Development of Cassava-Based Bio-Adhesive Using Polyvinyl Acetate (P.V.A.) for Engineered Wood Products Manufacturing

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INTRODUCTION

Adhesives are glue substances that serve as a binder which holds up materials together that is are able to make things adhere or stick together without deformation or failure through a process called adhesion (Baumann and Conner, 2003). Adhesives are categorized as either natural or synthetic. Natural adhesives include animal glues, casein glues, natural gums and resins, sodium silicates and vegetable glues. Vegetable glues are starch-based and are made from starches and dextrin (Kennedy, 2013). Starch has several advantages as a raw material in the production of adhesives, including: renewability, biodegradability, abundance, relatively cheap and affordability (Agboola, et al., 2010) and can also be used to produce diverse products as food, paper, textiles, beverages, confectionery, pharmaceuticals, and building materials (FAO, 2010).

Starch is produced from grain or root crops such as sweet potatoes, maize, wheat, rice, yam and cassava. The advantages of cassava for starch production over other grains or root crop includes: high purity level, excellent thickening characteristics, a neutral (bland) taste, desirable textural characteristics, is relatively cheap and it contains a high concentration of starch (dry-matter basis), (Masamba et al., 2001).

Cassava starch (*Manihot esculenta*) has numerous characteristics, including high paste viscosity, high paste clarity and high freeze-thaw stability which are advantageous to many industries. Cassava (*Manihot escuIental*) is a renewable, an almost unlimited resource and one of the most abundant substances in nature. It is one of the most important starchy root crops of the tropics used for food and industrial purposes. Cassava (*Manihot esculenta*) is a staple crop and food in many tropical regions, particularly in Africa, Asia, and Latin America. It is widely cultivated for its starchy tuberous roots, which are a significant source of carbohydrates in diets. The occurrence of cassava (*Manihot esculenta*) is prevalent in countries with suitable climates, and it plays a crucial role in food security for many communities. In Nigeria, it is consumed raw or fried as garri, starch flour and a variety of other items (Tonukari, 2004). The cassava project of the Nigerian government aimed at increasing the utilization of cassava for industrial purposes and as a foreign exchange earner has stimulated research into the processing and conversion of cassava and its products into industrial products and as raw materials. It is in line with this initiative that this study seeks the utilization of cassava starch, a secondary product in the production of garri from cassava which is usually drained off especially in the rural areas as a raw material for the production of adhesives. The effectiveness of an adhesive is determined by its bonding capability (resistance to load shear), ease of application, reasonable setting time, resistance to moisture, aging, heat and fungal attack, non-staining and gap filling (Finn, 2015). Cassava based adhesives have the unique advantage of having smooth, clear fine texture, non-staining, more viscous, stable and neutral pH. The nonpoisonous nature makes it a desirable choice particularly for domestic and most non-structural utilization (Masamba, *et al.*, 2003). The major drawback in the use of starch as an adhesive is the stability of the product over time (FAO, 2014). This study will also investigate possible improvement methods of the properties of the adhesives produced by studying the effects of borax and temperature on the viscosity, density and pH of adhesive and the use of different modifiers in the production of the adhesive.

Cassava starch (*Manihot esculental*) is extracted through processes involving washing, crushing, and separating the starch from the fibrous components of the root. Studies by Ocloo et al. (2013) discuss the extraction methods and the quality of starch obtained.

The use of starch-based adhesives has gained attention due to the biodegradability and renewability of starch. Research by Li and Sun (2015) explores the modification of starch for various applications, including adhesives.

Traditional adhesives often involve non-renewable resources and may contribute to environmental issues. The work of Nair et al. (2017) discusses the environmental impact of adhesive industries, providing a context for the need of sustainable alternatives;

Economic feasibility is a crucial aspect. Studies like those by Zhang et al. (2019) delve into the economic viability of utilizing alternative materials in adhesive production, providing insights into the potential advantages of cassava starch.

The Egyptians used vegetable glue adhesives in wood works and in the production of Papyri. It was during the 19th century that there was technological advancement which led to the sourcing and production of varieties of adhesive. In 1912, F.G Parkins found out that starch could be converted by mild caustic soda solution into liquid glue that was stable at room temperature.

Most of the popular adhesives currently used in the country are imported as such the clamour for adhesive that are locally produced has been on primary concern for embarking on this project. It is the aim of this project to produce wood adhesive from local raw materials using cassava as the case study or reference study. Though starch can be extracted from plants for example corn, barley, wheat, potatoes and cassava but for simplicity have to be reduced to cassava. The primary aim of this study is to investigate and promote the utilization of cassava starch as a sustainable and eco-friendly raw material for wood adhesive production.

