International Journal of Zoology and Applied Biosciences **ISSN: 2455-9571**
Volume 9, Issue 4, pp: 26-33, 2024
https://doi.org/10.55126/ijzab.2024.v09.i04.005 **http://www.ijzab.com**

Review Article

ARBOFORM – A LIQUID WOOD TECHNOLOGY: FUTURE OF BIOPLASTICS:A REVIEW

[1]Kaviya P, [2]Divya M P, [3*]Baranidharan K, [4]Ravi R, [5]Hemalatha P, and [6]Krishnamoorthi S

[1,3,4,6]Department of Forest Products and Wildlife, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India – 641 301.
[2]Forestry, Directorate of Research, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India – 641 003.
[5]Horticulture, Department of Forest Products and Wildlife, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India – 641 301.

Article History: Received 1st April 2024; Accepted 25th May 2024; Published 1st July 2024

ABSTRACT

Arboform, also known as "liquid wood," represents an innovative and sustainable approach in material science. It is an overview of Arboform technology, its manufacturing process, properties, applications, and environmental implications. Arboform is derived from lignin, a natural polymer abundant in wood, and is produced through a patented liquefaction process that transforms lignin into a moldable thermoplastic material. Unlike plastics, it offers several advantages, including biodegradability, low carbon footprint, and renewable sourcing. Its unique composition endows Arboform with desirable mechanical properties, such as high tensile strength, low thermal expansion, and excellent dimensional stability. Its versatility lends to a wide range of applications and its biocompatibility and non-toxic nature make it suitable for use in food packaging and medical devices, addressing growing concerns over plastic pollution and human health impacts. Despite its promising attributes, challenges remain in scaling up production, optimizing material properties, and ensuring cost competitiveness with conventional plastics. Nevertheless, Arboform represents a promising avenue for transitioning towards a more sustainable and circular economy, offering a renewable alternative to petroleum-based plastics and contributing to the mitigation of environmental degradation associated with conventional plastic production and disposal. It encompasses the potential of Arboform technology in advancing sustainable development goals and fostering innovation in material science towards a more resilient and eco-friendly future.

Keywords: Arboform, Liquid Wood, Thermoplastic, Tecnaro, Injection molding.

INTRODUCTION

Global plastic production and consumption have been increasing for the past few decades because of its high versatility. Even though they encounter various industrial applications and have become extremely useful for modern society in food preservation, insulating buildings, and increasing the fuel efficiency of our vehicles, among other things they are considered harmful to the environment because of their non-biodegradable character, high production-related carbon footprint, high volumes of waste, persistent pollution and harm to wildlife (OECD, 2022). Plastics are synthetic materials derived from petrochemicals which are malleable and molded into any shape of solid objects. It has permanent deformation without breaking. Polymer products consist of a wide range of synthetic or semi-synthetic organic and inorganic compounds (Saminathan *et al.,* 2014). They can easily substitute for other materials (such as glass, metal, wood, and natural fibres) in a wide range of applications (Alvarez-Chavez *et al.,* 2011). Worldwide annual plastics production is estimated to surpass 300 million tons by 2015 (Halden, 2010). Due to the overuse of plastic it accumulates as a landfill creating pollution to land and oceans. It is found worldwide from deserts to farms from mountain tops to deep oceans even though as tropical landfills and in arctic snow. The Reports of the plastic debris in the marine environment date back half a century with continuing

*Corresponding Author: Dr. K. Baranidharan, Professor (Forestry) and Head, Dept. of Forest Products and Wildlife, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India, Email: baranidharan.k@tnau.ac.in.

accumulation on the ocean surface over the past 60 years (Macleod *et al*., 2021).

Bioplastics are type of plastic that are produced from biological materials made from natural resources such as vegetable oils and starches (Atiwesh *et al*., 2021). Bioplastic are made from renewable resources such as corn, sugars, potatoes, etc. and they are produced by a range of microorganisms (Luengo, 2003). Bioplastics are produced by converting the sugar present in plants into plastic. Thermoplastics have the simplest molecular structure, with chemically independent macromolecules. By heating, they are softened or melted, then shaped, formed, welded, and solidified when cooled. Multiple cycles of heating and cooling can be repeated without severe damage, allowing reprocessing and recycling. Consumption is roughly 80% of overall plastic consumption. Renewable thermoplastics include; poly (lactic acid) (PLA), poly (vinyl alcohol) (PVAL, PVOH), and polyhydroxyalkanoates (PHAs) are degradable (Biron, 2012). To overcome the environmental issues created by plastics, bioplastics and thermoplastics – Biodegradable natural bio- polymer liquid wood called Arboform was invented which is made of lignin and natural fibres. The invention of "liquid wood" belongs to a team of researchers Helmut Nagele and Jurgen Pfitzer from the Fraunhofer Institute for Chemical Technology (ICT) in Pfinztal (Germany) in 1996 (Plăvănescu, 2014).

