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Design of Sustainable Noise Barriers for Highway Applications - A Review

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A B S T R A C T

In many countries, highway traffic noise is one of the main reasons leading to noise pollution. Various solutions are available for managing road traffic noise, but noise barriers remain the simplest, most effective, and widely used solution. These barriers are commonly installed along highways in proximity to acoustic-sensitive areas, like residential zones, hospitals, and schools. The sound-absorbing materials used in noise barriers mainly consist of inorganic and synthetic composites, like glass wool, stone wool, and polystyrene. While these materials offer cost-efficiency and high sound absorption capabilities, their production processes often have significant environmental impacts. Moreover, many of these materials are non-biodegradable, posing risks not only to human health but also to the environment.

This highlights the urgent need to develop and adopt alternative noise absorption materials derived from organic and sustainable sources. Natural materials such as coconut fibers, sugarcane bagasse, bamboo charcoal, and merino wool, as well as recyclable materials like sawdust and plastic waste, show promise as viable substitutes. These materials, in addition to reducing environmental impact, also offer opportunities for sustainable design in noise barriers. This paper reviews various studies on the mentioned subject, identifies gaps in current research, and highlights potential directions for future studies.

Keywords : *Noise Barriers, Sound Absorption Coefficient (SAC), Synthetic-Fibers, Natural fiber composites, Sustainable Materials.*

1. Introduction:

Highways are integral to modern infrastructure, facilitating transportation and driving economic growth. However, the increasing volume of highway traffic has brought significant environmental challenges, with noise pollution emerging as a critical concern. Extendedacquaintancewith highway noise adversely disturbs the health and welfare of communities in nearby residential areas, schools, hospitals, and other noise-sensitive zones. To address these issues, noise barriers have become a widely adopted solution for mitigating highway noise.

Traditionally, noise barriers have been constructed using materials,for example, rock wool, glass wool, and polystyrene, which have efficient sound absorption efficiency at a relatively low cost. However, these synthetic and inorganic materials often have substantialecologicaleffects during their manufacturing and are non-biodegradable, raising concerns about sustainability and long-term ecological effects. This has led to growing interest in designing sustainable noise barriers using natural and recyclable materials that can provide effective sound absorption while minimizing environmental impact.

This review paper focuses on the design of sustainable noise barriers for highway applications, emphasizing the use of alternative materials such as natural fibers (e.g., coconut fibers, sugarcane bagasse, and bamboo charcoal) and recyclable waste (e.g., sawdust and plastic waste). The paper critically examines the work on the acoustic properties and environmental implications due to these materials and highlights gaps in current research. By identifying opportunities for innovation and future studies, this study aims to contribute to the development of biodegradable noise barrier designs that align with global sustainability goals.

1.1 Methods of controlling noise on highways :

The various noise issues involving highways may be addressed by:

a) Control of motor vehicle noise sources.

b) Modification of the highway configuration.

c) Restriction of the transmission path of noise.

The noise barriers with various sound insulation materials or by various land-use, like earth berms, obstruct the path of sound, either by reflection or absorption of noise, so that this noise does not reach the protected area. The application of noise barriers is the utmostcommon method for the regulation of highway noise. Noise barriers comprise upright walls, earth ridges, or combinations of the two.

1.2 Working of Noise Barriers :

The noise barrier is positionedbetween therecipient and noise source, to prevent sound from imminent therecipientdirectly, as shown in Fig. 1. They are positioned to shieldhumansliving in the vicinitywho are susceptible to noise pollution. Noise barriershave a perforated outer material to capture the noise and acore made of materials,disperse incident sound waves. The core material is made up of other materials thatdiffuse sound waves inside the barrier.

Due to their high sound absorption properties, the quantity of noise absorbed by the barriers will beimproved, resulting in lower levels of noise in the nearby areas, keeping sound from passing through the panel. Refining sound absorption properties of the noise barrier and decreasingthe echoed sound can effectively reduce undesirableinfluencesof traffic sound on human settlements. Systematicallyscheming and devisingnoise reduction facilities, such as noise barriers, has the utmostnotable effects on noise reduction and absorption.