MATERIAL AND METHODS

Materials collection

The main component used to make this glue is cassava tubers, which were gathered from a farm in Cross State to extract starch. Other ingredients include:

Calcium carbonate (CaCo3): to improve viscosity

Distilled water: As solvent

Genope: For proper mixing of materials

Antifoamer: To remove the foam caused by genope

Acetate (P.V.A): used as water resistance

Natrosol cellulose (2.5HHBr)**:** Act as a thickener

Formaldehyde (CH_2O): As a preservative.

These materials were bought from specialized shop.

Materials Preparation

Extraction of Starch from Cassava Tubers

The Cassava tubers were harvested from a farm in Cross River State. Before use, the cassava tubers were peeled and washed. The peeled cassava was soaked in water to soften it. The cassava tubers were grounded in a grinding machine, into a Cassava paste. This breaks the plant cell and thus releases the cassava paste. After grinding, fine cassava was obtained which was soaked in water and left for three hours. Just to allow the cassava fine particles to settle. The fine cassava particles were screen with 200 micrometer sieve. More water was added as the cassava slurry will be rubbed on top of the sieve to achieve proper separation of the chaff or fiber from the main starch. As separation continues, the starch and water escapes through small pores while chaff and cell debris are retained on the surface of the screen. The starch and water was allowed to stay for five hours in order for it to settle down. Then the water will be slowly decanted and the surface of the starch was washed with water to remove dirt and non- starch which has settled with the starch.

The starch was sprayed on a clean tray and thoroughly sun-dried, so that it could be stored and preserved.

Sawdust Preparation

Sawdust: The sawdust is important materials in the production process of the particleboard. These sawdust used was obtained from the Akim Timber market Calabar, Cross River State.

The sawdust after gotten was sundried for two days so as to reduce the moisture content (MC) and was oven dry for two (2) hours to its minimal. Since sawing is a mechanical process, the sawing action results to various particle sizes hence, the sawdust comprises of different sizes. The dried sawdust was sieved using different sieve sizes attached to a sieve shaker.

A sieve shaker is a device used to separate particles of various sizes by vibrating or shaking a stack of sieves each with a different mesh size. As the sieve shaker operates smaller particles pass through the finer meshes while larger particles remain on the sieve with a larger mesh opening. This allows for the sorting of materials based on particle size. The sieve shaker can be used for dry sieving of sawdust to achieve the desired particle size distribution for particleboard production.

After sieving the resultant sieve sizes were grouped into coarse, medium coarse, fine and dust particle sizes. The particles retained in the 425µm was the medium coarse, the 300µm was the fine particles and pan were grouped as the dust particle.

Wooden Mold: a wooden mold of 300mm x 200mm x 15mm is prepared, the mold is without lid or bottom but plywood is introduced at the bottom and used as lid to facilitate pressing. The reason behind this is to allow for easy removal from the mold without cracking the product. Material combination are:

1. Wood particles of two sizes:

425 µm medium coarse, 300 µm coarse, Fine particles

2. Adhesives: Top bond adhesive, Bio-adhesive

3. Wooden mold

Forming Of Particleboard

First Layer Preparation:

A ratio of 15% of 300 µm fine coarse particles and pan particles was mixed with 18% adhesive (top bond adhesive for one particleboard and bio-adhesive for another).

This mixture was transferred into a wooden mold to form the first layer, ensuring a smooth and even surface by pressing.

Second Layer Preparation:

A ratio of 15% of 425 µm medium coarse particles was mixed with 18% of the same adhesive used for the first layer.

This mixture was applied on top of the first layer to form the second layer.

Third Layer Preparation:

Another mixture of 15% of 300 µm fine coarse particles and pan particles was mixed with 18% of the adhesive.

This was applied as the third and final layer.

Pressing Process:

After forming all three layers, the entire particleboard was subjected to a cool press for 3 hours to ensure proper adhesion and surface quality.

Drying Process:

After removing the board from the mold, it was sundried for 5 days.

For the bio-adhesive particleboard, additional oven drying was performed for 8 hours.

For the top bond adhesive particleboard, additional oven drying was performed for 8 hours.