LIQUID WOOD

Liquid wood is a high-quality thermoplastic biodegradable composite. The material Liquid wood is a bioplastic composite obtained from three natural ingredients: lignin, cellulose flax, hemp, or other plants, adding natural additives. The invention of "liquid wood" belongs to a team of researchers Helmut Nagele and Jurgen Pfitzer from the Fraunhofer Institute for Chemical Technology (ICT) in Pfinztal (Germany) in 1996. In 1998 they found a spin-off company Tecnaro. In 2010 they received the European Inventor Award for this innovation. The liquid wood can be processed at raised temperature and under high pressure, just like a synthetic thermoplastic material, using conventional plastic machines. Material offers sustainable and esthetical aspect with good mechanical and thermal properties at very competitive costs (given the extraordinary characteristics of it). It is a biopolymer composite made from lignin, a by-product of paper production, and other natural substances. It can be used as a substitute for plastic materials. It is of three types that include; Arboform, Arbofill, and Arboblend (Carausu, 2017). Arboform – 70% lignin plus other natural materials (Based on lignin, natural additives, and the natural fibers); Arboblend – 99% lignin plus other natural and synthetic materials (Wood plastic composite - contains the degree of biopolymers, such as lignin, starch, natural resins, waxes, and cellulose); Arbofill – 60% lignin plus other natural and synthetic materials (Biopolymer compound - it is a compound of petrochemical polymers and natural fibers, having the aspect of a natural cork) (Mazurchevici *et al.*, 2018). Characteristics of these three liquid woods are explained in Table1.

Table 1. Comparision of characteristics among types of liquid woods.

Arboform®	Arbofill®	Arboblend®
Made from 100% renewable raw materials	Made from up to 80% renewable raw materials	Made from up to 100% renewable raw materials
Biodegradable	Natural look with visible natural fibres	Biodegradable or resistant to micro-organisms
Root wood or natural fibre look	Moderate to high impact strength	Degradable in anaerobic conditions and in water
High rigidity	Moderate to high thermal resistance	Rigidity and viscosity adjustable within a large ranger
Low shrinkage	Food-compatible types	Moderate to very high impact strength
Excellent acoustic properties	Dishwasher safe	Moderate to high thermal resistance
Moderate thermal resistance	Fibre look in spruce, beech or coconut	Food-compatible types
Characteristic natural odour or odourless		Good printability and bond ability
		Good colourability using standard master batches
		Scratch resistance
		Flame-retardant as well as transparent or translucent types

ARBOFORM

Arboform is a biodegradable biopolymer material produced by heating lignin, cellulose, and natural fibres. It is a semi-crystalline biopolymer being, as it was previously mentioned, a mixture of amorphous lignin and crystalline fibre. Arboform is the trade name for bioplastic composite also known as LIQUID WOOD. As Arboform is a fully biodegradable material made from renewable resources its major composition includes lignin from kraft pulp, natural fibres, and bio-based additives of 30% of lignin, 60% of fibres and cellulose, and 10% of polylactic acid. Lignin acts as the main ingredient because it has several advantages: High functional group, High carbon content, good stability, and Good mechanical properties – due to aromatic ring and phenolic compounds, it is considered a potential material for the production of various polymers, and biomaterials due to the high content of phenolic compounds. Wood-based polymer made of lignin, cellulose, and natural additives that act as plasticizers, antioxidants, and fillers. Aramid fibres are used as base material to increase the properties of the Arboform. Dependingon the quantity of the mixed components, Arboform can be provided in three different variants: LV3 Nature, F45 Nature and LV5 Nature (Nedelcu, 2014).Adjusting both the quality and quantity of Arboform composition enables fine-tuning of strength, rigidity, dimensional stability across different temperatures, and other material properties to meet specific product demands. Plavanescu, 2014 had mentioned alternate composition of arboform variation and few biomass materials (Table 1 and Figure 1).The composition of "liquid wood" can be varied in what concerns quality and quantity allowing adjustments of strength, rigidity, dimensional stability with varying temperatures, fibres content and other material properties in order to comply with specific product requirements.

