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Fibre-Boards and Cutlery from Stubble and Rice Husk using natural and synthetic adhesives

B. Tech Capstone Project: CP-302

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CANDIDATE’S DECLARATION

We hereby certify that the work which is presented in the report, entitled “Mid Density Fiber-Boards from Stubble and Rice Husk” in part fulfillment of the requirement for the award of the Degree of Bachelor of Technology and submitted in the Department of Mechanical Engineering of Indian Institute of Technology Ropar is an authentic record of our own work carried out during a period from January, 2025 to May 2025 under the supervision of Dr. Prabeer Sarkar.

The matter presented in the report has not been submitted by us for the award of any other degree of this or any other University/Institute.

(**AYUSH SINGH, DINESH SWAMI, PRATIMA, YASH RAI)**

Signature of the Candidates

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: May 12, 2025

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1.0 Introduction

1.1 Origin of the Project idea

The cultivation of crops such as wheat and paddy results in the generation of crop residues, including stubble and rice husk, post-harvest. Agro-waste management has long been a significant challenge, attracting considerable research efforts aimed at finding sustainable solutions that are scalable across agricultural sectors. These efforts also focus on ensuring that the solutions are economically viable for widespread implementation.

Traditional crop residue management practices, such as plowing or animal grazing, are increasingly less feasible due to the mechanization of modern farming techniques. Consequently, many farmers resort to stubble burning as a quick and inexpensive method for clearing fields in preparation for the next crop cycle. However, this practice has led to significant environmental and public health concerns, particularly in regions like Punjab, Haryana, and Uttar Pradesh.

Stubble burning is one of the leading contributors to air pollution in India, causing severe respiratory issues and contributing to climate change. The smoke produced by burning crop residues contains high concentrations of particulate matter, carbon monoxide, and other harmful pollutants, which can lead to serious health complications and premature deaths. In addition to the direct health risks, stubble burning also has detrimental effects on soil quality, depleting essential nutrients and making the soil more vulnerable to erosion. This issue is exacerbated during the winter months, when the particulate matter is trapped in dense smog over northern India, significantly impacting air quality. In Delhi, stubble burning is responsible for approximately 15-20% of the total air pollution during this period.

1.2 Problem Definition and Goal

Various methods have been devised to curtail the problem, including spraying bio-decomposers, which break down these substances. Though effective, these measures are still limited to a very concentrated level, and wide-scale implementation is not feasible due to the time taken by the decomposition of the process. Time calls for alternative methods to address the problem. One such method is using these residual straws and husk to form a composite material, which can be used for fibreboards and other disposable cups. The residues will act as reinforcement fibers and bind through a matrix. Rice straws, in particular, are a potent source of lignin which provides mechanical strength and offers excellent resistance to various stresses. We chose agricultural waste like stubble and rice husk as the raw material for developing medium-density fiberboards

(MDF) because of the urgent need to find sustainable, scalable alternatives to both traditional wood-based MDF and harmful waste disposal practices like open-field burning. Every year, millions of tons of crop residue are left unused or burnt, especially in northern India, leading to severe air pollution, soil degradation, and greenhouse gas emissions. These residues, particularly stubble and rice husk, are rich in lignocellulosic fibers—making them ideal for use in engineered boards.

Our goal is twofold: environmental impact and industrial innovation. First, we aim to significantly reduce the harmful effects of residue burning by offering farmers a profitable, eco-friendly disposal alternative. Second, we want to create a sustainable, high-quality substitute for wood-based MDF, reducing deforestation and resource depletion in the furniture and construction industries.

Using agro-waste also ensures cost-effectiveness, wide availability, and rural participation. It aligns with circular economy principles—transforming waste into value-added products. By tapping into this overlooked biomass, we not only address pollution and sustainability challenges but also create local employment and open new pathways for green manufacturing. Our solution combines environmental responsibility with economic viability.

2.0 Existing Studies

The utilization of agricultural residues like rice straw and rice husk has gained significant attention as a sustainable alternative to traditional wood-based materials, driven by the need to reduce stubble burning and its associated environmental impacts. These residues are being explored for producing value-added products like mid-density fiberboards (MDF) and disposable cutlery, aligning with the broader goals of reducing plastic pollution and promoting circular economies.

One notable approach is the conversion of rice straw into disposable food-serving containers via refiner mechanical pulping (RMP), as demonstrated by Saini et al. (2021). This method, characterized by lower environmental impact than conventional chemical pulping, yields paperboards with properties comparable to grade-III Kraft paper (IS 1397:1990) in terms of tensile and burst index. The study highlighted RMP's advantages, including higher pulp yield (85-95% of the original raw material) and reduced effluent toxicity, as opposed to the significantly higher chemical oxygen demand (COD) of traditional Kraft pulping. However, the relatively lower mechanical strength of RMP paperboards may limit their use in more demanding structural applications. This research also emphasized the importance of internal and surface sizing, using Alkyl Ketene Dimer (AKD) and Polyvinyl Alcohol (PVA) to significantly improve water resistance (reducing water absorption from 387 $g \cdot m^{-2}$ to 3 $g \cdot m^{-2}$) and grease resistance, addressing critical commercialisation barriers.

A related study on rice husk-based cutlery manufacturing (2022) further reinforced these findings, identifying rice husk as a strong, heat-resistant material with significant potential for producing biodegradable tableware. The study also stressed the importance of cost-effective production methods to enhance market viability, noting that rice husk cutlery can withstand temperatures over 100°C without deformation, a crucial property for reusable tableware. This material's natural wax coating provides a smooth, glossy finish, enhancing its appeal as a premium alternative to plastic.

Moreover, the development of active, water-resistant films for food packaging has also been explored, as in the case of carboxymethyl cellulose (CMC)-polyvinyl alcohol (PVA)-Aloe vera films. These films, designed for enhanced water resistance and mechanical strength, align well with the needs of biodegradable cutlery, providing additional options for protective coatings that can extend product lifespan and usability in humid conditions.

Additionally, a comprehensive review by Boro et al. (2020) explored the market potential for biodegradable cutlery and tableware as substitutes for conventional plastics. The study highlighted that global demand for single-use cutlery is substantial, with India alone discarding approximately 120 billion pieces annually. It examined various plant-based alternatives, including rice husk, bamboo, areca leaves, wheat bran, and edible cutlery, emphasizing the environmental benefits of such materials. For instance, rice husk tableware was noted for its durability, heat resistance, and fully natural composition, making it a suitable replacement for traditional plastic utensils.

Collectively, these studies underscore the potential of agricultural residues like rice straw and rice husk as versatile, eco-friendly raw materials for mid-density fiberboards and disposable cutlery. This approach not only addresses the critical issue of stubble management but also supports sustainable product development, aligning with global efforts to reduce plastic waste and promote greener manufacturing practices.

3.0 Methodology

3.1 Collection and Preparation of Raw Materials

We source an adequate supply of agricultural waste, specifically rice husk and stubble, directly from local farmers. Both of these materials are abundantly available in agricultural regions, particularly after the harvest of paddy and wheat crops. The availability of rice husk is consistent throughout the year, as it is a by-product of rice milling, while stubble is readily available post-harvest, especially in regions with large-scale paddy and wheat cultivation.

We work closely with farmers to procure these raw materials, ensuring a steady and cost-effective supply. The direct purchase from farmers also supports the local agricultural community, providing them with an additional revenue stream for materials that would otherwise be disposed of through burning or other less sustainable methods.

Once collected, the rice husk and stubble undergo a cleaning and drying process to remove moisture and impurities, preparing them for further processing. This ensures that the raw materials are optimally suited for conversion into fiberboards and biodegradable cutlery, maintaining quality control and maximizing their potential for sustainable product development.

3.2 Collection and Preparation of Raw Materials

The processing of agricultural waste into usable fiber is a critical step in the production of mid-density fiberboards and biodegradable cutlery. This involves grinding, washing, and drying the raw materials to ensure they meet the required quality standards.

The collected rice husk and stubble are first ground to break down the fibrous material into smaller, more uniform particles. This grinding process increases the surface area of the fibers, enhancing their bonding with adhesives and improving the mechanical strength of the final product. Following grinding, the fibers are thoroughly washed to remove dust, dirt, and other contaminants that may affect the quality and safety of the final product. This step also eliminates unwanted residues that could interfere with adhesive bonding or compromise the product’s aesthetic appeal.

Once washed, the fibers are dried to remove moisture, which is critical for ensuring proper adhesive bonding and preventing mold growth. Drying can be performed through air-drying, sun-drying, or mechanical drying, depending on the scale of production and available resources. Proper drying also helps maintain the structural integrity and durability of the final products, ensuring consistent quality for fiberboards and biodegradable cutlery.

3.3 Preparation of Adhesive Mixtures

For producing biodegradable and sustainable tableware from agricultural waste like rice husk and stubble, selecting the right adhesive is critical. The adhesive must be biodegradable, non-toxic, water-resistant, and cost-effective for large-scale production. In this context, we utilized a range of natural adhesives, including carboxymethyl cellulose (CMC), starch, acacia gum, and lignin, each selected for their unique bonding properties and compatibility with plant-based fibers. Given the high lignin content in stubble and rice husk, a lignin-based adhesive is particularly effective, offering strong, natural bonding. This can be prepared by extracting lignin through alkaline or organosolv processes, dissolving it in warm water, and adding natural crosslinkers like citric acid for enhanced water resistance. The resulting adhesive mixture should be tested for strength, biodegradability, and water resistance, aligning with Reneware's goal of transforming agro-waste into sustainable, eco-friendly products.

