if they have a basic understanding of these qualities.

The stress-strain graph shown in Figure 11 is a supportive tool that can be utilized to learn about the material's behaviour when it is subjected to blast. The linear elastic zone is located at the beginning of the curve and is a region in which the material bends without undergoing any permanent deformation. The beginning of the curve is where we can find this zone. During the mathematical expression, the peak point, denoted by the word MAX, is the maximum stress the material can withstand before it permanently matures. As soon as this peak is reached, the tension drops, a sign that the material has failed, as mentioned by the U.S. Naval Academy [20].

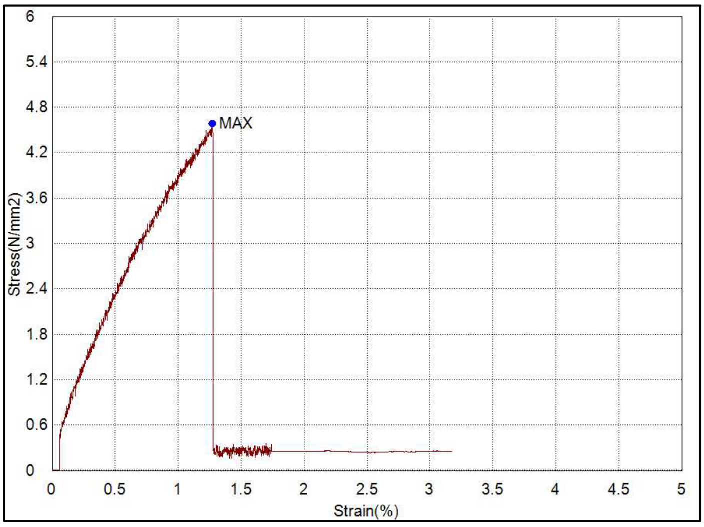

Figure 11: Strain vs stress graph.

3.2 Microscope Analysis

Using an Optical Microscope, as shown in Figure 12, 50× magnification banana fibre for observation on a composite surface. The banana fibre composite material demonstrates a consistently uniform surface shape, exceptional quality, and elasticity when subjected to mechanical stress, as shown in Figure 13. The substance possesses a highly structured internal configuration characterized by cellulose microfibrils and uniformly dispersed lignin, as mentioned by [21]. The material's load capacity, resistance to deformation, and structural integrity are affected by its smooth and uniform surface texture, microscopic microcracks and cavities, and a consistent cross-sectional area.

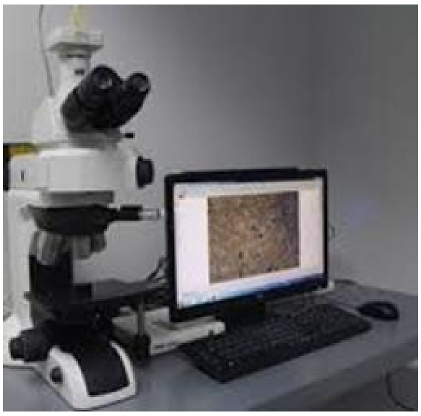

Figure 12: Optical microscope.

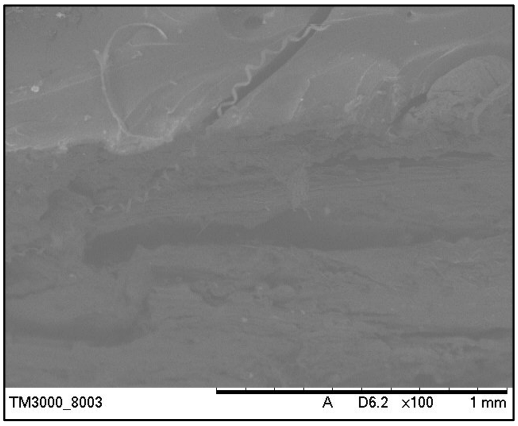

Figure 13: Sample of banana fibre with 50× magnification before the blast test.

There are considerable changes in the structural integrity and flexibility of banana fibre due to the application of blast pressure. Many other variables have contributed to this progress. Evidence indicates that the outer layer has been damaged, as indicated by the surface morphology, which exhibits increased roughness in conjunction with roughness and new flaws Figure 14 (Picture 1). This is the result of the fibre's degradation, and the cellulose microfibrils are disorganized on the inside, which manifests as signs of delamination and structural weakness Figure 14 (Picture 2). The presence of this revealing indication indicates that the interior of the material has undergone severe corrosion. The findings of the examination that was conducted using a cross-sectional approach suggest the presence of internal fractures and an increase in the number of cavities, as shown in Figure 14 (Picture 3), which finally results in a less uniform structure on the inside Figure 14 (Picture 4). Results for pictures 1, 2, 3, and 4 are correlated with [22] degradation process on natural fibre structure. A comparison of strain testing performed before and after the blast indicates a significant variance, highlighting the great influence that the blast pressure has brought about. The comparison was carried out before and after the blast itself. Therefore, it is of the utmost importance to be aware of the ramifications of these scenarios in the context of applications that use banana fibre in high-pressure conditions.