Material Testing

Viscosity test

The NDJ-5S digital viscometer is a rotational viscometer that works by rotating a spindle in a fluid sample at a set speed and measuring the resistance to rotation. This resistance is directly proportional to the fluid’s viscosity. The viscometer displays the viscosity value digitally in centipoise (cP), the unit of measurement for dynamic viscosity.

The NDJ-5S is particularly suited for testing a wide range of fluids including adhesives, resins, and paints. The viscosity test was carried out at the Fluid Mechanics Laboratory of the Department of Civil Engineering University of Cross River State Calabar.

The NDJ-5S digital viscometer measures viscosity in centipoise (cP). Below are the readings for Sample A: Bio-adhesive and Sample B: Top Bond Adhesive at different rotational speeds (RPM).

Moisture content (MC):

The weight of each board was taken. The sample was immersed in clean water at room temperature for 24 hours to determine the weight when fully saturated with cold air. It was then dried in the over until constant weight was achieved.

Moisture Content (%) = $\frac{Winitial - Wdry}{Wdry}$ x 100

$W_{initial}$ is the initial weight of the particle board.

W_{dry} is the weight of the particle board.

Water Absorption

The sample was cut into 200mm by 100mm by 15mm.

The sample was weighed and then immersed in clean water at room temperature. The test sample was carefully lowered down into water. The test sample was reweighed at the end of 1 hours each for 8 hours to determine the level of water absorption and percentage of water absorption.

Water Absorption Percentage (%) $\left(\frac{Final\ Weight - Initial\ Weight}{Initial\ Weight}\right) x\ 100$

Where:

Final Weight: The weight of the material after it has absorbed water.

Initial Weight: The weight of the material before it was submerged in water.

Thickness Swelling

Sample was immersed in fresh water at room temperature. The sample was carefully placed so as to allow for maximum thickness swelling. The sample was removed under room temperature and test was carried out after 1 hour for total of 8 hours immersion period.

The thickness of the board and percentage of thickness of both sample was calculated:

Change in thickness swelling = $T_2 – T_1$

Percentage thickness swelling = $\frac{T2-TI}{T2}\ x\ 100$

Impact Test

Impact test on Bio-adhesive and top bond adhesive particleboard (using a rebound hammer).

It is important to note that the method applied on this experiment is a non-destructive method

Rebound hammer is a non-destructive testing tool originally designed to measure the surface hardness of particleboard or concrete. The basic working principle of the rebound hammer is based on the rebound of a spring-controlled mass after it hits the surface of the material being tested.

The procedure for using the rebound hammer to test the impact resistance of particleboard involves the following steps:

i. Preparation of Test Surface

The particleboard surface is dry and free from any debris. The surface is flat and stable to ensure accurate results.

ii. Positioning the Rebound Hammer

Holding the rebound hammer perpendicular to the surface of the particleboard. This Ensure that the plunger makes direct contact with the test surface.

Using the rebound hammer formula

$f_c = a.\ R + b$

Where

f_c = compressive strength in N/mm²

R = rebound hammer (given in PSI)

a and b = calibration constants (a = 0.7 and b = 5)

DISCUSSION OF RESULTS

Viscosity test

Table 1; variation in Viscosity test

Rotational Speed (RPM)	Sample A Bio-adhesive (cP)	Sample B Top bond adhesive (cP)
10 RPM	920	780
20 RPM	880	740
30 RPM	850	720
50 RPM	830	700

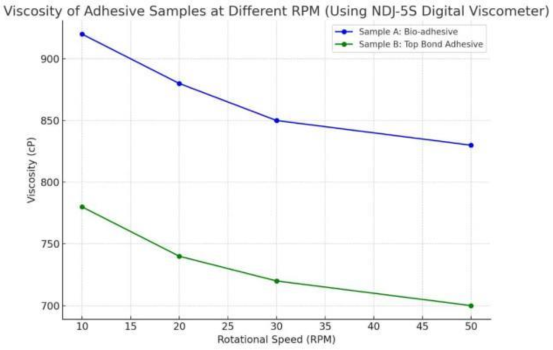

Figure 1: Viscosity uptake variation in the two samples

The graph shows the viscosity of both Sample A (Bio-adhesive) and Sample B (Top Bond Adhesive) as measured using the NDJ-5S Digital

Viscometer at different rotational speeds (RPM). As the rotational speed increases, the viscosity of both samples decreases, indicating a shear-thinning behavior.

Sample A (Bio-adhesive) has a higher viscosity than Sample B (Top Bond Adhesive) at every RPM.

At 10 RPM, Sample A has a viscosity of 920 cP, while Sample B has a viscosity of 780 cP.