3.4 Formulation and Molding

The formulation and molding process is a critical stage in the production of sustainable tableware and medium-density boards from agricultural waste like rice husk and stubble. This step transforms raw, fibrous materials into strong, biodegradable products suitable for diverse applications.

To prepare the formulation, the finely ground rice husk and stubble are first combined with natural adhesives such as carboxymethyl cellulose (CMC), starch, acacia gum, and lignin. This mixture is then added to heated water, promoting the even distribution of the adhesive throughout the fibrous particles. The continuous mixing not only ensures uniform adhesion but also helps partially hydrolyze the fibers, enhancing their binding capacity.

As the mixture is heated, the water gradually evaporates, reducing the overall moisture content. This phase is crucial, as a high moisture level can weaken the final product’s structural integrity. The process continues until a thick, moldable paste with minimal residual moisture is achieved. This paste can then be shaped into the desired form using appropriately designed molds, depending on the final use case, such as cutlery or medium-density boards.

Once molded, the material is subjected to controlled drying and curing under a pressure range of 10-20 bar at a temperature of 150°C for approximately 30 minutes. This step helps compact the material, enhancing its density and mechanical strength. After this initial pressurization, the material is left under pressure for an extended period to ensure complete curing and stabilization. This results in durable, eco-friendly items that align with Reneware's mission to transform agro-waste into innovative, sustainable products.

4.0 Tools and Machinery Used

To fabricate mid-density fibreboards and biodegradable cutlery from agricultural residues, a combination of accessible and essential tools was employed during various stages of material processing, mixing, molding, and curing. Due to the limited availability of high-end laboratory equipment, practical and innovative alternatives were utilized effectively, ensuring the feasibility of the project in real-world low-resource conditions.

4.1 Kitchen Grinder

A conventional kitchen grinder was employed for the fine grinding of rice husk and stubble. In the absence of industrial-grade pulverizers or hammer mills, the grinder served as a reliable tool for reducing particle size to improve fiber dispersion and enhance bonding with adhesives. Although not optimized for continuous heavy-duty processing, it enabled consistent particle breakdown suitable for batch-scale trials.

4.2 Portable Electric Kettle

A portable electric kettle was used to heat and mix the ground agricultural fibers with various adhesive formulations. This device facilitated the uniform blending of materials while allowing controlled moisture reduction. The heating also aided in gelatinization of starch-based binders and pre-activation of crosslinking agents like citric acid, making the slurry ready for molding. The kettle proved effective in small-scale formulations where temperature control and stirring were manageable.

4.3 Mold Assemblies

For shaping the composite mixtures, custom press-fit molds were used. The mold assembly comprised a rectangular cavity placed on a base metal plate. A corresponding top plate—precisely cut to fit—was used to apply uniform compression. The molds were lined with butter paper or lubricated to facilitate easy demolding and ensure smooth surface finishes. These setups allowed for controlled shaping of both fiberboards and tableware.

4.4 Hot Press

A laboratory-grade hot press machine was used to subject the molded composites to both thermal and mechanical curing. The machine was operated at a pressure range of 10–20 bar and a temperature of 150°C. Each sample was hot-pressed for approximately 30 minutes to ensure adequate compaction, inter-fiber bonding, and crosslinking of the binder systems. This equipment was central to achieving the desired mechanical strength and structural integrity of the final products.

4.5 Hot Air Oven

Post hot-pressing, a hot air oven was employed to accelerate the drying and curing of the composite samples. The oven provided consistent heat at controlled temperatures, aiding in the evaporation of residual moisture and further strengthening of the material matrix. This step was particularly important to avoid warping, internal shearing, and fungal degradation due to retained moisture. Some trials also involved partial oven-drying followed by ambient air or sun-drying.

5.0 Material Trials for Sustainable Product Development

5.1 Tableware:

First Trial:

Materials Used :

- Rice Husk
- Starch
- Water

Composition:

Rice husk 100g
Starch powder 100g
Water 60g

Process: This was an initial trial for testing

the linkage and strength of the starch binder with rice husk. A slurry of starch and water is prepared with 100g of starch and 60g of water.
Rice husk is mixed in the slurry and is mixed thoroughly. This mixture is poured into a flat mould to settle up. After drying, the plate is removed from the mold and further dried to remove moisture.

Rice husk fibers are too large. Also the starch has not been cooked hence no proper binding is present resulting in no shear, tensile and compressive strength.

<u>Second Trial:</u>

<u>Materials Used :</u>

- Rice Husk
- Starch
- Water

<u>Composition:</u>

Rice husk (Grinded) 150g
Starch powder 50 g
Water 150g

<u>Process</u>: Rice husk is grinded and mixed with water and starch. This mixture is heated to 150-200 degrees Celsius till the water is reduced to around 25% and a thick paste-like mixture is ready. This is poured in a bowl shaped mould and covered by another smaller concentric bowl-shaped mold and press fitted by hands only.
Mixture is allowed to get dry and when it dries, it contracts and leaves the mold and comes out of it. It is further dried.
This sample was too brittle, hardness was low, and was shedding material. some flexibility is also needed

Third Trial:

Materials Used :

- Rice Husk
- Starch
- Sugar
- Water


Composition:

Rice husk (Grinded) 150g
Starch powder 50 g
Sugar powder 10g
Water 150g

Process: Rice husk is grinded and mixed with starch and sugar and water. This mixture is heated to 150-200 degrees Celsius till the water is reduced to around 25% and a thick paste-like mixture is ready. This is poured in a bowl shaped mould and covered by another smaller concentric bowl-shaped mold and press-fitted by hands only.
Mixture is dried with the help of a room heater.
In this trial, the material got stuck to the wall of mold and due to sugar caramelization material could not dry correctly.

Fourth Trial:

Materials Used :

- Rice Husk
- Starch
- Water
- Glycerine

Composition:

Rice husk (Grinded) 150g
Starch powder 50 g
Glycerine 5g
Water 150g

Process: Rice husk is grinded and mixed with starch and water. This mixture is heated to 150-200 degrees Celsius and after that glycerine is added to boiling mixture and further heated till the water is reduced to around 25% and a thick paste-like mixture is ready. This is poured in a bowl shaped mould and covered by another smaller concentric bowl-shaped mold and press-fitted by hands only.
Mixture is allowed to dry.

To improve water-retention capacity of the cutlery Aloe-vera gel-based coating is applied

To prepare the aloe vera-based coating, a homogeneous mixture is formed by blending aloe vera gel, starch, carboxymethyl cellulose (CMC), and glycerine in distilled water. Aloe vera gel provides natural antimicrobial and water-repellent properties, while starch and CMC act as film-forming agents that enhance adhesion and structural integrity of the coating. Glycerine is added as a plasticizer to improve flexibility and prevent cracking upon drying. The mixture is gently heated to activate starch gelatinization and ensure uniform dispersion, then applied onto the surface of cutlery or composite boards using brushing or dipping methods, followed by drying to form a thin, smooth, and water-resistant biodegradable coating.
With this coating water holding time is significantly increased.
The coating is then applied with the help of a brush. This also improves the surface finish and provides anti microbial properties.

5.2 Fiberboards :

First Sample:

Materials Used :

- Rice Husk
- Starch
- Citric acid
- Glycerine
- Water

Composition:

Rice husk 150g
Starch powder 60g
Citric acid 13-14 g
Glycerin 12ml
Water 60g

Process: In this study, fiberboard was fabricated using rice husk as the primary lignocellulosic material. Starch was employed as the main binder due to its natural adhesive properties, while citric acid acted as a crosslinking agent to enhance the water resistance and bonding strength of the composite. Glycerine was added as a plasticizer to impart flexibility and reduce brittleness in the final product. Adequate water was incorporated into the mixture to aid in homogenization and to facilitate the gelatinization of starch and the crosslinking reaction.

The mixture was thoroughly blended to ensure uniform distribution of all components. It was then subjected to thermal treatment under controlled heating conditions. This process initiated the crosslinking between starch and citric acid, resulting in improved adhesion among the rice husk particles and the formation of a stable composite matrix.

The material was transferred into a mould after preparing the mixture and reducing the moisture content to a desired level. The moulded mixture was then hot-pressed to obtain the desired board shape under the pressure of 15 bar. Following the pressing stage, the board was further heated in an oven at a temperature of 110 degrees Celsius for 4 hrs, to evaporate any residual moisture and to ensure complete curing, resulting in a rigid and dimensionally stable medium density board.

Second Sample:

Materials Used :

- Rice Husk
- Starch
- CMC powder
- Citric acid
- Glycerine
- Water

Composition:

Rice husk 100g
Stubble 50g
Starch powder 30g
CMC 30 g
Citric Acid 9 g
Glycerine 9 m;
Water 100-150g (accordingly)

Process: The second sample was prepared following a similar initial process as the first, using rice husk as the base material with starch as the binder, citric acid as the crosslinking agent, glycerine as a plasticizer, and water for homogenization and activation of the crosslinking reaction. The mixture was blended and thermally treated to initiate starch–citric acid crosslinking, and moisture was reduced to the desired level before molding.

For this sample, two key modifications were introduced to enhance board performance.

First, carboxymethyl cellulose (CMC) was added alongside starch to improve adhesive strength and binding efficiency. Second, crop stubble was incorporated into the rice husk mixture to increase the long-fiber content, which contributed to greater mechanical strength and reduced brittleness in the final board.