Table 2. Variations in Composition.

Matrix		
Lignin	30%	60%
Fibre reinforcement (Loose Fibres)		
Hemp	10	60
Flex	10	60
Additives		
Processing aids	0	10
Impact modifier	0	20
Flame retardants	0	15

Table 3. Properties Among variants of Arboform (Vaideanu *et al.,* 2021).

Properties	F 45 Nature	ZE 50 Nature	L,V3 Nature
Yield stress (N/mm^2)	18.2	29.2	60.0
Yield strain (%)	3	0.69	1.30
Tensile Modulus (N/mm^2)	6270	4852	6666
Impact strength(KJ/m^2)	2	5	8
Smell	Typical	Low	Very low

PRODUCTION

Process of production

Production of arboform mainly encompasses the following process; lignin extraction, addition of additives, thermal treatment, molding and shaping, and cooling and solidification. According to Tecnaro Gmbh production process involves several steps; Raw Material Selection, Extraction of Lignin, Mixing with Natural Fibers, Additives Incorporation, Thermoplasticization, Molding and Shaping, Cooling and Solidification, and Finishing and Quality Control. Raw Material Selection: Arboform is primarily made from lignin, a natural polymer derived from wood pulp, along with natural fibers such as hemp, flax, or wood flour. These raw materials are chosen for their renewable and sustainable properties. Extraction of Lignin: Lignin is extracted from wood pulp or other lignocellulosic sources through a chemical process. This involves breaking down the lignin-carbohydrate bonds in the plant material to isolate the lignin component. Mixing with Natural Fibers: The extracted lignin is then mixed with natural fibers such as hemp, flax, or wood flour. These fibers help reinforce the final material and enhance its mechanical properties. Additives Incorporation (Optional): Depending on the desired properties of the final product, additives such as plasticizers, fillers, or colorants may be incorporated into the mixture. Thermo plasticization: The lignin and fiber mixture undergoes a thermo plasticization process, where it is heated to a specific temperature to soften and become moldable. Molding and Shaping: The softened Arboform mixture is then molded and shaped into the desired form using techniques such as injection molding, compression molding, or extrusion. Cooling and Solidification: Once the material has been shaped, it is allowed to cool and solidify, retaining the desired form. Finishing and Quality Control: After solidification, the finished Arboform product may undergo additional finishing processes such as trimming, sanding, or surface treatment. Quality control measures are also implemented to ensure that the final product meets the required standards.

Table 4. Comparision of properties of arboform vs plastic materials (Tecnaro).

Property	Arboform	Polyethylene	Polypropylene	Polystyrene
Tension at break (N/mm^2)	14–22	8–30	30–40	45–65
Modulus of elasticity (in tension, N/mm^2)	2000–7000	50–500	600–1700	1200–3300
Thermal expansion (10^{-6}/C)	10–50	170–200	100–200	70
Shrinkage upon molding (%)	0.1–0.3	2–3	2–3	1–3

Table 5. Properties of arboform compared with wood panels (Wegener *et al.*, 2006).

Properties	**Arboform**	**Medium Density Fibre Board**	**High Density Fibre Board**	**Particle Board**
Density (kg/m^3)	1300-1400	650	800	650
Bending Strength	25-45	28	38	22
MOE	3700	2000-7000	4600	3500
Thickness Swelling	4.5	9	12	9
Thermal conductivity	0.38	0.14-0.16	0.18 – 0.22	0.12 – 0.13

Methods of production

Production of arboform is similar to that of plastic production. There are several types of production methods used for manufacturing which includes injection molding, extrusion, blow molding, pressing, and calendaring. Before going for production the raw materials should be combined to form granules. These granules are formed by mixing and tamping all the ingredients without applying any heat stress. A distinct method is employed to produce ARBOFORM® granules, ensuring minimal heat stress on its natural components, particularly the fibers, to preserve their integrity and reinforcing properties, contrasting with conventional plastic granulation processes. Preserving the integrity of all natural components, especially the fibers, is crucial as exposure to thermal stress could cause their decomposition, resulting in a notable decline in their ability to reinforce the material (Nagele *et al.*, 2002). Injection molding is the most widely adopted method in commercial sectors where heated polymer is forced into a mold cavity under pressure.