At 50 RPM, Sample A has a viscosity of 830 cP, and Sample B has a viscosity of 700 cP.

The difference in viscosity between the two samples suggests that Sample A (Bio-adhesive) is generally thicker and more resistant to flow than Sample B (Top Bond Adhesive) across all RPM settings.

Effect of Rotational Speed:

As the rotational speed increases, both adhesives show a decreasing viscosity. For example:

Sample A: At 10 RPM, the viscosity is 920 cP, but at 50 RPM, it drops to 830 cP.

Sample B: At 10 RPM, the viscosity is 780 cP, and at 50 RPM, it drops to 700 cP.

This decrease in viscosity with increased RPM further confirms that their viscosity changes depending on the applied shear force over time of testing.

Moisture content:

Table 2; Initial moisture Weight of Board samples

Time (hours)	Weight A (g)	Weight B (g)
Initial	300.0	270.0
2	290.0	260.0
4	280.0	250.0
6	275.0	240.0
8	269.7	231.9

For particle board A: the final dry weight (after 8 hours) is 269.7g.

For particle board B: the final dry weight (after 8 hours) is 231.9g as shown in table 2 above. It showing variation loss of MC to final stage of usage.

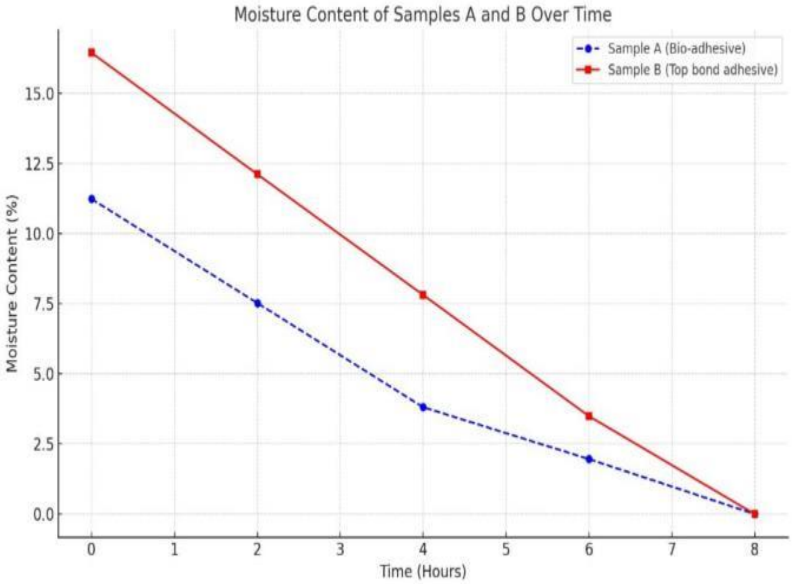

Figure 2: MC variation in the two samples

Table 3; Final Moisture Content weight of board samples

Time (hours)	Moisture Content of A (%)	Moisture Content of B (g)
Initial	11.23	16.44
2	7.52	12.11
4	3.81	7.81
6	1.96	3.49
8	0.00	0.00

Sample A: starts with a lower moisture content than Sample B as it loses less moisture initially. Both samples reach moisture content by the end of the 8-hour drying period as showed in the graph in figure 2 above

Initial Moisture Content weight of sample:

At the start (0 hours) Sample A has a moisture content of 11.23%, while Sample B has a higher moisture content of 16.44%.

This means that Sample B (without a water preservative) holds more water initially compared to Sample A, which has a water preservative that slows moisture retention.

Moisture Loss over Time:

Both samples show a steady decrease in moisture content over time.

The curves are not linear they display a gradual slope indicating that moisture is being lost at a slower rate as the drying process progresses.

Rate of Moisture Loss:

Sample B loses moisture more rapidly than Sample A. This is indicated by the steeper slope of Sample B’s curve particularly in the first 4 hours as showed in figure 2 above. By the 6-hours volunmentry dry weight mark, Sample B has nearly reached its final dry weight.

Sample A, on the other hand, retains its moisture for a longer period of time with a more gradual decline in moisture content.

Sample A (Bio-adhesive) contains a water preservative which explains why it holds onto moisture more effectively than Sample B. This preservative slows the evaporation of moisture which results in a slower rate of moisture loss.

Sample B (Top bond adhesive) which lacks a water preservative loses moisture more rapidly. This make Sample B more prone to drying faster.