The modified mixture was transferred to a mold and hot-pressed at 15 bar. Unlike the first sample, the mold plates were pre-heated during pressing, which accelerated the onset of crosslinking and allowed for a more uniform heat distribution throughout the material. As a result, the subsequent oven curing step was shortened. The board was oven-dried at 110 °C, but for a reduced duration compared to the first sample, effectively removing residual moisture and finalizing the curing process.

Despite these improvements, some warping was observed at the edges of the board. This was more pronounced in thinner samples and likely caused by differential moisture loss and thermal gradients during oven drying. Additional optimization of drying conditions and board thickness may be necessary to minimize this effect in future iterations.

(before drying)

(after drying)

Third Sample:

Materials Used :

- Rice Husk
- Starch
- CMC powder
- Citric acid
- Glycerine
- Water

Composition:

Rice husk 110g
Stubble 80g
Starch powder 20g
CMC 40 g

Citric Acid 9 g
Glycerine 9 m;
Water 100-150g (accordingly)

Process: The third trial followed the same general preparation method as the previous samples, involving thermal pre-treatment and blending of rice husk, crop stubble, starch, citric acid, glycerine, and water. However, in this iteration, the composition of the rice husk and stubble mixture was adjusted to explore the effects of varying fiber ratios on board properties. Additionally, the binder formulation was modified by altering the relative amounts of starch and carboxymethyl cellulose (CMC) to further enhance adhesive performance and optimize crosslinking behavior.

Following the reduction of moisture content to the desired level, the mixture was placed in a mold for hot pressing under the standard pressure of 15 bar. As in the second trial, the mold plates were pre-heated to ensure rapid and uniform heat transfer.

To address the warping issues encountered in earlier samples, a revised oven-drying procedure was implemented. Initially, the molded board was placed in the oven while covered with both top and bottom plates. This approach allowed for controlled and uniform heat exposure during the early stages of drying. After partial drying, the top plate was removed, and the board was flipped to ensure even moisture removal from both sides. This technique helped maintain dimensional stability and minimized thermal stress during oven curing.

The board was dried in the oven to reach a moisture content of approximately 5–10%. To further reduce moisture and harden the board surface, the sample was subsequently subjected to sun drying. This additional drying step successfully lowered the residual moisture content but resulted in slight warping during the final sun-drying stage, likely due to uneven exposure and surface tension effects under ambient conditions.

Fourth Sample:

Materials Used :

- Rice Husk
- Starch
- Epoxy raisen (099)
- Epoxy hardener (099)

Composition:

Rice husk 50g
Stubble 50g
Epoxy raisin 100g
Epoxy hardener 50g

Process: In addition to the starch-based trials, a sample board was prepared using an epoxy resin system to evaluate its performance as a synthetic binder for rice husk and crop stubble composites. This approach aimed to assess improvements in mechanical strength, surface finish, and moisture resistance compared to bio-based formulations.

For this sample, processed rice husk and crop stubble were used in equal proportions—50 g each—serving as the reinforcing lignocellulosic filler. Both materials were finely ground and sieved to achieve uniform particle size for better dispersion and compaction within the resin matrix.

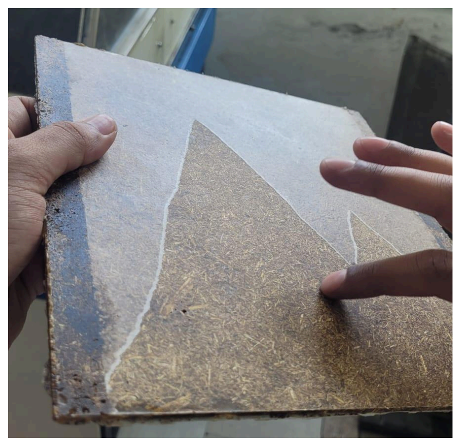
The epoxy binder system was prepared by mixing epoxy resin and hardener in a 2:1 ratio, using 100 g of epoxy resin and 50 g of hardener. The components were thoroughly mixed to initiate the curing reaction and ensure a consistent blend.

The epoxy mixture was then combined with the rice husk–stubble blend and mixed thoroughly to achieve even coating of the fibers. The inner surface of the mold was pre-lubricated and lined with butter paper to facilitate easy demolding and to improve surface smoothness of the final product.

The composite mixture was evenly spread into the mold cavity and subjected to hot pressing in a preheated press. The pressing was carried out at a constant pressure of 15 bar, with the mold plates heated to 150 °C. Heating was applied for 15–20 minutes to initiate crosslinking and to compact the board uniformly.

Following the pressing stage, the mold was allowed to cool at room temperature to complete the curing process. The cured board was successfully demolded, revealing a high-quality surface finish and excellent structural integrity. The use of epoxy resulted in a rigid, well-bonded composite with minimal internal voids and improved mechanical performance, suitable for structural or load-bearing applications.

Filling mold with composite mixture.



Fifth Sample:

Materials Used :

- Rice Husk
- Starch
- Epoxy raisen (099)
- Epoxy hardener (099)

Composition:

Rice husk 100g
Stubble 80g
Epoxy raisin 80g
Epoxy hardener 40g

Process: A second epoxy-based composite board was prepared using the same resin system and fabrication procedure as the previous sample, with adjustments made to the material composition to study the effect of fiber-to-resin ratio on board properties.

In this trial, the formulation included 100 g of rice husk and 80 g of crop stubble as the lignocellulosic filler, offering a higher proportion of fibrous material compared to the previous epoxy board. The binder system consisted of 80 g of epoxy resin and 40 g of hardener, maintaining the standard 2:1 mixing ratio to ensure proper crosslinking and curing.

The rice husk and stubble were pre-processed to a fine consistency, ensuring good fiber dispersion. The epoxy resin and hardener were thoroughly mixed, then blended with the fiber mixture to uniformly coat the particles.

As with the earlier epoxy trial, the mold was pre-lubricated and lined with butter paper to aid in demolding and preserve surface quality. The composite mixture was evenly distributed in the mold and subjected to hot pressing at 15 bar with mold plates maintained at 150 °C. Heating was applied for 15–20 minutes to initiate resin curing under pressure.

After heating, the mold was left to cool at room temperature to complete the curing process. The board was successfully removed from the mold, showing good surface finish and structural cohesion. The increased fiber content and reduced resin proportion resulted in a slightly more textured surface and a denser, more fibrous board structure. Despite the lower resin content, the board retained adequate rigidity and bonding, indicating effective wetting and adhesion between the epoxy and the filler materials.

Sixth Sample:

Materials Used :

- Rice Husk

- Starch
- Epoxy raisen (099)
- Epoxy hardener (099)

Composition:

Rice husk 80g
Stubble 60g
Starch 25g
Acacia gum 5-7g
Citric acid 3-5g
CMC 8-10g
Epoxy resin 60g
Epoxy hardener 30g
Water 15-20 ml

Process: A final composite board was fabricated using a hybrid binder system combining natural biopolymers and synthetic epoxy resin to leverage the strengths of both—environmental friendliness from natural components and enhanced mechanical performance from epoxy.

The process began with the preparation of the natural binder mixture. In a small quantity of water (15–20 mL), starch and CMC were dissolved and activated through mild heat treatment in the presence of citric acid. This step promoted partial gelatinization of starch and crosslinking initiation, forming a cohesive adhesive base. Acacia gum was also added during this stage to enhance viscosity and contribute to bonding properties.

Once the natural binder reached a uniform and partially thickened consistency, finely processed rice husk and crop stubble were gradually incorporated and thoroughly mixed to ensure homogeneous fiber distribution within the matrix.

Subsequently, the epoxy resin and hardener were mixed in a 2:1 ratio and added to the natural binder–fiber mixture. The epoxy addition improved the structural cohesion and mechanical strength of the final board by reinforcing the inter-fibre bonds and enhancing moisture resistance.

The well-mixed composite was then poured into a pre-lubricated mold lined with butter paper to aid in demolding and preserve surface quality. The filled mold was transferred to a preheated hot press and subjected to a pressure of 15 bar at a temperature of 150 °C. Heating was maintained for 15–20 minutes to activate the curing of the epoxy component and promote additional crosslinking within the natural binder system.

After pressing, the mold was allowed to cool gradually at room temperature, completing the curing process. The final board was demolded successfully, showing excellent surface finish, improved rigidity, and balanced mechanical properties. This hybrid approach demonstrated promising compatibility between natural and synthetic binders, offering a potential pathway for sustainable yet high-performance composite board fabrication.

However, this trial did not yield a successful outcome. The mixture failed to cure properly and did not achieve the desired hardening, likely due to incompatibility between the natural binders and the epoxy system or excess residual moisture. During the demolding process, the board adhered strongly to the mold plates despite prior lubrication, leading to significant damage upon removal. The retained moisture within the mixture made the board structurally weak, prone to deformation and internal shearing. Even the applied heat from the press was insufficient to fully eliminate the moisture content, ultimately resulting in an unsuccessful and compromised sample.

Sample	Rice Husk (g)	Stubble (g)	Starch (g)	CMC (g)	Citric Acid (g)	Glycerin (ml)	Epoxy Resin (g)	Epoxy Hardener (g)	Water (g/ml)	Other Components
1	150	0	60	0	13-14	12	0	0	60g	-
2	100	50	30	30	9	9	0	0	100-150g	-
3	110	80	20	40	9	9	0	0	100-150g	-
4	50	50	0	0	0	0	100	50	0	-
5	100	80	0	0	0	0	80	40	0	-
6	80	60	25	8-10	3-5	0	60	30	15-20ml	Acacia Gum 5-7g

6.0 Material Properties and Functional Benefits

6.1 Structural Components and Their Properties

Rice Husk Powder as Primary Filler

Rice husk powder serves as the main filler, providing essential rigidity and water resistance due to its high silica content. This agricultural by-product creates a sturdy framework for tableware while utilizing what would otherwise be waste material. Rice husk composites typically demonstrate good thermal stability and can withstand the temperatures necessary for food service applications.

