Optimization and mechanical characterization of casein and seaweed resin with hemp reinforcement: a review

Abhinav Reddy Mettu[1], *Nagapuri* Pradeep[1], *Orugala* Shashivardhan[1], *A.* Anitha Lakshmi[1]*

[1]Department of Mechanical engineering, Gokaraju Rangaraju Institute of Engineering and Technology, India

Abstract. Plastic is a versatile material used in many products, but its production with petroleum-based materials has harmful environmental consequences. To address this issue, sustainable and biodegradable alternatives like hemp plastic are needed. Hemp plastic is made solely from hemp plants, which absorb four times more atmospheric carbon dioxide than other plants, making it an ideal solution. Additionally, hemp fiber is more durable than the standard fiber used in conventional plastic production. Casein, a naturally occurring protein in milk, can also be used to create biodegradable polymers for small items. Seaweed produces polysaccharides that can be used as a biomaterial or binding agent for creating bioplastics. In this project, hemp composites reinforced with casein and seaweed are created and characterized to evaluate their mechanical and chemical properties. These sustainable and biodegradable materials can replace petroleum-based plastics, minimizing their negative environmental impact.

1 Introduction

The focus will be on several recent bio-composites articles as well as several experiments and research projects involving natural fibers like hemp, sisal, and jute, resins like epoxy and vinyl ester, and fillers like coconut filler and sawdust. Madhusudhana H.K.[1]. The present project will develop replacement materials for uses like light-duty vehicle packaging or consumer goods packaging. Also, it uses organic hemp-based natural fiber to lessen the carbon impact of greenhouse gas emissions. Neves, Anna Carolina C., and others [2]. Investigate and compare the mechanical characteristics of composite materials made of polyester, epoxy, and superior hemp fiber. According to Madhusudhana H K et al.[3] Natural fiber-reinforced bio-composites are created by combining vinyl ester resin with easily obtainable hemp fiber, using a hand lay-up technique. M. K. Gupta and others [4].

*Corresponding author: anitha.akkireddy@gmail.com

In this study, various treatments will be utilized to enhance the characteristics of polyester-based hemp composites. The mechanical and dynamic mechanical properties of a hemp/polyester composite and its water absorption capacity can be altered by treatments such as alkali and benzoylation chemical processes, as well as eco-friendly methods like sodium bicarbonate treatment. A. M. Kalla et al. [5]. The intention was to improve the casein films' mechanical and water vapor barrier qualities by using cellulose fibers made from CSP. S. Musio et al. [6]. The productivity and quality of wet-spun yarns made from long hemp fibers were investigated in this study, with a focus on the influence of genotypes, harvest dates, retting processes, and processing. Two harvesting points, full bloom, and seed maturity, were considered, and typical green-stem cultivars were compared to yellow-stem varieties.P. Brzyski and others.