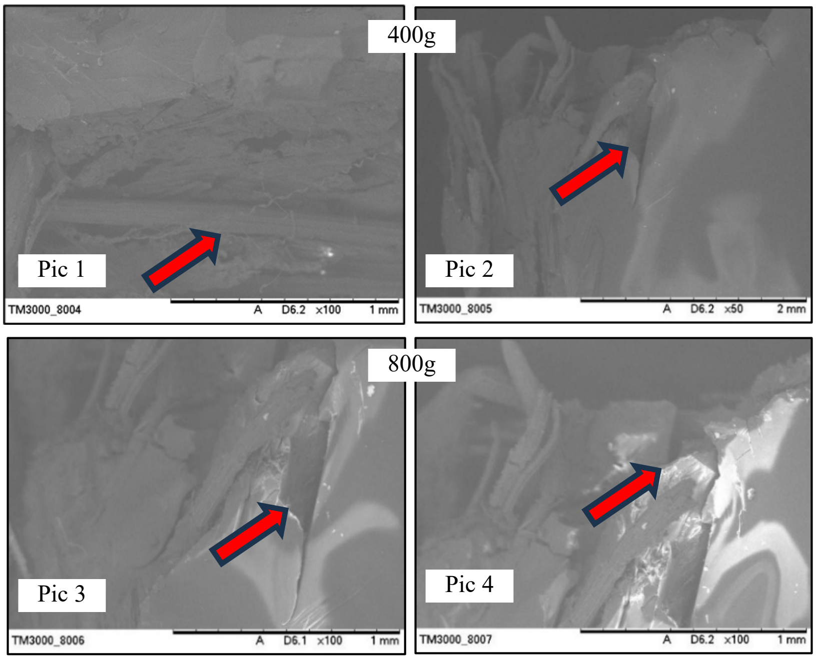

Figure 14: Sample of banana fibre with 50× magnification after blast test.

Comparative research was carried out on banana fibre's structural integrity and elasticity while it was subjected to blast pressure. The findings of this research have demonstrated that unique patterns of change have evolved. As a result of the blast, surface modifications have revealed a significant rise in roughness and flaws, indicative of damage to the outer layer. In the presence of an increased number of micro-cracks and cavities, which may further weaken the fibre over time, there is a drop in structural integrity, proven by a decline in structural integrity [23], and this is because the fibre may become even weaker over more extended periods. The structure on the inside is weakened due to a disruption in the arrangement of microfibrils on the inside, which causes the structure to become less robust, as mentioned by [24]. In particular, the analysis reveals that cracks and holes in the interior fibre become more evident after the explosive has been detonated. The comparisons of strain tests carried out both before and after the blast, illustrate the significant influence blast pressure has on banana fibre. The strain tests were carried out both before and after the blast to understand how banana fibre performs when subjected to high-pressure conditions is the most crucial factor to consider.

3.3 Thermocouple Results

The findings of thermocouples for banana fibre subjected to blast pressures of 400g and 800g indicate that the temperature and voltage responses change over time because of the blast pressures, as shown in Table 4. The findings allow this to be the conclusion that can be formed, as mentioned [25]. After reaching a high of 39.68 °C at 2000 s, Channel 1 (400g) immediately drops to 37.06 °C at 2171.88 s. The temperature begins at 32.12 °C and continues rising until it reaches its maximum. Consideration is given to the temperature range that falls within these parameters. The temperature of Channel 2, which weighs 800g, begins at a higher level of 38.12 °C, then drops to 27.61 °C by the time it strikes 2000 s, and then makes a modest recovery to 30.90 °C at 2171.88 s. Channel 2 started at a greater temperature than the other channels. Channel 1, on the means, has voltage readings that range from -0.035 to 0.046, which is significantly lower than Channel 2, which has voltage readings that range from -0.030 to 0.043. Considering the data, there are substantial variations because of the blast strength of the explosion.

Table 4: Thermocouple data banana fibre after blast.

Relative Time	øC (Channel 1: 400 g)	øC (Channel 2: 800 g)	Volt	Volt
0	32.12042236	38.11712646	-0.00583	0.027359
200	33.07989502	36.46203613	-0.03525	0.00618
400	34.11132813	34.73498535	0.028687	-0.01442
600	34.73498535	33.39172363	0.010391	-0.00945
800	35.0947876	33.91943359	-0.01772	-0.00172
1000	33.75152588	34.13531494	-0.01694	-0.00183
1200	32.69610596	31.95251465	-0.01701	-0.00366
1400	34.87890625	32.9119873	0.046432	-0.03033
1600	35.2387085	32.55218506	-0.00662	0.026703
1800	34.8069458	32.48022461	0.011078	-0.01253
2000	39.67626953	27.61090088	-0.00519	-0.01158
2171.88	37.06170654	30.89709473	-0.01659	0.042862

The data suggest that unexpected heating and cooling cycles affect the fibre's physical properties. The conclusion that can be shown in the graph, as shown in Figure 14 from examining these findings, is that increasing the frequency of micro-cracks and cavities is correlated with greater temperatures. This suggestion, in line with [26], is a direct result of the higher temperature from Thermal strains, and unequal heat distribution is the cause of these micro-cracks and cavities.