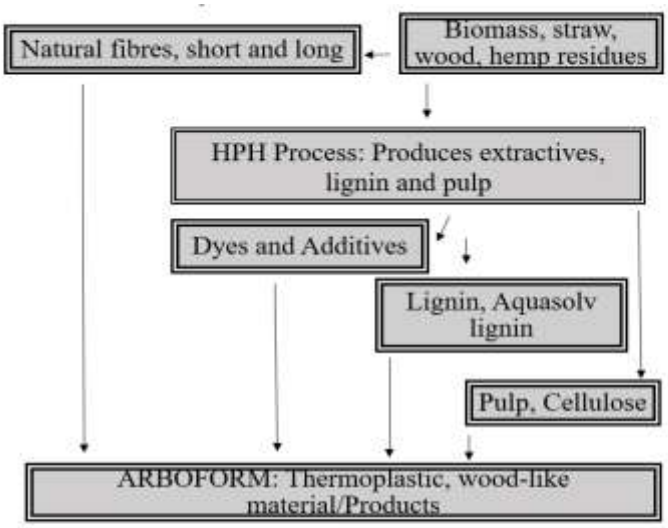

Figure 1. Biomass materials required for production of arboform.

Injection molding

Injection molding is one of the most important and efficient manufacturing techniques. Today more than one third of all thermoplastic materials are injection-molded (Gao *et al*., 2014). Injection molding is a process used for thermoplastics and thermosetting plastics. The process involves melting the plastic material and injecting it into a mold under high pressure. Injection molding is ideal for producing large quantities of identical parts with high precision and low waste. It is a four-phase cyclic process that includes the phases of filling, packing, cooling, and ejection (Kwong, 2001). Molding conditions or process parameters play an important role in injection molding. The quality of the molded part including strength, warpage, and residual stress is greatly influenced by the conditions under which it is processed. Molding conditions also affect the productivity, cycle time, and energy consumption of the molding process. Molding conditions have a close relationship with other factors such as materials, part design, and tooling, which determine the quality of the plastic products (Dang, 2014). Parameters for arboform production includes the following; injection pressure 1000 – 1800 bar (2/3 of machine efficiency), follow-up pressure 500 – 1000 bar (60% machine efficiency), injection speed 150 – 450 mm/s, back pressure 20- 40 bar, mold temperature 20 – 55^{o} c, cooling time must be about 20% higher than normal thermal plastic. Even though the paramters for production are fixed several guidelines are there to be followed; Granules should not be pre-dried, normal storage conditions (dry at temperature 25 °C). The injection molding machine manufacturing temperature is to be achieved by low-melting PE-LD (low-density polyethylene). The material must be kept in the injection molding machine maximum 15 minutes, under manufacturing temperature conditions; in the case of longer dwell time clean intermediately with LD-PE. Molding temperature should be below 160 °C. Lignin-compounds must not be maintained in the same place with other hot polymers; cool down immediately, e.g. by using water (Plăvănescu, 2014). The granules are electrically heated at (150-170) °C for Arbofill Ficher, Arboform L, V3 Nature 160°C, Arboblend V2 Nature (160- 180)°C and Arboform L, V3 Nature reinforced with Aramid Fibers (165- 180)°C, the melt homogenized thermally by mechanical shear between cylinder and screw is injected into a mold afterwards, which is cooled and solidified with water at room temperature. The water transfer into the mold is ensured by a circuit provided with a cooler (Nedelcu *et al*., 2013).