Stubble Fiber as Secondary Reinforcement

The stubble fiber powder acts as a secondary filler that enhances the lightweight nature of the final product while contributing cellulose strength. These natural fibers improve the overall mechanical properties of the composite, particularly impact resistance, which is crucial for durable tableware3. Research shows that incorporating agricultural fibers like rice stubble can significantly enhance flexural properties and reduce overall weight.

Binding System

The formulation employs a multi-component binding system:

- Starch functions as the primary natural binder, creating the initial matrix structure
- Acacia gum works as a film-former and natural adhesive that increases elasticity
- Bio-based epoxy resin and hardener create a thermoset structure with enhanced water resistance
- CMC improves bonding between components and manages water interactions

Functional Additives

- Citric acid acts as a natural crosslinker that enhances the durability of the starch/gum system
- Glycerol serves as a plasticizer, contributing flexibility and toughness to prevent brittle behavior

6.2 Technical Importance of composition

Each component in the formulation serves a critical role:

- **Rice husk powder**: The high silica content (90-96% of ash) provides natural water resistance and thermal stability. Research shows rice husk can be effectively used as filler in various polymer matrices.
- **Stubble fiber:** Adds tensile strength while maintaining lightweight properties. Research indicates that rice stubble can improve mechanical performance when properly incorporated.
- **Starch binder:** Creates a biodegradable matrix that can bind with other natural materials. Modified tapioca starch has shown excellent performance as a binder in composite applications.
- **Acacia gum**: Provides unique air-setting properties and can dry at room temperature, enhancing processing capabilities. It improves elasticity and creates natural adhesion between components.
- **Citric acid:** Acts as a natural crosslinking agent that enhances the interaction between

starch and other components, improving durability and water resistance.

- **CMC:** Enhances water management properties and improves bonding between dissimilar materials, which is crucial for composite integrity.

6.3 Negative Effects of Imbalanced Composition

Excess Component Quantities

Excess Rice Husk Powder:

- Would create an overly rigid and brittle product prone to breakage
- Reduces tensile strength as filler loading beyond optimal levels leads to decreased mechanical properties
- May cause poor dispersion and particle agglomeration, creating weak points in the structure

Excess Stubble Fiber:

- Creates processing difficulties and poor fiber dispersion
- Increases water absorption which degrades product performance[8]
- Leads to fiber agglomeration that creates stress concentration points, reducing impact strength

Excess Starch/Binders:

- Creates tacky processing conditions
- Increases susceptibility to moisture and humidity
- May lead to incomplete curing or inconsistent properties

Excess Citric Acid:

- Causes over-crosslinking that makes the product excessively rigid and brittle
- May negatively impact the pH balance affecting biodegradability
- Could interfere with other reactions in the composite

Excess Glycerol:

- Results in overly soft and flexible products unsuitable for structural applications
- May cause excessive moisture sensitivity
- Could interfere with proper curing of thermoset components

6.4 Insufficient Component Quantities

Insufficient Rice Husk Powder:

- Reduces rigidity and dimensional stability
- Decreases water resistance properties necessary for tableware
- Diminishes thermal stability needed for hot food/beverage applications

Insufficient Stubble Fiber:

- Leads to poor impact resistance and reduced mechanical strength
- Decreases the lightweight nature of the composite
- Results in poor fiber reinforcement effect

Insufficient Binders:

- Creates weak bonding between components
- Results in poor structural integrity and premature product failure
- Leads to particle shedding during use

Insufficient Citric Acid:

- Results in poor crosslinking between starch and other components
- Reduces durability and water resistance
- Shortens product lifespan, especially in wet conditions

Insufficient Glycerol:

- Creates excessively brittle products with poor impact resistance
- Leads to cracking and breakage during normal use

7.0 Mechanical Testing

7.1 Introduction to Mechanical Evaluation

The mechanical performance of agricultural waste-based fiberboards was rigorously evaluated to validate their suitability for cutlery and tableware applications. Testing followed ASTM D1037 ("Standard Test Methods for Evaluating Properties of Wood-Based Fiber and Particle Panel Materials"), ensuring industry-aligned assessment of structural integrity and functional durability.

Modulus of Elasticity (MOE)

- Evaluated stiffness under bending forces via 3-Point Bend Test.
- Applied steady loading until reaching predefined deflection, measuring stress response.
- Critical for predicting structural rigidity during static loads.

Modulus of Rupture (MOR)

- Determined maximum bending stress tolerance before failure using Tensile Test.
- Specimens loaded continuously until fracture, recording peak stress at rupture.
- Indicates resistance to dynamic or abrupt bending stresses.

Supplementary Performance Metrics

Internal Bonding Strength (IB)

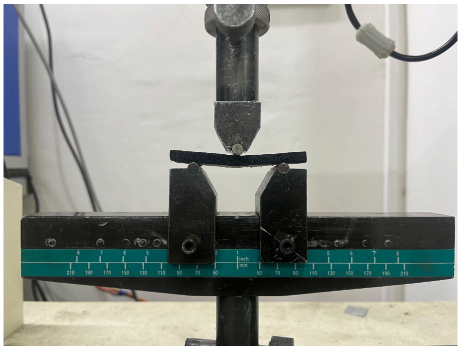
- Assessed interlaminar adhesion to evaluate structural cohesion.

Thickness Swelling (TS) & Water Absorption (WA)

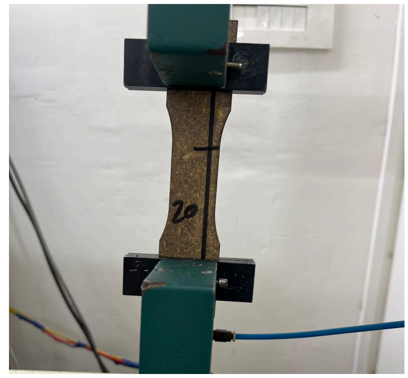
- Quantified dimensional stability and moisture resistance after water immersion.

7.2 Testing Methodology

- MOE and MOR: Calculated through 3-Point Bend and Tensile Tests, respectively.
- IB, TS, WA: Conducted using industry-standard protocols to ensure reproducibility.



Three-Point Bending Test

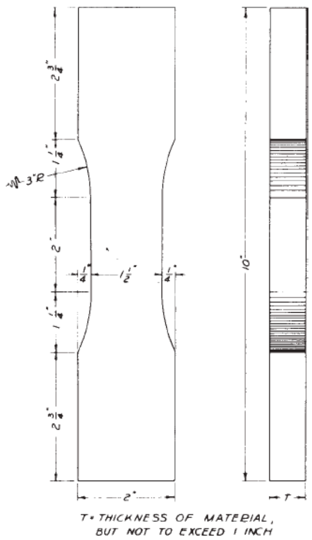


Tensile Strength Test

7.3 Tensile Test:

- **Test Specimen**: Each specimen was prepared as shown in Fig below.
- **Speed of Testing**: The load was applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine of 4 mm/min to 5 mm/min according to the material.
- **Calculation:** The Modulus of Elasticity was calculated for each specimen in accordance with the following equation:
    - where:
    - b = width of the reduced cross-section of the specimen measured in dry condition, in. (mm),
    - d = thickness of the specimen measured in dry condition, in. (mm),
    - E_t = modulus of elasticity in tension parallel to the surface of the panel, psi (MPa), lg = gage length or distance between the gage points of extensometer, in. (mm), DP⁄Dy = slope of the straight line portion of the load-deformation curve, lbf/in. (N/mm)

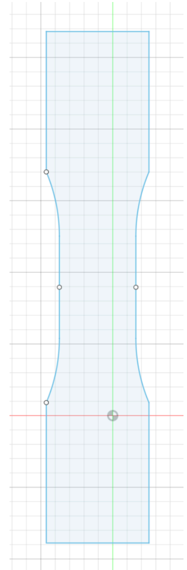
$$E_t = \frac{lg}{bd}\frac{\Delta P}{\Delta y}$$



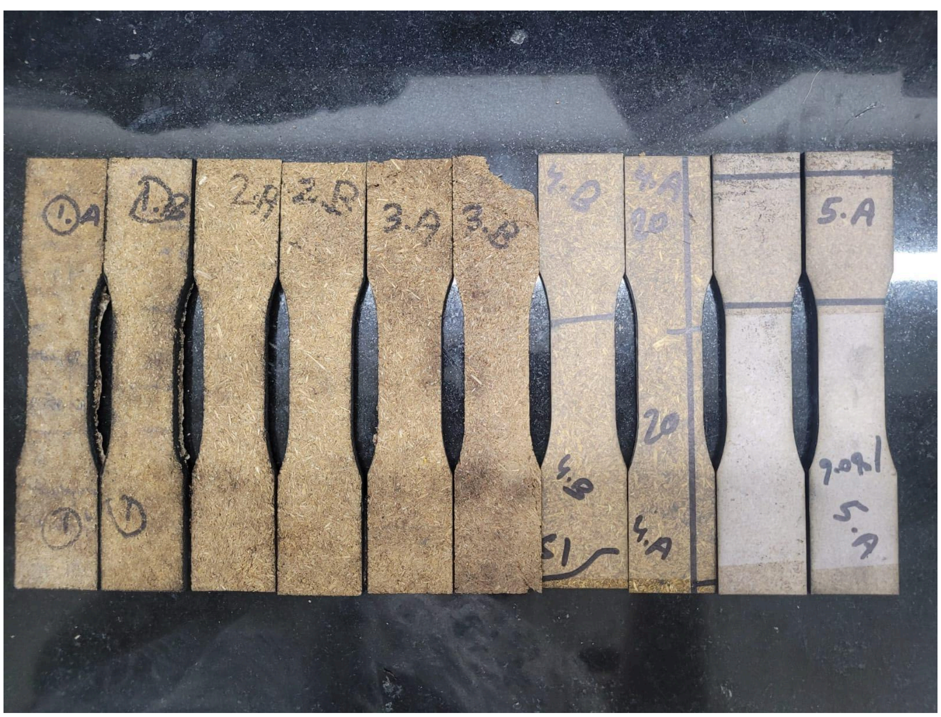
Metric Equivalents

in.	¼	1	1¼	1½	2	2¾	3	10
mm	6	25.4	32	38	51	70	76	254

Sample acc to ASTM D1037



CAD drawing for laser cutting



2 samples for each of 5 compositions of different thickness

7.4 3-Point Bend Test:

- **Test Specimen:** Each test specimen (2-5) was 51 mm in width. The length of each specimen was 2 in. (51 mm) plus 24 times the nominal thickness.
    - The thickness of the boards was measured as
    - For Sample 1 = 6 mm, length = 80mm, width =25mm
    - For Sample 2 = 4.95 mm, length =170mm
    - For Sample 3 = 4.4 mm, length =156mm
    - For Sample 4 = 3 mm, length = 123mm
    - For Sample 5 = 5.6 mm, length =185mm
    - Span Length: The span length for samples 2,3 & 5 was 110, for sample 1 it was 50mm, for sample 4 it was 70mm
- **Speed of Testing:** The load was applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine was 5mm/min
- **Calculations**: The Modulus of Rupture was calculated for each specimen in accordance with the following equation:

$$R_b = \frac{3P_{max}L}{2bd^2}$$

- where,
    - Pmax = maximum load, lbf (N)
    - L = length of span, in. (mm)
    - b = width of specimen measured in dry condition, in. (mm),
    - d = thickness (depth) of specimen measured in dry condition, in. (mm),

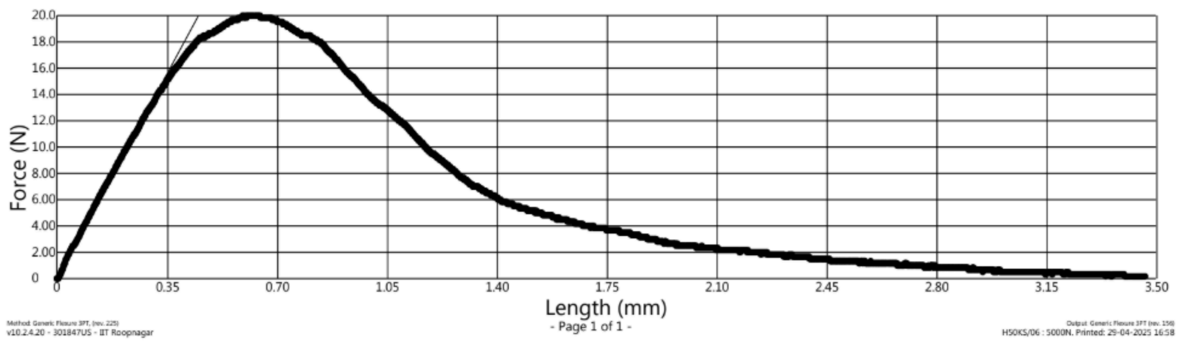
8.0 Results

Sample	Density
Sample 1	667kg/m3
Sample 2	462kg/m3
Sample 3	486kg/m3
Sample 4	1062kg/m3
Sample 5	830kg/m3