[7] We evaluated the ability to strengthen a binder based on hydrated and metakaolin lime by looking at the impact of adding natural admixtures of compressive and flexural strengths, as well as the distribution of pore sizes. et al. S. C.[8] Examined how the physical characteristics and behaviors of the biofilm were affected by plasticizers (glycerol), different ratios of seaweed, starch, and cellulose, and biodegradable seaweed-based bioplastic. .J. Andorra et al. [9] To lower the production costs of bioplastics while preserving their properties, PHB was combined with fillers like calcium carbonate and cellulose (CL)(CC), both of which are readily accessible, cost-effective, and biocompatible. This was achieved through the use of a heat-assisted solution casting method. L. Fernandez Espada and others [10].started with To produce materials with a high water absorption capacity and acceptable mechanical qualities, the processing parameters for manufacturing soy protein bioplastics utilizing injection molding needed to be improved. A. S. Jethoo et al. [11] This research was done to ascertain how fiber reinforcing affected the thermoplastic starch's tensile strength (TPS). H. A. Khalil et al. [12] To determine the effects of incorporating OPS nanoparticles into the seaweed films, their physical, mechanical, and morphological properties were investigated. S. Panthapulakkal [13]The primary objective of this study was to assess the effectiveness of two types of composites: polypropylene-based Composites made of short hemp fiber and glass fiber are also available. S. Lomartire.[14] Cellulose derivatives Due to their powerful mechanical capabilities, hydroxypropyl methylcellulose (HPMC) and methylcellulose (MC) were used to construct a biofilm. However, macroalgae show more promise as a bioplastic source due to their greater biomass, fast growth rate, ease of maintenance in various environments, and economic feasibility. A. Pranata [15] The impact of the immersion solvent type on the Tensile strength of bioplastics made of cellulose is demonstrated in this study. Rice straw displays the highest tensile strength, measuring 43 MPa, while tea trash, cocoa husks, and sugarcane bagasse have tensile strengths of 30.6, 20, and 6.1 MPa, respectively.Y. Yusmaniar [16] It aims to develop a palatable and green bioplastic by combining seaweed with polysaccharides from avocado, jackfruit, and durian. Yanan Song and others[17] The incorporation of hemp fibers into the composites resulted in improved mechanical properties and triggered PLA crystallization. This is attributed to the excellent homogenous dispersion, good wettability, high modulus, and uniform stress distribution of the hemp fibers as they transitioned from the continuous PLA matrix to the dispersed fiber phase. In the composite manufacturing process, pelletized fibers were used to expedite fiber separation and wetting. Asrofi, Mohamad, and others.[18] In this study, licorice root starch, tamarind seed starch, and berry seed starch were all successfully used to make bioplastic materials. Bio-plastic manufacture demonstrated better mechanical, morphological, thermal, and antibacterial properties without licorice root. Sun, R. C., and Liu, C. F. .[19] Utilizing the solution casting method, a composite bioplastic comprised was effectively created using sugarcane bagasse fiber and tapioca starch. By extending the ultrasonication time (bath type), the moisture barrier characteristics, morphological structure, and tensile strength of the composite bioplastic can be improved.Akbar Hanif Dawam

Abdullah, Masitoh, and others. [20] The bioplastic produced from cassava starch without the incorporation of CNT exhibited a high tensile strength of 7.44 MPa. However, the addition of CNT to cassava starch resulted in an optimal tensile strength at a 2% CNT concentration. The maximum tensile strength achieved for the starch/CNT bioplastic was 13.52 MPa. F. A. Syamani, et al.[21] Bioplastic made from modified cassava starch demonstrates increased tensile strength when oil palm trunk (OPT) cellulose fibers are added, compared to a bioplastic made without the addition of fiber from modified cassava starch. However, the addition of 1% OPT pulp fibers may result in only a slight increase in the tensile strength of the bioplastic. Yue, Hangbo, and other [22]Incorporating cellulose fibers from bioplastics produced from modified cassava starch and oil palm trunk (OPT)enhances their tensile strength, compared to bioplastics made solely from adaptable cassava starch. In addition, 1% OPT pulp fibers were added can also lead to a slight improvement in the tensile strength of bioplastics. Chin-San Wu.[23] The mechanical properties and compatibility of combining glass carbon fiber (GCF) with Maleic anhydride-modified PLA (PLA-g-MA) and polylactic acid (PLA) were assessed. Analysis using the results of NMR, FTIR, and XRD that the -OH groups in GCF and the anhydride carboxyl groups in PLA-g-MA reacted to form ester groups, which substantially modified the crystal structure of the composite material. The mechanical properties and compatibility of combining glass carbon fiber (GCF) with polylactic acid (PLA)and maleic anhydride-modified PLA (PLA-g-MA) were evaluated. Analysis using FTIR, NMR, and XRD revealed that the -OH groups in GCF and the anhydride carboxyl group of PLA-g-MA reacted to form ester groups, which substantially modified the composite material's crystal structure.

2. Experimentation

Madhusudhana H.K. et al. [1] studied an experimental investigation of hemp-reinforced hybrid composites (HRHC) fracture toughness.