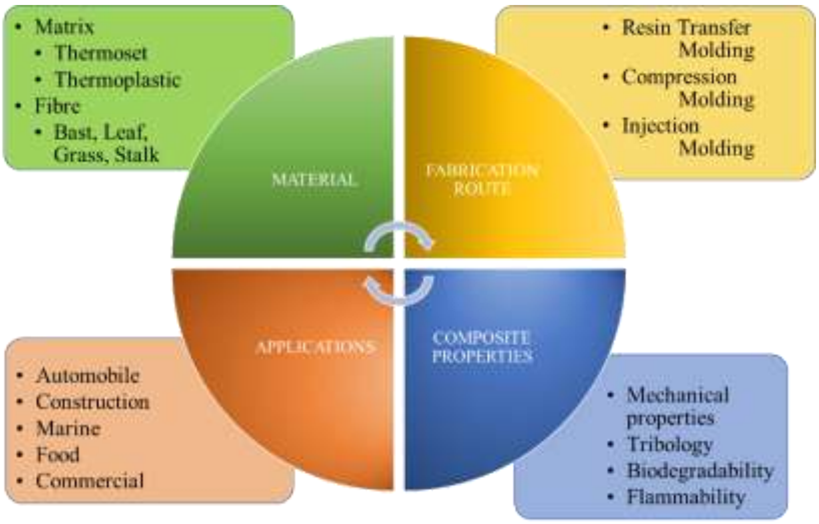

Figure 2.Overview of Arboform production (Akhil *et al.,* 2023).

PROPERTIES

Arboform behaves like any petrochemical plastic material which means it can be heated and molded/ injected into a broad range of complex moldings. It combines the positive properties of natural wood with the processing capabilities of thermoplastic materials. The Arboform formula indicates a major dependence of the mechanical properties on the content of fibres (particularly hardwood fibres), which ensures a wide range variation of the injection molded parts material properties. Properties of arboform includes; Tribological property, Biodegradability, Flammability, and Mechanical properties.

Tribology

The tribological behavior of a material refers to how it interacts with other surfaces when subjected to friction, wear, and lubrication. While specific studies on the tribological behavior of Arboform may be limited, some general characteristics can be inferred based on its composition and properties. Study of friction wear lubrication in the design of bearings. Science of interacting surfaces in relative motion. Arboform, being a lignin-based biopolymer, is likely to exhibit certain tribological characteristics: The samples were produced in an industrial-scale injection molding machine. Nanoindentation experiments have revealed that, in both series of biopolymer samples, an increase in temperature or a change in the injection direction from 0 deg to 90 deg produces an increase in hardness. On the other hand, Young's modulus is slightly affected by the increase in temperature, and not affected by the injection angle. Tribological characterization has shown that all samples, except the AR-AF injected at 175 °C, present noticeable wear and have a similar friction coefficients $\mu \sim 0.44$–0.49 at Hertzian contact pressures p_0 between 90 and 130 MPa. Interestingly, the reinforced polymer produced at 175 °C shows no wear and low friction of $\mu \sim 0.19$ at $p_0 = 90$ MPa. Our results show that the reinforced Arboform biopolymers are a good candidate to replace other polymers in many mechanical and tribological applications (Broitman *et al.*, 2019).

Biodegradability

In terms of biodegradation, arboform behaves like wood as it decomposes into water, humus, and carbon proving it to be more eco-friendly than plastics emitting fumes when incinerated. Degradability rate of arboform , arboblend and cellulose were shown in Fig 4. The material properties – biodegradability and reusability up to ten times without modifications of its features - recommended it to be the near future alternative to all plastic materials. In aqueous medium arboform completely degrades in 120 days (Plăvănescu, 2014).

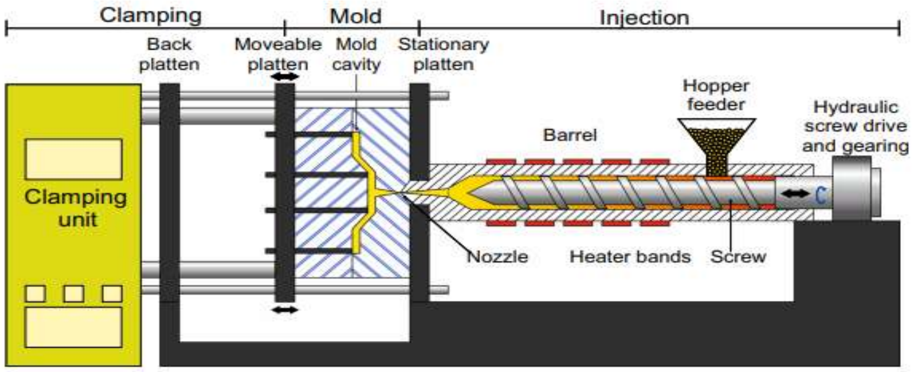

Figure 3. Injection molding process Khosravani, M. R., & Nasiri, S. (2020).