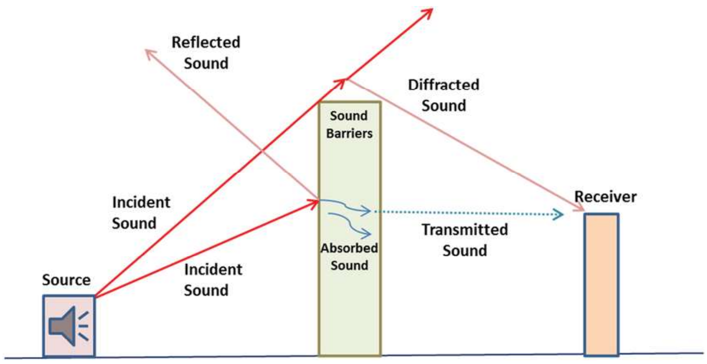

Fig. 1. Working of Noise Barriers [12]

1.3 Natural-fiber composites in Noise Barrier :

Many studies were conducted to investigate the utilization of natural fiber as a sound absorption material in noise barriers. The use of natural fibers does not disturbthe environment throughout their creation and application. Also, discarding natural fibers is not troublesome, like synthetic materials, as they are made from natural resources. Therefore, research on the utilizationof diversenatural fibers in sound insulation applications, like noise barriers, acoustic enclosures, etc., is important to achieve the goal of sustainable development. The important objectives of thestudyare to review the usage of natural-fiber composites as a substitutefor artificial materials, as sound absorption materials in noise barriers.

2. Literature review :

The noise barriers used on different highways mainly have perforated outer material, which mainly absorbs the noise, thereby reducingthe reflection of incoming sound waves. The various sound-absorbing materials possessing high sound absorption efficiencies are usually made up of synthetic material, which cannot be disposed of in the solid state in the environment, nor can they be incinerated in industries, as they create a large volume of air pollution.

2.1 Problems with Synthetic Fibers :

Mamun et al.,[1] highlights some problems with the synthetic fiber waste, including their non-biodegradability, which results in waste accumulation in the form of landfills, which impact the environment. They also reviewed various recycling methods for synthetic fibres, including mechanical, chemical, and biotechnological approaches.

Bhalla & Singh, 2017 [2]presented the harmful and dangerous effects of synthetic and semi-synthetic fibers on human health by summarizing the various chemicals used in the manufacturing of various synthetic textile fibers, along with their toxicities.

The fibers are the lowest unit raw material, used for producing yarns and fabrics in the textile industry. There are two types of fibers,natural fibers and man-made fibers. The natural fibers, obtained from vegetables, animals, or minerals, such as cotton, jute, linen, wool, and silk. The man-made fibers, obtained from synthetic fibers, are made in laboratoriesusing chemicals. Therefore, the usage of synthetic fibers is harmful to the environment and human health.

2.2 Modifications in Existing Noise Barriers :

Fode et al., [3] reviewed the effects of waste synthetic fibers, specifically covering several synthetic materials, polyester, nylon, and polyethylene replacement, on the physical, mechanical, durability, and microstructural properties of concrete. Many studies indicatethat reinforcing waste artificial fibers in concrete by 0.1 –1% ofthe weight of cement diminishes workability, increases compressive, bending, and splitting tensile strength, and improves durability.

Lokhande et al.[4]reviewed highway noise abatement across different regions and illustrated the effectiveness of noise barriers, and suggested various eco-friendly alternatives. The study comprisesdiverse types of noise barriers and theircrucial parameters, likethe type of material used, design characteristics, attenuation, cost-efficacy, and life-cycle cost analysis (LCCA).

The concrete noise barrier exhibitsmaximum sound attenuation ranging from 5 dB(A) to 15 dB(A) and possessesa longstanding service life. Also, vegetation belts can be an alternative to concrete noise barriers. The grouping of two can prove to be anadditionaloperative noise barrier, where vegetation can act as an absorbent material and a concrete fence as a barrier. They also recommend using different natural fibers in sound absorbers, e.g., jute, flax, hemp, pineapple, sisal, and banana.

Lavrentjev and Rämmal [5] showed that the reflective surface of the noise barriers results in decreased performance, because the noise is reflected to its noise source and can reflect back again,as an arrangement of parallel walls is very common in highway applications. They found that an array of Helmholtz resonators (HRs), formed in the barrier surface, causes improved absorption in the material.