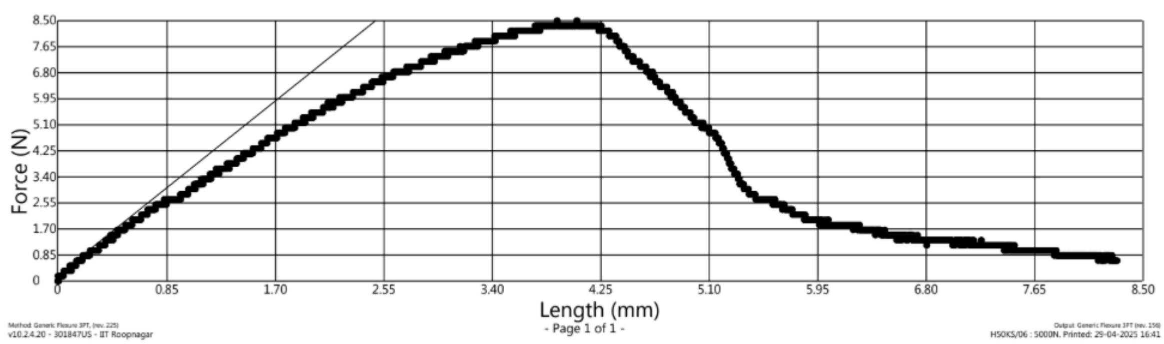
8.1- 3 point bending test

Force vs displacement graphs

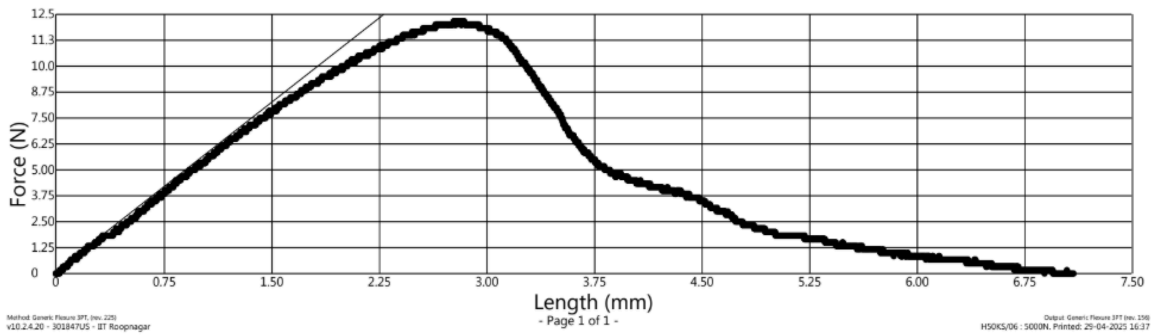
- Sample 1



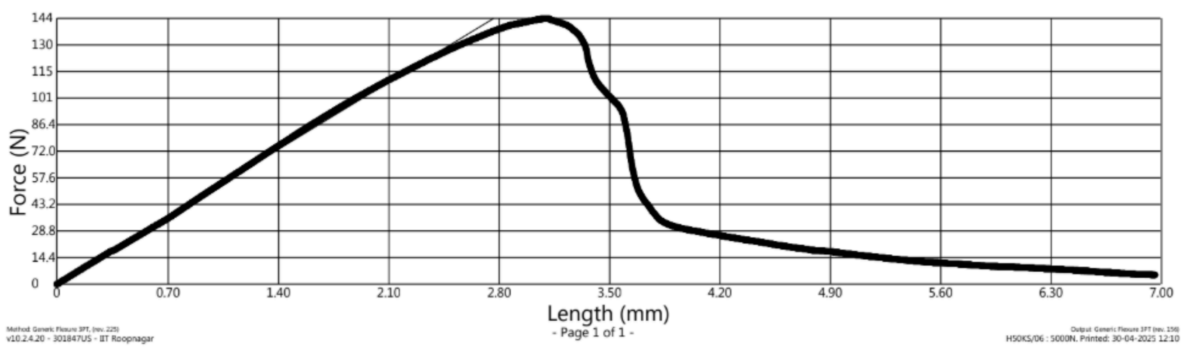
- Sample 2



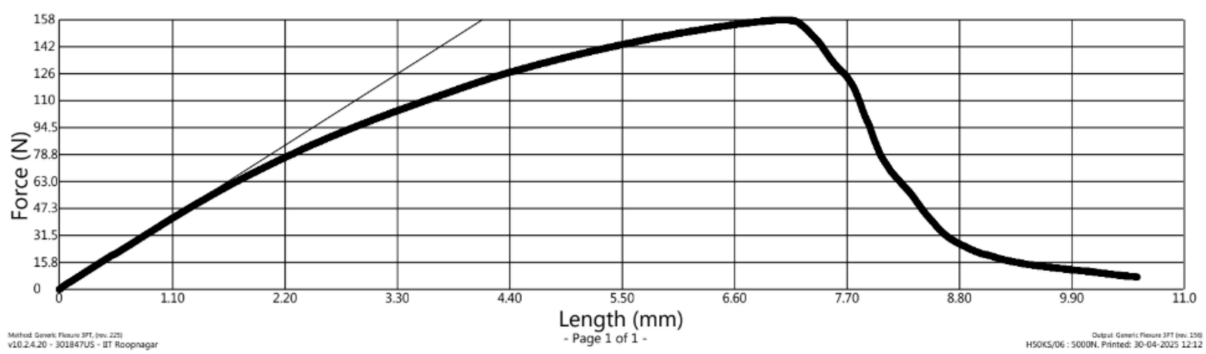
- Sample 3



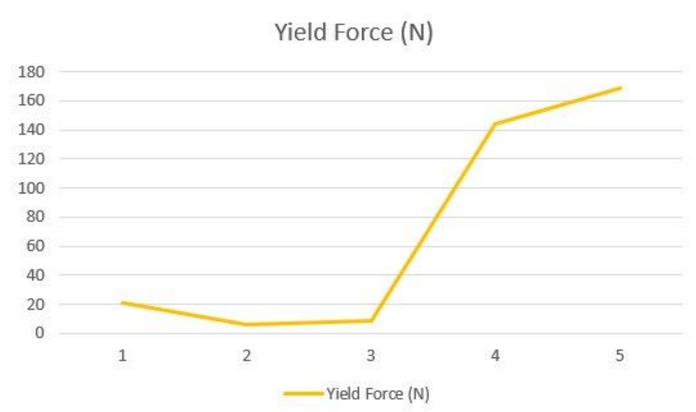
- Sample 4



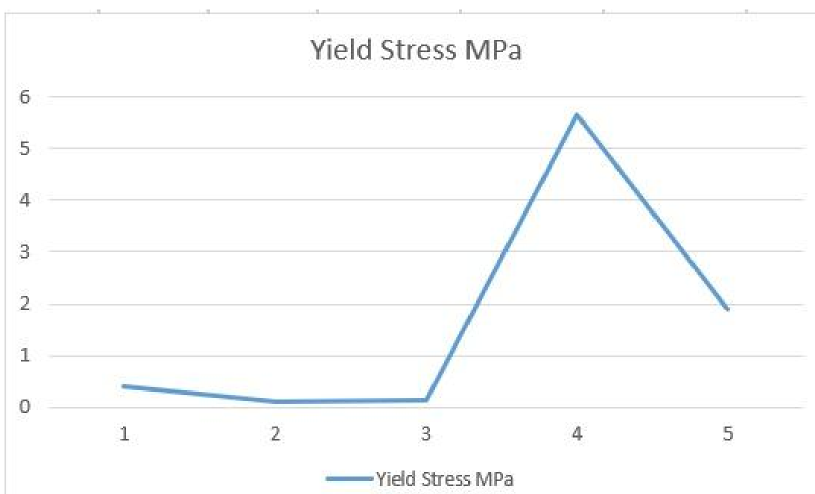
- Sample 5



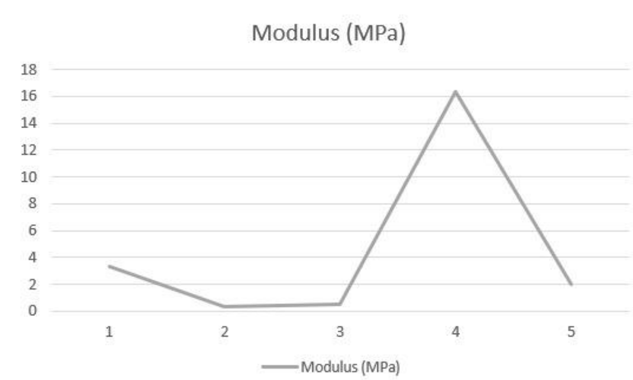
8.2 Comparison of Yield Forces, Yield Stress, Modulus (combined for all samples)



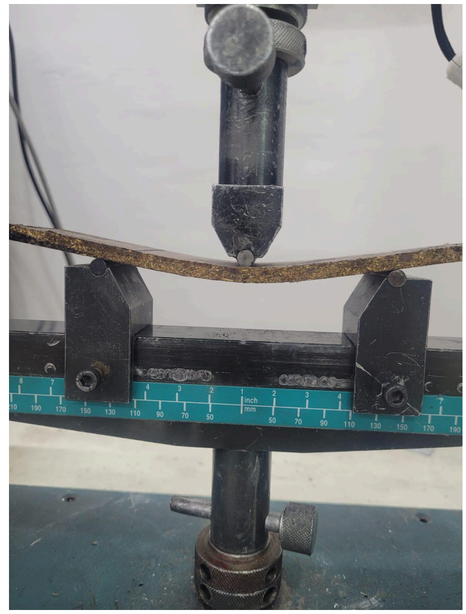
Samples made from Epoxy Resin showed significantly higher strength and failure at Higher forces.



Comparison of Yield stress of samples of varying thickness hence cross sectional areas.