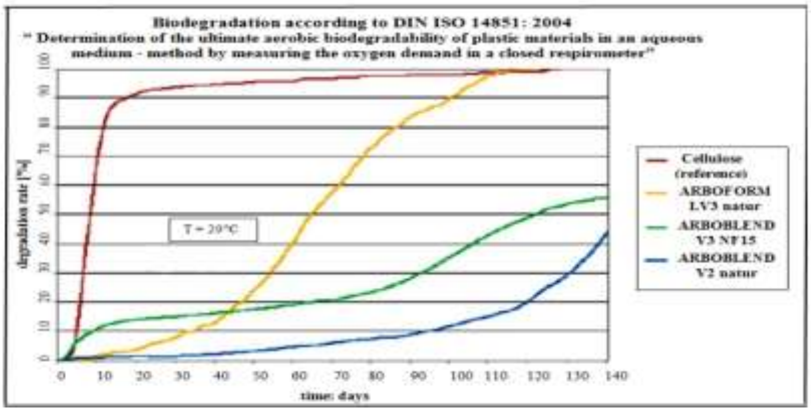

Figure 4. Biodegradation of Liquid wood (Plăvănescu, 2014).

Flammability

As arboform is composed of lignin and natural polymers it has better to heat and flame because lignin itself is a flame-retardant, only a small amount of extra specific additives has to be used (no more than 10%). It has a good resistance to chemical agents (average resistance to acids & alkalis) and thermal stability, are infused, does not shrink, and is carbonized at temperatures above 500 ˚C and are thermally stable up to 95 °C. Special quality of aramid fibers make increases the resistance of arboform due to its special characters which includes; high toughness, thermal expansion zero absorption vibration, shock absorbing, shock and fatigue resistant and good thermal insulation (Puiu *et al.*, 2018).

Mechanical property

The mechanical properties values are very close to those of wood-like plastics with commercial lignin. Properties include; Impact strength, Tensile strength, Bending strength, Modulus of Elasticity, and Hardness. When the amount of cellulose in Arboform is increased from 30 to 60%, Tensile strength increases from 9.5 to 14.5 N/mm^2, Bending stress increases from 23 to 39 $N/mm^{2,}$ and Indentation hardness and impact strength remain almost constant. Mazurchevici 2015 studied the surface characteristics of arboform by ASTM standards in an controlled environment and reported that Arboform L V3 Nature has 24.15 Ω and Arboform L V3 Nature + Aramid Fiber has 12.33 Ω Surface resistivity. A study was conducted by Nedelcu *et al.,* 2014 to test the impact resistance of liquid wood by charpy impact tester using ISO standard showed an result of 11-15 kJ/mp for arbofill, 20-26 kJ/mp for arboblend and 8-a4 kJ/mp for arboform and reported that it has the ability to replace plastic material in an wider aspect. Some of the properties of arboform are compared with variants of arboform, plastic materials and wood panels which are shown in table 3, 4, 5 respectively.

APPLICATIONS

Arboform is a material which has the ability to replace plastic materials can be used in all sectors instead of plastic. As it is biodegradable, non-pollutant to the environment most of the people shows their interests towards using of ecofriendly materials. It can be used in construction, automobiles, household, furniture, musical instruments, the electrical industry, toy manufacturing, etc (Tecnaro).

CONCLUSION

Arboform a lignin based biodegradable polymer with its innovative liquid wood technology, represents a promising future for bioplastics. Through its unique manufacturing process that minimizes thermal stress on natural components, particularly fibers, ARBOFORM showcases the potential of sustainable materials in reducing environmental impact while maintaining performance standards. As industries continue to prioritize eco-friendly alternatives, ARBOFORM stands out as a frontrunner, offering a glimpse into the exciting possibilities of bioplastics in shaping a greener and more sustainable future.

ACKNOWLEDGMENT

The authors express sincere thanks to the head of the Dept. of Forest Products and Wildlife, Forest College and Research Institute, TNAU, Mettupalayam, Tamil Nadu, India for the facilities provided to carry out this research work.

REFERENCES

Saminathan, P., Sripriya, A., Nalini, K., Sivakumar, T., &Thangapandian, V. (2014). Biodegradation of plastics by Pseudomonas putida isolated from garden soil samples. *Journal Advance Botany Zoology*, *1*(3), 34-38.

Organisation for Economic Co-operation and Development. (2022). *Global plastics outlook: Economic drivers, environmental impacts and policy options*. OECD Publishing.