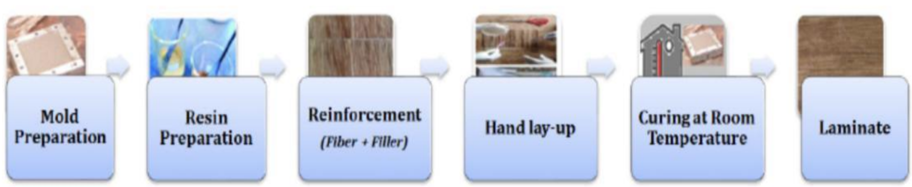

Figure 1 Hand Lay Process **[1]**

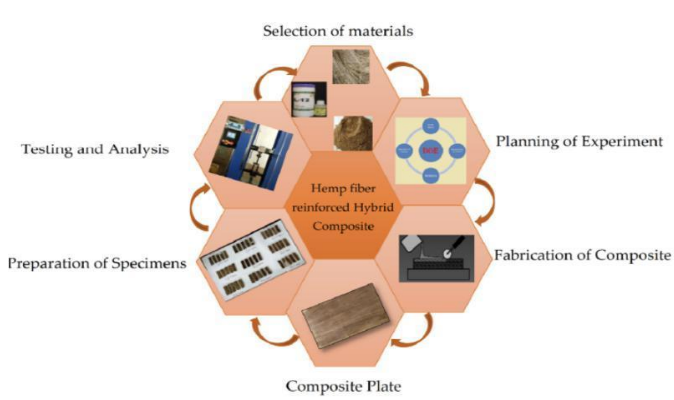

Figure 2 Flow Chart of Process **[1]**

Anna Carolina C. Neves et al. [2], Mechanical parts that met ASTM criteria were produced through flexural and tensile testing. Hemp strands that were continuous and straight were combined with polyester. or epoxy. in ratios of 10%, 20%, and 30% under pressure in steel molds. The mixture was then allowed to cure for 24 hours at room temperature. Statistical analysis using ANOVA and Tukey tests was conducted on the resulting data. This study may provide useful insights for selecting the appropriate thermoset matrix and hemp fiber content in the design of ballistic armor..M. K. Gupta and others

[4] Composites were produced using a manual hand lay-up method with a continuous fiber content of 15%. Alkali treatments involving 5% NaOH, 5% benzoyl chloride, and 5% NaHCO3 were applied to the treated hemp fibers, which were then used to reinforce the unsaturated polyester resin matrix..A. M. Kalla et al. [5] Casein films' mechanical and water vapor barrier characteristics were enhanced by incorporating reinforcement from cellulosic fibers. Coconut shell powder was used to extract cellulose. (CSP) and utilized as a natural fiber source, providing 27.5% cellulose after undergoing delignification and mercerization before being added to the casein films..S. Musio and others [6] Both unrated and dew-retted stems were subjected to scutching, with the unrated Snipped fiber bundles were bio-degummed and then hackled. The hackling and scutching processes were conducted using flax machines..L. Fernandez Espada and others [10] The impact of processing variables on the thermomechanical and hydrophilic properties of a 50/50 (wt/wt) combination of soy protein and glycerol was investigated, using the temperature of the mold, the injection pressure, and the cylinder temperature reference values of 70°C, 500 bar, and 40°C, respectively..A. S. Jethoo et al. [11] Starch-based bioplastics are hard and brittle and easily break when folded. Brittleness is reduced by using just the right amount of plasticizer as opposed to too much, which lowers the tensile strength of bioplastics. H. A. Khalil et al. [12] Incorporating OPS nanoparticles resulted in significant alterations to the structural, mechanical, and physical properties of seaweed-based films.