Fig. 2. Array of the HR formed on the surface after drilling holes [5]

Haron et al.[6]demonstrates the effectiveness of an existing noise wall barrier installed in schoolpremises for shielding noise from heavy traffic. The study consists of characterizing road traffic noise bands and evaluating the effectiveness of wide band sound insertion loss and low-frequency noise reductioninthe range of 20 to 200 Hz. The results exhibited that the barrier altered the characteristicsrangeof road traffic noise butwas not able to decrease sound pressure level (SPL) below the allowable limit of the World Health Organization (WHO) for the school area, and lessen the low-frequency noise sufficiently.

Obadiah [7] investigates two problems in their study. One is the impact on the lives of people due to noise, and the other is the solution to road noise problems. Dense vegetation screen planting can be used as a noise barrier, but this arrangement only provides minor acoustic attenuation, about 1 dBA for a 10m depth.

Deaconu et al.[8] performed simulation and experimental assessments of the sound absorption coefficient of a material, based on a transfer function method according to standard SR EN ISO 10354-2. The simulation assessment is performed with the help of ACTRAN software. The results are obtained for variousthicknesses to establish a relationship between thickness, absorption coefficient, and frequency response.

Jiang and Kang [9] investigated the performance of noise barriers in reducingthe environmental impact of motorways, not only their effect on reducing noise and visual intrusions of moving traffic, but also their effect onvisual impact itself. They carried out various experiments using computer-imagined video scenes and motorway road traffic noise soundtracks to show experimental circumstancesunder various conditions.

There area total of five conditions in the study, whichinclude motorway only, motorway and tree belt, motorways and 3-meter timber barrier, 5-meter timber barrier, and 5-meter translucent barrier. The outcomesof the study presented that noise barriers help reducethe ecological impact of motorways but contributed no note worthy variations in ecological quality, when the influence of motorways remainedlittle. Hence, noise barriers presentedreductionproperties like a tree belt but showed to be additionally beneficial when road traffic levels went high.

Halim et al.[10] investigates the efficacy of different noise barriers, i.e., vegetation, concrete hollow block, and panel concrete at three urban residential areas aroundthe Klang Valley region in Malaysia. The three forms of noise barriers stood positioned next to Sungai Besi Highway, DUKE & KESAS Highway, respectively. The insertion loss offered by barriers was used to identify the efficacy of the same.

Vegetation documented the lowermost insertion loss in the study. The concrete hollow blocks are acompetentform of noise barrier to shield receivers from noise pollution due to road traffic. Thus, a pane of concrete offerssteady insertion loss and surpasses the smallest value of operative noise barrier, followed by concrete hollow block and vegetation.

2.3 Alternative Materials to Synthetic Fibers :

Segura et al.[11] used agricultural and agro-industry waste material to address noise and thermal insulation problems. They investigated a multi-layered panel prepared from coconut fibre and fruit stones,as of agro-industry leftover for acoustic attenuation, acoustic, and thermal transmission.

Laxmi et al. [12] investigates the feasibility of combinations of Waste Tyre Rubber (WTR) granules with Fly-Ash (FA) for making efficient and lightweight sound absorption material. This study addresses the disposal of amassing WTR is a substantialecological problem across the globe. They plan and develop a compound mix by means of FA, WTR granules with cement. The constituents are dry-mixed in several proportions. Cylindrical molds with two diameters and a defined depth are used to examine acoustic properties, employing standard ISO 10534–2. In addition to the assessment of compressive strength, samples' acoustical parameters are also determinedby means of impedance tube test for the evaluation of acoustic properties of the composite matrix designed fora sound barrier.