Comparison of Modulus of each sample

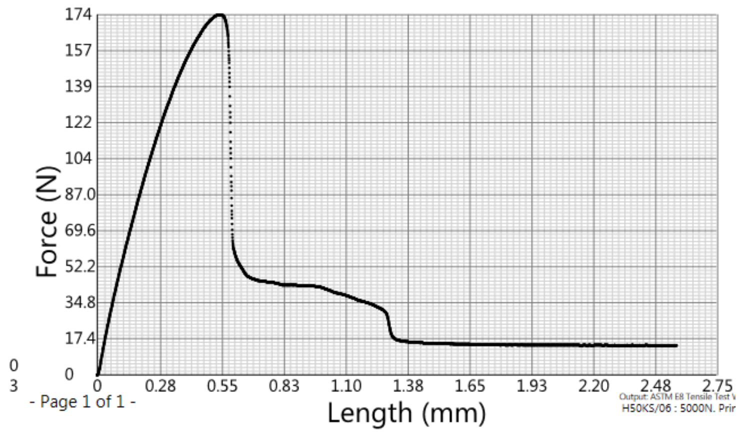




inch
mm

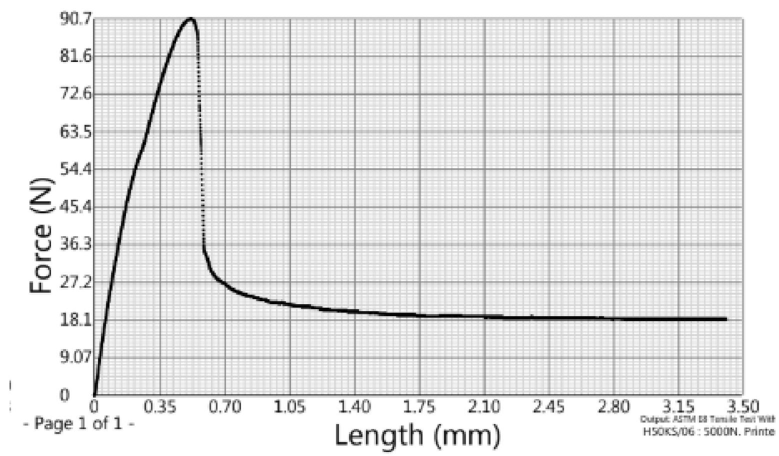
8.3 Tensile test

Force vs displacement graphs

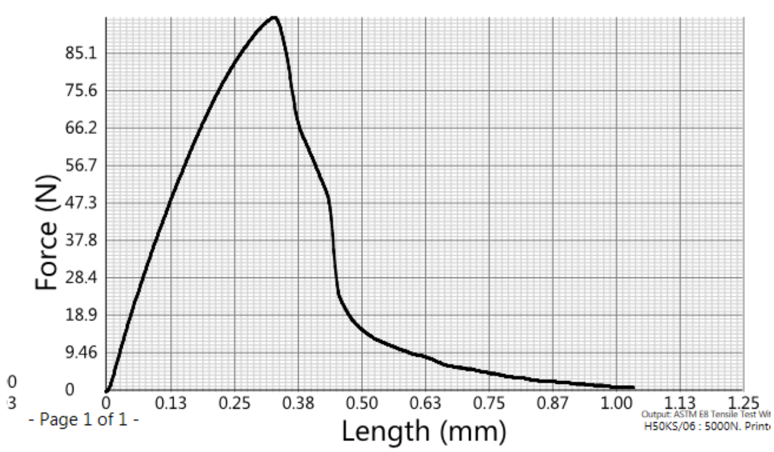
- Sample 1



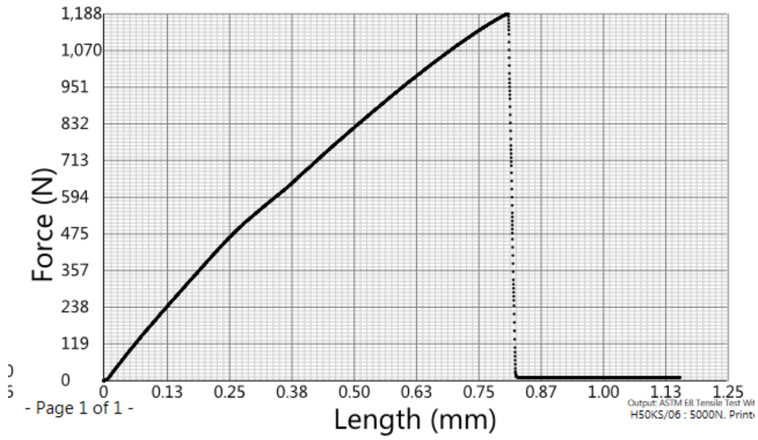
- Sample 2



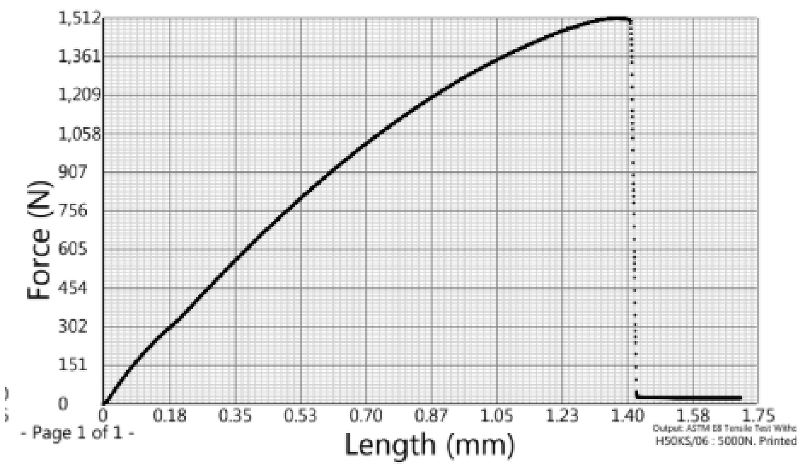
- Sample 3



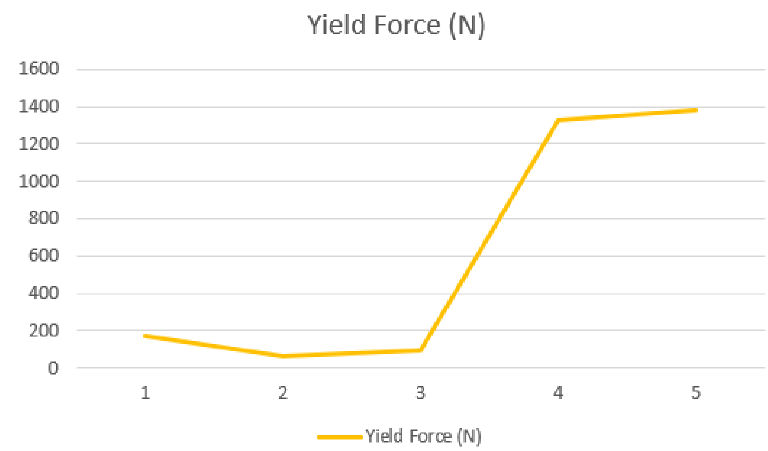
- Sample 4

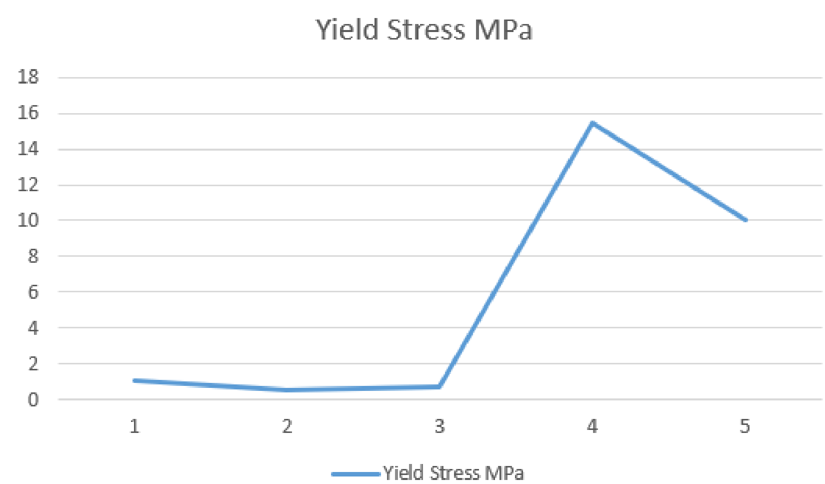


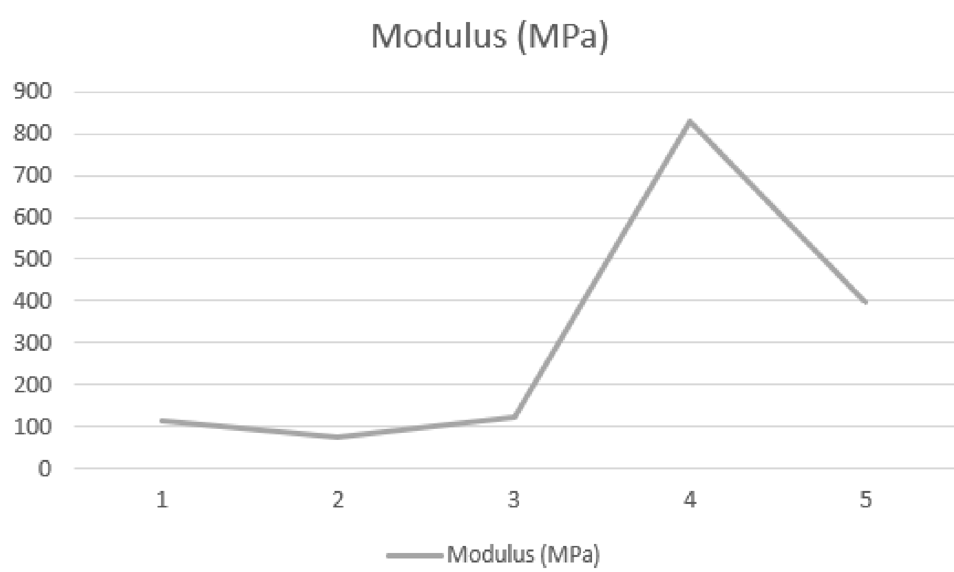
- Sample 5

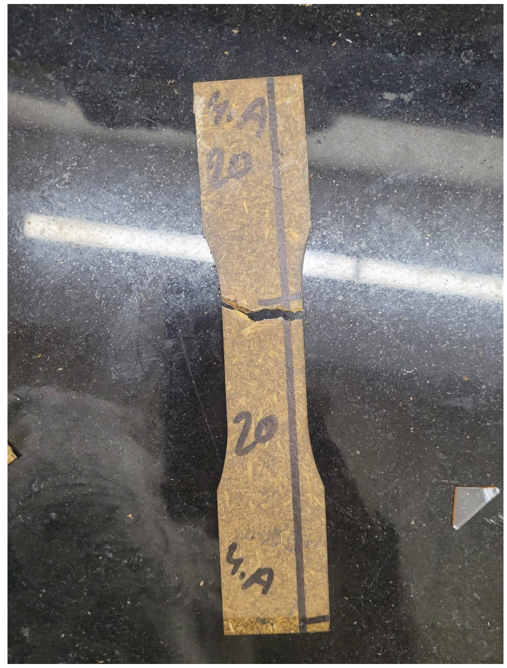


8.4 Comparison of Yield Forces, Yield Stress, Modulus (combined for all samples)





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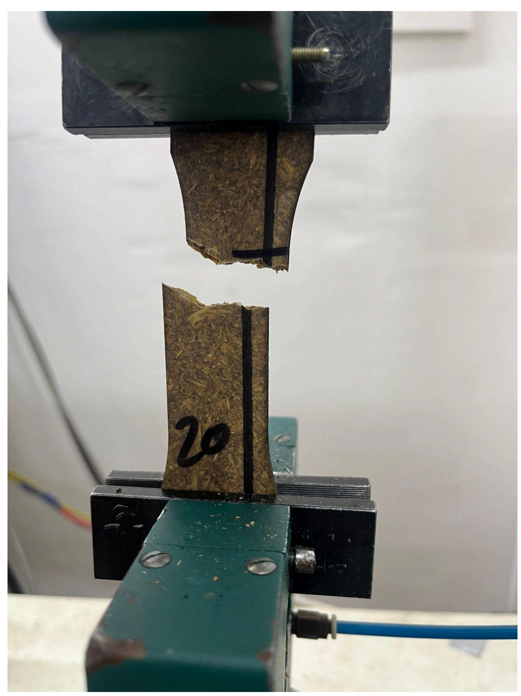
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9.0 Observations

9.1 Cutlery Trials: Material Processing and Performance

- Initial cutlery prototypes using coarsely ground rice husk and starch binder yielded poor binding, rough surfaces, and brittle, weak structures with negligible water resistance. This was primarily due to large fiber size and incomplete starch gelatinization, resulting in almost no measurable tensile, shear, or compressive strength.
- Subsequent trials with finer grinding of rice husk improved surface finish and material homogeneity, leading to smoother textures and enhanced water repellency. However, early samples remained brittle and prone to material shedding, highlighting the need for further binder optimization.
- Incorporation of carboxymethyl cellulose (CMC) into starch-based formulations significantly improved structural cohesion, reduced flaking, and increased mechanical integrity, making the cutlery more robust for single-use scenarios.
- Addition of sugar as a plasticizer in one trial led to caramelization and improper drying, causing the material to stick to molds and fail to cure correctly.
- Glycerine, when added in small quantities, increased flexibility and toughness, reducing brittleness and improving user experience.
- Application of aloe vera gel as a post-molding coating notably enhanced water-holding time, demonstrating the potential of natural hydrophobic treatments for biodegradable tableware.
- Despite open-mold limitations, the cutlery achieved satisfactory rigidity and form, indicating that with improved mold design and controlled curing, higher precision and strength are attainable for practical use.

9.2 Fiberboard Fabrication: Binder Systems and Mechanical Outcomes

- Boards fabricated with natural adhesives (starch, CMC, citric acid, and glycerine) showed poor to moderate strength and stiffness but were susceptible to moisture-induced warping and had limited load-bearing capacity.
- Adjustments in the ratio of stubble to rice husk and the inclusion of CMC improved mechanical performance, but optimal fiber dispersion and moisture control during curing remained critical to minimize warping and internal shearing.
- Epoxy resin-based boards (Samples 4 and 5) exhibited a dramatic improvement in mechanical properties, with modulus values of 830.5 MPa and 398.5 MPa, and yield stresses of 15.45 MPa and 10.045 MPa, respectively. These samples also

withstood significantly higher yield forces (1325–1380 N), confirming their suitability for structural and load-bearing applications.