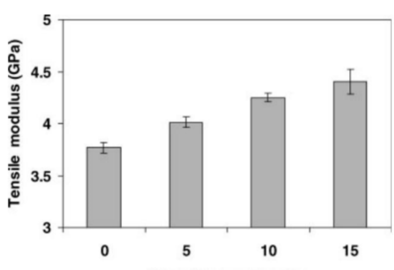

Figure 3 Tensile modulus and glass fiber content interaction of Composites made of polypropylene and hemp**.[13]**

Panthapulakkal, S. [13] It has been shown that incorporating glass fibers can enhance the flexural, tensile, and impact characteristics of composites that contain short hemp fibers..Y. Yusmaniar [16] A composite film constructed of durians had the best performance and had a 68.84% water resistance rating. Asrofi, Mohamad, and others.[18] It was discovered through the use of FTIR analysis that the different natural materials that were gathered had to cross-link. The bioplastic-based materials had good thermal stability. Sample S2 showed 99% bacterial inhibition of gram-negative E. coli bacteria

Figure 4. (a) Oil palm trunk powder, (b) Cellulose fibers isolated from oil palm trunk powder. **[21]**

Syamani, F. A., et al.[21] OPT cellulose fibers are used to create bioplastic with enhanced tensile strength, as their diameter is a little less than OPT pulps. Chin-San Wu. [23] The DSC curves indicated that the melting temperatures between PLA/GCF and PLA-g-MA/GCF decreased as the GCF content increased. However, PLA-g-MA/GCF blends were easier to handle as They required less mixing torque and had lower melt temperatures. Although B. cepacia was used as the incubator, biodegradation occurred only to a limited extent.

3. Result and Discussion:

Madhusudhana H.K et al. [1] Using the Taguchi approach, the fracture toughness behavior of HRHC is examined as a result of the variables, such as a change in the ratio of epoxy resin and fillers like banana, sawdust, and powdered coconut shell. The current research will develop replacement materials for consumer product packaging or light-duty automotive uses. Also, to lessen the carbon imprint of greenhouse emissions, it uses natural fabric produced from organic hemp. Anna Carolina C. Neves and colleagues [2], After that, the mixture of 24 hours of cure time at room temperature is permitted. Making an informed decision on the thermoset matrix and hemp fiber content utilized in ballistic armor may be aided by this. Madhusudhana H. K. and others [3] Tensile strength of the created composites was discovered to peak at 25% reinforcement, 10% filler, and an 8-millimeter-thick sample. Due to the applications of these materials, creating eco-friendly products requires a sustainable development approach. Gupta, M. K. et al. [4] In every regard, treated hemp composites outperform untreated hemp composites. A. M. Kalla et al.[5] Incorporating cellulose into casein-based composite films was found to enhance their mechanical characteristics, as shown by the notable improvements in Young's modulus and tensile strength. The results suggest that cellulose obtained from CSP could be a viable reinforcement fiber for composite film production. By utilizing composite sheets for food packaging, the use of agricultural waste is maximized while reducing pollution. S. Musio and others [6] Scutching and hacking were followed with greater strength and stiffness than seed maturity at full flowering. Green-stem varieties are less successful at scutching than yellow-stem varieties. P. Brzyski and others [7] The average pore width decreased by 0.5% and 1% in recipes containing casein but increased when the casein level reached 3% and 5%. Only 0.5% of the casein admixture decreased the total amount of porosity. The findings demonstrate a clear relationship between porosity and the strength parameters. S. C. and co. [8] The reported disintegration rate of bioplastics made from seaweed, starch, cellulose, and other composites is outstanding, while the measured heat stability and water solubility are only somewhat good. We can count on the use of plastic with this seaweed-based plastic because it is renewable and environmentally benign, and plastic pollution is growing every day. .J. Andorra et al. [9] The addition of calcium carbonate to the biopolymer resulted in composite materials with altered mechanical properties, Young's modulus has increased, among other things while the incorporation of cellulose had the opposite effect..L. Fernandez Espada and others [10] When examining the effects of processing parameters on glycerol injection molded bioplastics, it was observed that the bending characteristics of these materials were less sensitive to changes compared to their tensile properties or water absorption capacity. Interestingly, the glass transition temperature of all soy-based bioplastics was found to occur within the range of 50 to 75 degrees Celsius, which appears to be associated with regions of high protein content..A. S. Jethoo et al. [11] A bioplastic's tensile strength is dependent on the amount of fiber reinforcement present. After a certain point, it starts to fall as fiber reinforcement grows, presumably because the amount of binding agent or biopolymer has decreased. H. A. Khalil et al. [12] The nano-OPS/seaweed composite films' mechanical properties improved (except for elongation at break). The surfaces of the nano-OPS/seaweed composite films gained more hydrophilic qualities with the addition of an additional OPS nanofiller. S. Panthapulakkal (13). The composite material's strength characteristics were discovered to get better as the glass fiber percentage rose. For instance, a hybrid composite consisting of 15% short glass fibers by Flexural strength of weight was 101 MPa, and its modulus was 5.5 GPa.. S. Lomartire.[14] Due to their enormous biomass, macroalgae are thought to be a promising source of bioplastics.,fast growth rate, cost-effectiveness, and ease of cultivation in a variety of situations. Furthermore, certain seaweed species present in a biofilm can enhance packaging protection, as they contain photoprotective compounds that may absorb harmful UV rays. The bioactive