MacLeod, M., Arp, H. P. H., Tekman, M. B., & Jahnke, A. (2021). The global threat from plastic pollution. *Science*, *373*(6550), 61-65.

Alvarez-Chavez, C. R., Edwards, S., Moure-Eraso, R. L., and Geiser, K. (2011). Sustainability of Bio-based Plastics: General Comparative Analysis and Recommendations for Improvement. *Journal of Cleaner Production*, 23 (1), 46-7

Halden, R. U. 2010. “Plastics and Health Risks.” *Annual Review of Public Health* 31, 179-94.

Luengo, J. M., Garcia, B., Sandoval, A., Naharro, G., and Olivera, E. R. 2003. Bioplastics from Microorganisms. *Current Opinion in Microbiology,* 6, 251-60

Atiwesh, G., Mikhael, A., Parrish, C. C., Banoub, J., & Le, T. A. T. (2021). Environmental impact of bioplastic use: A review. *Heliyon*, *7*(9).

Biron, M. (2012). *Thermoplastics and thermoplastic composites*. William Andrew.

Plăvănescu, S. (2014). Biodegradable composite materials arboform: a review. *International Journal of Modelling Manufacturing Technology*, *6*, 63-84.

Mazurchevici, S., Quadrini, F., & Nedelcu, D. (2018). The liquid wood heat flow and material properties as a function of temperature. *Materials Research Express*, *5*(3), 035303.

Carausu, C., Comaneci, R., & Nedelcu, D. (2017, October). The influence of technological parameters on the dynamic behavior of “liquid wood” samples obtained by injection molding. In *AIP Conference Proceedings,* 1896, (1). AIP Publishing.

Nedelcu, D., Plavanescu, S., & Puiu, E. (2014). Impact resistance of “liquid wood”. *Advanced Materials Research*, *1036*, 13-17.

Nägele, H., Pfitzer, J., Nägele, E., Inone, E. R., Eisenreich, N., Eckl, W., & Eyerer, P. Arboform–athermoplastic, processable.

Dang, X. P. (2014). General frameworks for optimization of plastic injection molding process parameters. *Simulation Modelling Practice and Theory*, *41*, 15-27.

Kwong, C. K. (2001). A case-based system for process design of injection moulding. *International Journal of Computer Applications in Technology*, *14*(1-3), 40-50.

Gao, H., Zhang, Y., Zhou, X., & Li, D. (2018). Intelligent methods for the process parameter determination of plastic injection molding. *Frontiers of Mechanical Engineering*, *13*, 85-95.

Khosravani, M. R., & Nasiri, S. (2020). Injection molding manufacturing process: Review of case-based reasoning applications. *Journal of Intelligent Manufacturing*, *31*, 847-864.

Nägele, H., Pfitzer, J., Nägele, E., Inone, E. R., Eisenreich, N., Eckl, W., & Eyerer, P. (2002). Arboform®-a thermoplastic, processable material from lignin and natural fibers. *Chemical Modification, properties, and Usage of Lignin*, 101-119.

Broitman, E., Nedelcu, D., Mazurchevici, S., Glenat, H., & Grillo, S. (2019). Tribological and nanomechanical behavior of liquid wood. *Journal of Tribology*, *141*(2), 022001.

Puiu, E. L. E. N. A., Leontie, L. I. V. I. U., Dumitraş, M. I. H. A. I., Asandulesa, M. I. H. A. I., Văideanu, D. O. R. I. N., & Petrescu, T. C. (2018). The thermodynamic behavior of "liquid wood". *Buletinul Institutului Politehnic Din Iaşi*, *64*(1), 201.

Akhil, U. V., Radhika, N., Saleh, B., Aravind Krishna, S., Noble, N., & Rajeshkumar, L. (2023). A comprehensive review on plant based natural fiber reinforced polymer composites: fabrication, properties, and applications. *Polymer Composites*, *44*(5), 2598-2633.

Wegener, G., Windeisen, E., Scholz, G., Schrader, C., Pfitzer, J., & Nägele, H. (2006). Material alliance of lignin with natural fibres. *Proceedings of the 9th EWLP*, 126-129.

Văideanu, D., & Petrescu, T. C. (2021). A comparative study of the properties of different "Lichid Wood" presentation forms. *Buletinul institutului politehnic din iaşi. SecţiaMatematica. MecanicăTeoretică. Fizică*, *67*(2), 27-41.