Water Absorption

Table 4; Water Absorption

Time (hours)	Wet Weight of Sample A (g)	Water Absorption % (Sample A)	Wet Weight of Sample B (g)	Water Absorption % (Sample B)
Initial	300	0%	270	0%
1	310	3.33%	285	5.56%
2	315	5.00%	290	7.41%
3	320	6.67%	295	9.26%
4	325	8.33%	305	12.96%
5	330	10.00%	315	16.67%
6	335	11.67%	325	20.37%

7	338	12.67%	330	22.22%
8	340	13.33	335	24.07%

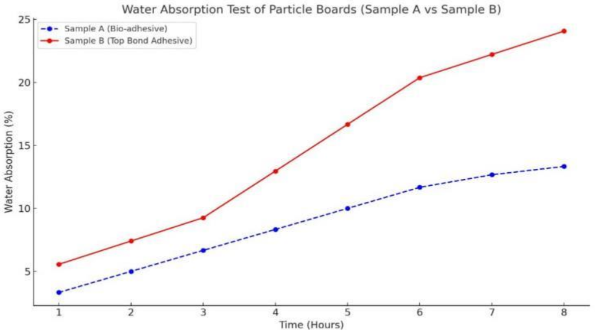

Figure 3: Water absorption uptake over time for the two samples

The graph in figure 3 showed water absorption over time for two different particle boards Sample A (Bio-adhesive) and Sample B (Top Bond Adhesive).

Initial Water Absorption (0–2 hours):

Sample A (Bio-adhesive) shows a slower initial water absorption rising from 3.33% to 5.00% in the first 2 hours.

Sample B (Top Bond Adhesive) absorbs water more rapidly starting from 5.56% at the 1-hour mark and increasing to 7.41% after 2 hours.

Middle Time Points (3–5 hours):

At 3 hours Sample A water absorption is 6.67% while Sample B is already at 9.26%.

At 4 hours the gap widens with Sample A absorbing 8.33% and Sample B at 12.96%. This indicates that Sample B adhesive structure is more prone to water penetration especially as exposure time increases.

By 5 hours Sample B absorption has climbed to 16.67% while Sample A is still at a moderate 10.00%.

Late Water Absorption (6–8 hours):

Between 6 and 8 hours Sample A reaches a 13.33% water absorption after 8 hours while Sample B surges to 24.07%.

The gap between the two samples is very clear by this point with Sample B absorbing significantly more water than Sample A. This shows that the Top Bond Adhesive (Sample B) allows more water to penetrate into the particle board over time.

Thickness Swelling

Table 5: Initial weight of thickness Swelling

Time (hours)	Water Absorption % (Sample A)	Water Absorption % (Sample B)
Initial	0%	0%
1	3.33%	5.56%

2	5.00%	7.41%
3	6.67%	9.26%
4	8.33%	12.96%
5	10.00%	16.67%
6	11.67%	20.37%
7	12.67%	22.22%
8	13.33	24.07%

Table 6: final weight of thickness Swelling

Time (hours)	Thickness Swelling Sample A (mm)	Percentage Swelling Sample A (%)	Thickness Swelling (Sample B) (mm)	Percentage Swelling Sample B (%)
0	**15.0000**	**0%**	**15.0000**	**0%**
1	**15.4995**	**3.33%**	**15.8340**	**5.56%**
2	**15.7500**	**5.00%**	**16.1115**	**7.41%**
3	**16.0005**	**6.67%**	**16.3890**	**9.26%**
4	**16.2495**	**8.33%**	**16.9440**	**12.96%**
5	**16.5000**	**10.00%**	**17.5005**	**16.67%**
6	**16.7505**	**11.67%**	**18.0555**	**20.37%**
7	**16.9005**	**12.67%**	**18.3330**	**22.22%**
8	**16.9995**	**13.33**	**18.6105**	**24.07%**

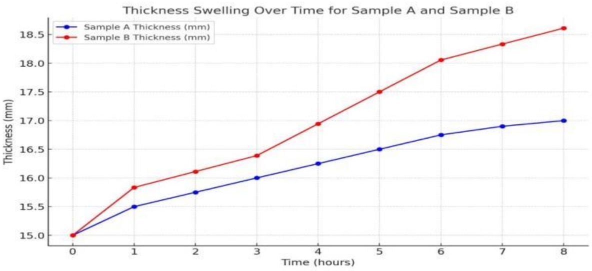

Figure 4. Variation in thickness swelling of samples A and B

The figure 4 above illustrates the thickness swelling behavior of two particleboard samples, Sample A and Sample B over an 8-hour period of soaking regimes. The experiment measures the swelling of the boards as they absorb water a key property in determining their suitability for applications in humid or wet environments.