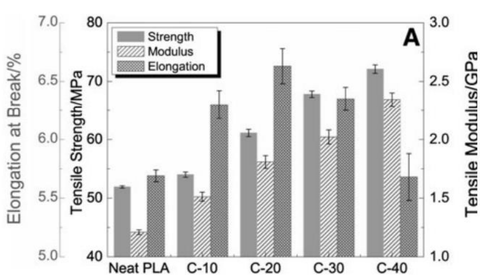

Figure 5: Effects of hemp content on the tensile.**[17]**

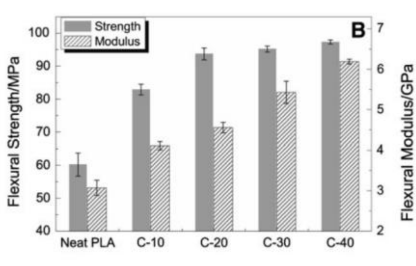

Figure 6
Effects of hemp content on the flexural [17]

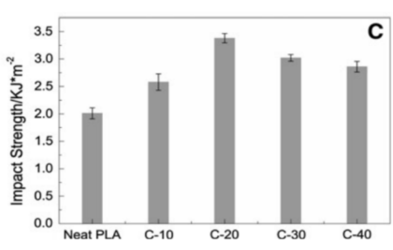

Figure 7
Effect of hemp content on impact strength.**[17]**

compounds derived from seaweed, which possess antioxidant and antibacterial properties, may also extend the shelf-life of food and drugs by increasing their preservation. A. Pranata [15] Additionally, the cellulose obtained from rice straws can be extracted trifluoroacetic acid usage (TFA), resulting in the creation of a bioplastic material with tensile strength characteristics similar to those of polyvinyl chloride and polystyrene (PVC).Y. Yusmaniar [16] Due to the reduced amylose the concentration of durian seeds compared to those of jackfruit and avocado, the durian biofilm had the maximum 4.69 MPA in tensile strength, 1.92% in yield extension, and 2.02% in elongation at break.

Song, Yanan, et al [17]. It preserved the hemp fibers' high length-to-diameter ratio, which aided in the composites' good and uniform properties. When used within a specific dose range, silane coupling agents improved tensile and flexural properties, however excessive coupling agents decreased modulus by migrating into the matrix. Mochamad, Asrofi, and others[18]. The results of this study suggest that tamarind and berry seed extract can be used to create bioplastic materials that can be used to package food. Sun, R. C., and Liu, C. F. .[19] It was discovered that the bioplastic material's maximum tensile strength increased. from 1.1 MPa (for the sample without ultrasonication) to 2.5 MPa after 15 minutes of ultrasonication. However, prolonged ultrasonication led to a weakening of the composite bioplastic material. The observed changes in the morphological structure provide evidence that ultrasonication can improve to improve the adhesive bonding between the fiber and the matrix and disperse the fiber within the matrix, thus contributing to the observed improvement in tensile strength.Akbar Hanif Dawam Abdullah, Masitoh, and others .[20] Bioplastic starch/CNT can degrade for up to 7 days when grown on the Aspergillus Niger fungus, and when CNT is added, Ca"C function groups form. F. A. Syamani, et al.[21] The results indicated that the bioplastic material produced from 1% OPT cellulose and modified cassava starch was more thermally stable than bioplastic produced using 1% OPT pulp, as the former decomposed at a higher temperature.