- The higher density of epoxy-based boards (up to 1062 kg/m³) correlated with superior mechanical strength and dimensional stability, underscoring the importance of resin content and compaction.
- Hybrid binder systems combining natural and synthetic adhesives demonstrated potential but faced challenges in curing and demolding, often due to incompatibility or excess residual moisture.

9.3 Tensile Test Insights

- Samples 1–3 (natural adhesives) had low modulus (75.45–120.5 MPa) and yield stress (<1.1 MPa), confirming limited structural strength and suitability mainly for non-structural or disposable applications.
- Samples 4 and 5 (epoxy resin) outperformed natural adhesive boards across all tensile parameters, with Sample 4 (higher resin ratio) achieving the highest modulus and yield stress, illustrating the direct impact of binder system and content on board performance.
- Thickness and cross-sectional area influenced absolute yield force, but normalized yield stress and modulus were primarily determined by material composition and binder effectiveness.

9.4 Process and Composition Effects

- Uniform mixing, controlled moisture reduction, and precise hot-pressing were essential for consistent mechanical properties. Inadequate curing or excess moisture, especially in natural adhesive samples, led to reduced strength and warping.
- The technical role of each component was evident: rice husk provided rigidity and water resistance; stubble improved lightweight strength; starch and CMC formed the main adhesive matrix; citric acid enhanced crosslinking and water resistance; glycerine imparted flexibility.
- Imbalances in any component-excess or deficiency-resulted in compromised mechanical properties, such as brittleness, poor bonding, excessive softness, or susceptibility to moisture.

9.5 Functional and Application Potential

- Biodegradable cutlery and boards from agro-waste show promise for eco-friendly, single-use applications, with further optimization needed for durability and water resistance in reusable products.
- Epoxy-based fiberboards are immediately viable for structural and load-bearing uses, while natural adhesive formulations require further enhancement to meet similar standards.
- Surface coatings (e.g., aloe vera gel) and hybrid binder approaches offer avenues for improving water resistance and mechanical performance without compromising biodegradability.

10.0 Conclusion

This project demonstrates the significant potential of utilizing agricultural residues-specifically rice husk and stubble-for the development of biodegradable cutlery and medium-density fiberboards (MDF). Through systematic material trials, process optimization, and mechanical testing, it was established that these agro-waste-derived composites can achieve practical mechanical properties suitable for real-world applications. The use of natural binders such as starch, CMC, citric acid, and glycerine resulted in products with moderate strength and biodegradability, while epoxy-based formulations delivered superior mechanical performance and durability, making them viable for structural and load-bearing uses.

Mechanical testing following ASTM D1037 standards confirmed that the epoxy resin boards exhibited the highest modulus and yield stress, correlating with their increased density and improved dimensional stability. Natural adhesive boards, while more environmentally benign, require further optimization to enhance their strength, water resistance, and longevity for broader adoption. The addition of functional additives and surface coatings, such as aloe vera gel, further improved water resistance and surface quality, highlighting the importance of post-processing treatments in product performance.

The project also underscores the broader environmental and economic benefits of this approach. By transforming crop residues that would otherwise contribute to air pollution through stubble burning into value-added products, this solution directly addresses pressing ecological concerns while providing farmers with alternative revenue streams. The versatility, compostability, and strength of rice husk-based products position them as strong contenders in the growing market for eco-friendly tableware and packaging, with the ability to withstand high temperatures and repeated use without compromising safety or quality.

In summary, the successful fabrication and testing of fiberboards and cutlery from rice husk and stubble validate the feasibility of agro-waste valorization for sustainable product development. The findings highlight that with continued innovation in binder systems, processing methods, and product design, these materials can serve as robust, scalable alternatives to conventional plastics and wood-based composites. The project paves the way for further research into hybrid binder systems, advanced coatings, and process automation, ultimately supporting a circular economy and contributing to a cleaner, more sustainable future.

11.0 Future development

11.1 Material and Binder Optimization

Hybrid Binder Enhancement: Investigate the use of compatibilizers such as maleic anhydride or silane coupling agents to improve adhesion between natural polymers (starch, CMC) and synthetic epoxy resins.

Advanced Biodegradable Polymers: Experiment with biodegradable thermoplastics like PLA (Polylactic Acid) and PHA (Polyhydroxyalkanoates) to enhance both mechanical and environmental performance.

Nano-Reinforcement: Incorporate nano-fillers such as nano-clay, cellulose nanofibers, or graphene oxide to improve tensile strength, dimensional stability, and barrier properties.

11.2 Process Improvement

Controlled Fiber Size Reduction: Employ ball milling or cryogenic grinding to obtain uniform, fine particles, thereby enhancing binder adhesion and surface finish.

Moisture-Optimized Drying: Introduce vacuum drying, microwave drying, or infrared-assisted curing to reduce moisture-related defects such as warping, internal shearing, and incomplete curing.

Programmable Hot-Pressing: Shift to multi-stage programmable presses with variable pressure and temperature profiles to allow uniform curing and enhanced dimensional control.

11.3 Surface Treatment and Coating

Hydrophobic Biocoating: Apply natural waterproof coatings using aloe vera gel, beeswax, or shellac post-curing to improve water resistance and microbial safety for food-contact products.

UV-Curable Biopolymers: Explore the use of UV-curable plant-based resins for rapid surface hardening without the need for prolonged thermal exposure, increasing production throughput.

11.4 Structural and Mechanical Design Innovations

Reinforced Geometry for Cutlery: Design molds with ribbed or honeycomb profiles to naturally reinforce high-stress regions and reduce breakage during use.

Multi-layered Composite Boards: Implement core–shell structures, using a denser outer layer (high epoxy content) and a fibrous inner core for strength, insulation, and reduced cost.

11.5 Production Scale-Up and Automation

Modular Extrusion System: Develop a tabletop extruder for continuous paste preparation, ensuring uniform mixing and feeding into molds.

Automated Mold Handling: Incorporate servo-controlled hydraulic pressing systems with integrated mold heaters to ensure repeatable product quality and lower labor dependency.

11.6 Environmental and Economic Integration

Carbon Credit Registration: Explore eligibility for carbon credits via platforms such as Gold Standard or Verra by documenting emissions avoided through stubble valorization.

Rural Micro-enterprise Models: Establish cooperative clusters among farmers for raw material collection, primary processing, and supply chain development—enabling decentralized manufacturing hubs.

11.7 Product Diversification

Compostable Packaging Solutions: Use modified binder-fiber blends to produce biodegradable films, trays, and food containers through thermoforming or compression molding.

Architectural Applications: Explore use of MDF in interior wall panels, acoustic dampeners, or false ceilings, where biodegradable and lightweight materials are increasingly in demand.

12.0 References -

- Development of biodegradable tableware from novel combination of paddy straw and pine needles: A potential alternative against plastic cutlery. Akansha Gupta a, Garima Singh a, Pooja Ghosh a, Kalpana Arora b, Satyawati Sharma Volume 11, Issue 6, December 2023, 111310
- RICE HUSK AS POTENTIAL RESOURCE FOR BIOMEDICAL APPLICATIONS: A REVIEW Aryanny Nasir Nadia Adrus·Siti Paulienam Mohd Bohari

- Extraction and characterization of lignin from different biomass resources Dereca Watkins, Md. Nuruddin, Mahesh Hosur *, Alfred Tcherbi-Narteh, Shaik Jeelani Department of Materials Science & Engineering, Tuskegee University, Tuskegee, USA
- Research Insights into Punjab’s Stubble Burning. Menace Ruchi Kohli , Anu Mittal and Amit Mittal
- Production of Particleboard from Agricultural Waste - A Sustainable Approach to Waste Management Modupe Elizabeth Ojewumi1*, Emmanuel Omotayo Ojewumi2, Oresegun Olakunle Ibrahim3, Obanla Rukayat Oyinlola4, Faith Oluwapelumi Oladapo1, Kayode Joshua Jolayemi1
- Mechanical Properties of Particleboard Made from Rice Husk Takao Ota1* and Tomoya Okamoto2
- Analysis of Physical and Mechanical Properties of Rice Husk-based Particle Board M. Milawarni1,*, Sri Aprilia2, Nasrullah Idris3, E. Elfiana4, Y. Yassir1, Yasir Asnawi1, S. Suryati1, Novi Quintena R5, Jenne Syarif5, Nawawi Juhan5

- Conversion of rice straw into disposable food-serving bowl via refiner mechanical pulping: an environmentally benign approach to mitigate stubble burning and plastic pollution. Shashank Saini, Ashish A.Kadam,Vivek Kumar
- Candelilla wax: Prospective suitable applications within the food field. N´estor E. Aranda-Ledesma , Israel Bautista-Hernandez , Romeo Rojas , Pedro Aguilar-Zarate ´ c,Nancy del Pilar Medina-Herrera a, Cecilia Castro-Lopez ´ d,,Guillermo Cristian Guadalupe Martínez-Avila
- Review On Natural Binders. Mayur S. Desai , Sourabh P. Jadhav, Akash S. Jadhav, Mayuresh N. JadeDepartment of pharmaceutics , Rajarambapu College of pharmacy
- Development of active, water-resistant carboxymethyl cellulose-poly vinyl alcohol-*Aloe vera* packaging film Sweetie R. Kanatta,*, Sweta H.Makwanab
- https://www.researchgate.net/publication/231390976_Manufacture_of_High-Performance_Rice-Straw_Fiberboards
- https://www.sciencedirect.com/science/article/abs/pii/S0926669015000461
- https://www.researchgate.net/publication/335857348_Rice_Straw_and_Flax_Fiber_Particleboards_as_a_Product_of_Agricultural_Waste_An_Evaluation_of_Technical_Properties