Initial Conditions of the board swelling (0 Hours)

At the start of the experiment both Sample A and Sample B had an initial dry thickness of 15 mm. This baseline serves as a reference for observing the subsequent swelling due to water absorption.

Conditions of the board swelling of Sample A (Bio-adhesive)

The thickness of Sample A increases slowly throughout the experiment with minimal swelling observed in the first few hours.

After 8 hours the thickness increases to 16.9995 mm, representing a swelling of 13.33%. This slow and steady swelling indicates that Sample A has lower water absorption properties likely due to its treatment.

Conditions of the board swelling Sample B (Top bond adhesive)

In contrast Sample B shows a more rapid and pronounced increase in thickness. By the first hour the thickness increases significantly reaching 15.834 mm.

As time progresses the rate of swelling remains consistent and by the end of the 8-hour period the thickness reaches 18.6105 mm a 24.07% increase in thickness.

Flexural testing of sample

Sample A:(Bio-adhesive): Compressive Strength:

Starts at 20.4 N/mm² at Test Point 1. It dips slightly at Test Point 2 to 19.0 N/mm² but recovers to 20.4 N/mm² from Test Points 3 to 5.

Overall it shows stability with relatively consistent values across the test points.

Rebound Hammer Load: Figure 5 below showed a comparison between Test Points (x-axis) Compressive Strength (N/mm²) and Rebound Hammer Load (PSI) for two samples:

Starts at 22 PSI at Test Point 1.

Drops to 20 PSI at Test Point 2, but maintains a value of 22 PSI from Test Points 3 to 5.

The close correlation between compressive strength and rebound hammer load shows that harder surfaces produce higher compressive strengths.

Table 7; Rebound hammer

Test Point	Rebounds Hammer Load (PSI) Sample A	Compressive Strength (N/mm²)	Rebounds Hammer Load (PSI) Sample B	Compressive Strength (N/mm²)
1	22	20.4	22	20.4
2	20	19.0	20	19.0
3	22	20.4	16	16.2
4	22	20.4	16	16.2
5	20	19.0	20	19.0
		Avg. Point =19.84 N/mm²		Avg. point = 18.16 N/mm²

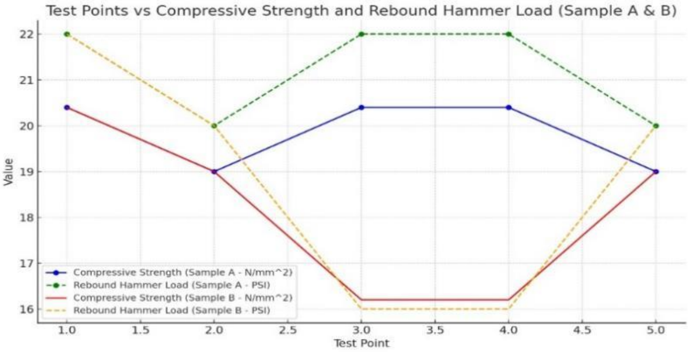

Figure 5: variation of rebound test of samples

Sample B (Top bond adhesive):Compressive Strength:

Starts at 20.4 N/mm² at Test Point 1 (similar to Sample A).

However after Test Point 2 it drops to 16.2 N/mm² at Test Points 3 and 4 indicating a notable reduction in strength.

The strength slightly increases to 19.0 N/mm² at Test Point 5 but it remains lower than Sample A.

Rebound Hammer Load:

Starts at 22 PSI at Test Point 1.

Drops to 16 PSI at Test Points 3 and 4 matching the decrease in compressive strength.

The hammer load increases to 20 PSI by Test Point 5, but overall remains lower than Sample A at most points.

Sample A (Bio-adhesive) generally maintains a higher compressive strength and rebound hammer load across all test points. This suggests that the Bio-adhesive material is more resistant to compressive forces and has a harder surface compared to Sample B.

Sample B (Top bond adhesive) shows a noticeable reduction in compressive strength and hammer load after Test Point 2. This drop indicates that the material have weaknesses or inconsistencies making it less capable of withstanding compressive forces at certain points.

Both samples show a strong correlation between the rebound hammer load and compressive strength. As the rebound hammer load decreases, the compressive strength also decreases, indicating that the surface hardness of the material is linked to its ability to resist compression.

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