Yue, Hangbo, and other. [22] The thermal stability of bioplastic with 1% OPT cellulose is higher than bioplastic with 1% OPT pulp, as evidenced by the fact that In comparison to bioplainic made from 1% OPT pulp, the breakdown temperature of bioplastic made from modified cassava starch with 1% OPT cellulose was higher. Chin-San Wu [23]. The composite material comprising PLA-g-MA and GCF (20 wt%) experienced a weight loss exceeding 92% after 21 days of biodegradation. As the concentration of GCF increased, a higher degree of biodegradation was observed. Moreover, the GCF's intrinsic viscosity and molecular weight of composites exhibited more pronounced decreases, indicating a strong correlation between biodegradability and these material properties.

4 Conclusion

➢ Hemp fibers' physical and mechanical characteristics were studied to determine their suitability as reinforcement materials in composite materials. The moisture content of hemp fibers was measured at 10% when tested at 23 °C and 50% RH. This high moisture content may have a significant impact on the relatively large void content observed in composites made from these fibers.

➢ The damage that conventional and other bioplastics are causing to the environment is becoming intolerable, so hemp plastics should completely replace conventional plastics, even if using just hemp plants to manufacture plastics involves more work and resources.

➢ Adding biodegradable bioplastic to fiber will help the composite become stronger and more eco-friendly in usage than other conventional plastics available.

➢ In this investigation, we'll contrast the characteristics of two various composites. We may determine which hemp-based bioplastic composite is the best by contrasting its qualities with those of hemp-seaweed and hemp-casein.

5 References

1. H.K. Madhusudhana, M.P. Kumar, A.Y.Patil, R.Keshavamurthy, T.M.Y.Khan, I.A.Badruddin, S.Kamangar, Analysis of the Effect of Parameters on Fracture Toughness of Hemp Fiber Reinforced Hybrid Composites Using the ANOVA Method, **13(17),** (2021)
2. A.C.C.Neves, L.A.Rohena, D.P.Mantovani, J.P.R.G.Carvalho, C.M.F.Vieira, F.P.D.Lopes, N.T.Simonassi, F.S.da Luz, S.N.Monteiro, Isolation and characterization of cellulose from coconut shell powder and its application as reinforcement in casein composite films. Industrial Crops and Products**, 172,** 114122 (2022)
3. Madhusudhana H K, Bhagyashree Desai , C S Venkatesha, Experimental Investigation on Parameter Effects on Fracture Toughness of Hemp Fiber Reinforced Polymer Composites, vol. **5** (2018)
4. M. K. Gupta, R. K. Gond, & A.Bharti, Effects of treatments on the properties of polyester based hemp composite, (2018).
5. A. M. Kalla, M.Eljeeva, H. A.Pushpadass, S. Kumar, & S. N.Battula, Isolation and characterization of cellulose from coconut shell powder and its application as reinforcement in casein composite films (2022).
6. S. Musio, J. Müssig, & S. Amaducci, Optimizing hemp fiber production for high performance composite applications. Frontiers in Plant Science, **9**, 1702 (2018).
7. P. Brzyski, Z. Suchorab, & G. Łagód, The Influence of Casein Protein Admixture on Pore Size Distribution and Mechanical Properties of Lime-Metakaolin Paste, Buildings, **11(11)**, 530 (2021).
8. S.C. Shravya, V.N. Lakshmi, P. Pooja, C.M. Kishore Kumar, & B.M.S Murthy, Seaweed a sustainable source for bioplastic: a review. Int. Res. J. Mod. Eng. Technol. Sci., **3**, 2582-5208 (2021).
9. A.J. Adorna, G.R.L. Ventura, V.D. Dang, R.A. Doong,, & S.J.R.Ventura, (2022). Biodegradable polyhydroxy butyrate/cellulose/calcium carbonate bioplastic composites prepared by heat-assisted solution casting method. Journal of Applied Polymer Science, **139(7)**, 51645.
10. L.Fernández-Espada, C.Bengoechea, F.Cordobés, & A.Guerrero, Thermomechanical properties and water uptake capacity of soy protein-based bioplastics processed by injection molding, Journal of Applied Polymer Science, **133(24)** (2016).
11. A.S.Jethoo, Effect of fiber reinforcement on tensile strength and flexibility of cornstarch-based bioplastic. In IOP Conference Series: Materials Science and Engineering (Vol. **652**, No. 1, p. 012035). IOP Publishing (2019, October).
12. H. A . Khalil, Y. Y . Tye, Z . Ismail, J.Y. Leong, C.K.Saurabh, T.KLai, ... & R.Dungani, Oil palm shell nanofiller in the seaweed-based composite film: Mechanical, physical, and morphological properties, BioResources, **12(3)**, 5996-6010 (2017).
13. S.Panthapulakkal, &M. Sain, Injection-molded short hemp fiber/glass fiber-reinforced polypropylene hybrid composites—Mechanical, water absorption and thermal properties. Journal of applied polymer science, **103(4)**, 2432-2441(2007).
14. S.Lomartire, J. C. Marques. & A. M . Gonçalves, An Overview of the Alternative Use of Seaweeds to Produce Safe and Sustainable Bio-Packaging. Applied Sciences, **12(6)**, 3123. (2022).
15. A.Pranata, H.Nasution ,H. Harahap, & A.Yustira, The effect solvent type on natural fiber immersion process on tensile strength of cellulose-based bioplastic. In IOP Conference Series: Earth and Environmental Science (Vol. **912**, No. 1, p. 012062). IOP Publishing(2021, November).