Two indications of temperature differences include discolouration and a loss of strength, both of which are indicators of thermal degradation. As a result of the heat, cellulose microfibrils break, resulting in a structural weakening of the material that is of interest. It was determined by Ismail, 2019 [27] that comparing these thermocouple findings with strain test observations shows that parts that exhibit more substantial structural damage after the blast coincide with settings with higher temperatures. When it comes to establishing how well banana fibre operates under high-pressure settings, it is vital to have a solid understanding of the thermal impacts that are taking place.

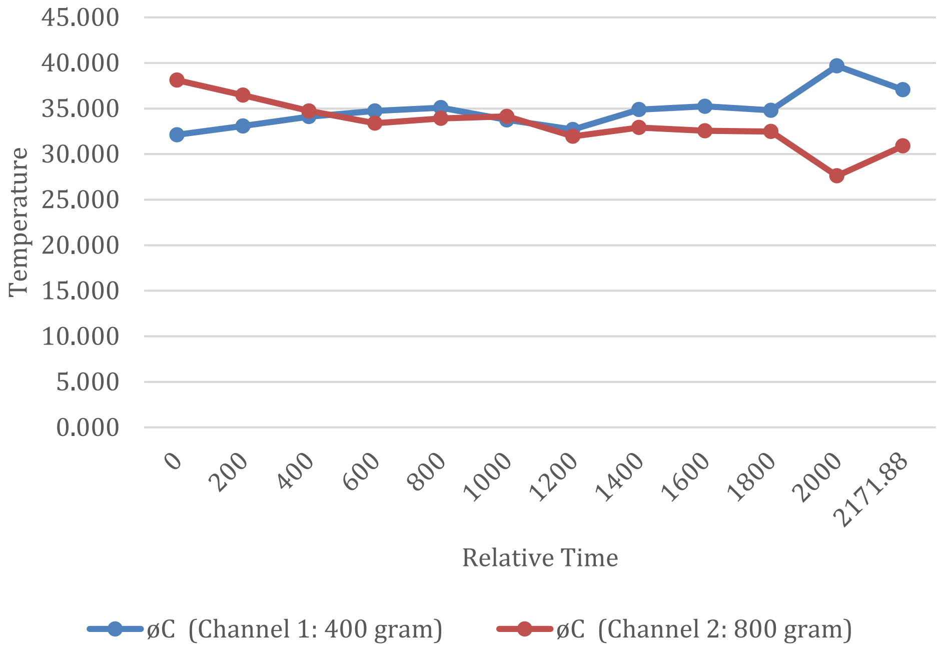

Figure 14: graph temperature vs relative after blast.

4 CONCLUSION

This study aimed to conduct a comprehensive investigation of the structural integrity and flexibility of banana fibres as its primary method of investigation. To gain a deeper comprehension of the characteristics of the banana fibres, several different blast pressures were applied to them. The results, which included strain tests that were carried out both before and after bomb attacks, resulted in a substantial amount of information being acquired regarding the maximum stretchability of the fibres as well as the failure locations. This information was gathered because of the results.

The entire tensile testing procedure revealed a pattern in which the tensile strength decreased as the blast pressure increased. This pattern was identified in the whole process. Throughout the process, this pattern remained entirely consistent. This tendency was observed multiple times at various points over the length of the testing session. Banana fibres showed resistance and suffered only minor damage when subjected to blast pressures lower than 400 g. Due to these conditions, it reached a tensile strength of 12,482.57 MPa, a maximum force of 64.81 N, and a stress of 2.16 N/mm^2. The strain test results indicated that the maximum stroke value for this sample was 1.59 mm, and the strain value was 2.45%. It was possible to acquire this information regarding the sample. At its maximum point, the temperature reached 39.68 degrees Celsius.

When the fibres were subjected to higher blast pressures (800g), a considerable decrease in their tensile strength was observed in the fibres. Nevertheless, the tensile strength of the fibres grew to 24,965.15 MPa, with a maximum force of 137.61 N and a stress of 4.59 N/mm^2. The strain test results indicated that this sample's maximum stroke value was 0.83 mm, and the strain value was 1.27%. Under these circumstances, the temperature reached its highest point of 38.12 °C, then dropped to 27.61 °C, ultimately reaching a level of 30.90 °C, which is regarded to be maintaining a stable temperature.

The quantitative results show that it is possible to conclude that banana fibres demonstrate enhanced levels of strength and resilience when subjected to higher blast pressures. This conclusion may be reached because banana fibres are tested. Because of these findings, a significant advancement has been accomplished in comprehending how banana fibres respond when subjected to explosive forces. In addition, the findings offer important information that can be utilized in constructing materials intended for blast protection. New insights have been obtained that are beneficial to producing well-made, long-lasting materials capable of withstanding explosive forces for various applications.

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