16. Y.Yusmaniar, D. I .Syafei. , M.Arum, E . Handoko, C.Kurniawan, & M. R. Asali, Preparation and characterization of Seaweed based Bioplastic Blended with Polysaccharides derived from various seeds of Avocado, Jackfruit, and Durian, In Journal of Physics: Conference Series (Vol. **1402**, No. 5, p. 055097). IOP Publishing(2019).
17. Song, Yanan, et al. Mechanical properties of poly (lactic acid)/hemp fiber composites prepared with a novel method, Journal of Polymers and the Environment **21.4** (2013): 1117-1127.
18. Asrofi, Mochamad, et al. Characteristic of composite bioplastics from tapioca starch and sugarcane bagasse fiber: Effect of time duration of ultrasonication (Bath-Type), Materials Today: Proceedings, **46** (2021): 1626-1630.
19. C F Liu 1, R C Sun, M H Qin, A P Zhang, J L Ren, J Ye, W Luo, Z N Cao., Succinoylation of sugarcane bagasse under ultrasound irradiation, Bioresource Technology, **99(5)**, 465-1473(2008).
20. Masitoh, Akbar Hanif Dawam Abdullah, et al, the effect of carbon nanotube content on the nature of bioplastic from cassava starch." Jurnal Sains Materi Indonesia, **20.4** (2019).
21. F. A Syamani, et al. Characteristics of Bioplastic Made from Cassava Starch Filled with Fibers from Oil Palm Trunk at Various Amounts, IOP Conference Series: Earth and Environmental Science. Vol. **439**. No. 1. IOP Publishing, (2020).
22. Yue, Hangbo, et al, On the improvement of properties of bioplastic composites derived from wasted cottonseed protein by rational cross-linking and natural fiber reinforcement, Green Chemistry, **22.24** (2020): 8642-8655.
23. Wu, Chin-San, Renewable resource-based composites of recycled natural fibers and malleated polylactide bioplastic: Characterization and biodegradability, Polymer Degradation and Stability **94.7** (2009): 1076-1084.