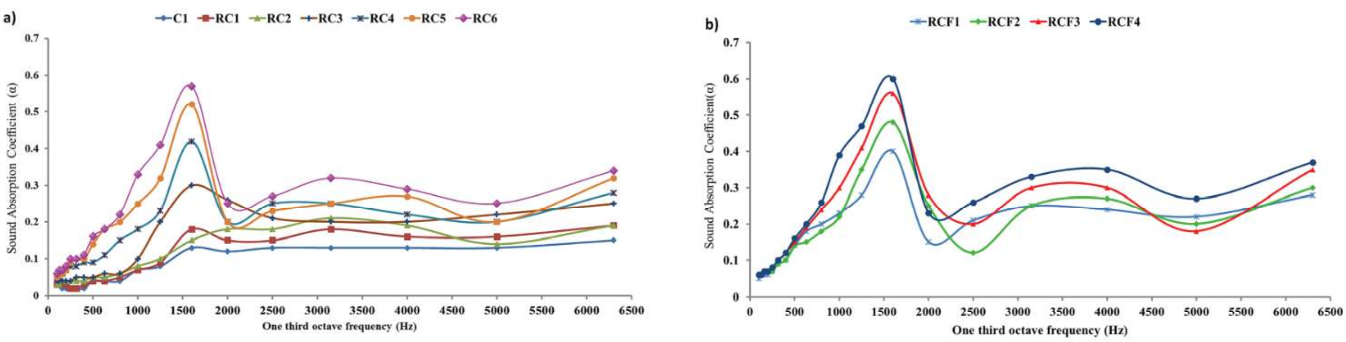

Fig. 3. SAC of composite matrices in 1st stage and 2nd stage of the study[12]

Xie et al.,[13] conducted a study on the creation of cement-based composite material by utilizing industrial waste fly-ash cenosphere and waste glass fibers for road sound barriers. They studied the material proportion of sound capture, insulation, and improved material properties.The material was tested for compressive strength using GB/T 50081-2019 standard, sound absorption property examination by ISO 10534:2001 standard, using an impedance tube testing system, using transfer functions between microphones.

The results summarize that the sound absorption layer obtained good results with a certain forming compression and aggregate-to-binder ratio. The thickness proportionbetween sound capture and insulation layers is kept as 60:40, acoustic transmission loss of the materialarrives at 38 dB.

Sakthivel et al., [14] conducted a study on thermal and sound insulation samples developed from sugarcane bagasse and bamboo charcoal for automotive applications. The ingredients used forthe study are waste sugarcane bagasse and bamboo charcoal. The bagasse fiber and bamboo charcoal are prepared by compression molding.

Five specimens of sugarcane bagasse fibers and bamboo charcoal with severalamounts of resin are prepared. The standard sound absorption coefficients (α) are measured according tothe standard ASTM E 1050-10. Thecreated specimensexhibitedimproved sound absorption propertiesinthe frequency range of 50 Hz to 4000 Hz. Itwas observed that as the frequency upsurges, the sound absorption coefficient (SAC) of all specimens also grows. Therefore, sound absorbing performance changes linearly with the thickness.

Silva et al.,[15] assessed the sound absorption coefficient of samples made with three natural fibers, i.e., sisal, coconut husk, and sugar cane, using empirical and experimental methods.The study aimed to explore the choice of natural fibers as analternative to synthetic fibers, as shown in Fig. 4.

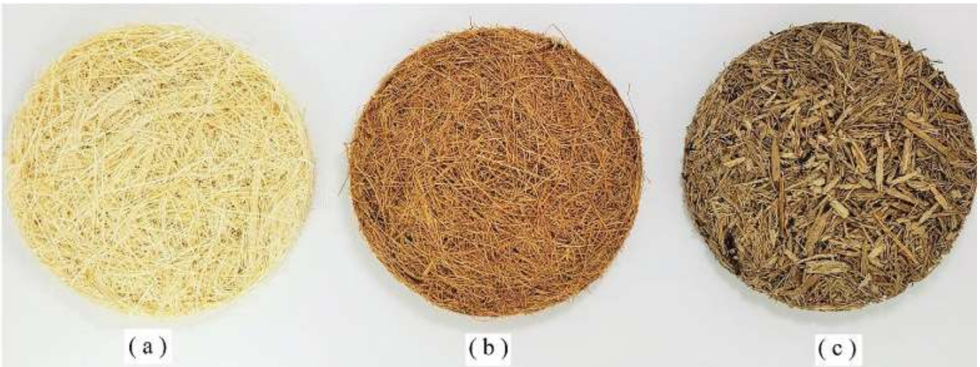

Fig. 4. Samples: a) sisal, b) coconut husk, and c) sugar cane [15]

In the study, ten samples were created, each with three fibermaterials and with different thicknesses were evaluated. The experiential methodsof Delany and Bazley, Allard, and Champoux were employed in this study. The results of the experiential methods were compared with the results of experimental investigationby means ofthe transfer function method employing standard ASTM 1050-12, which usesthe impedance tube test, shown in Fig. 5.

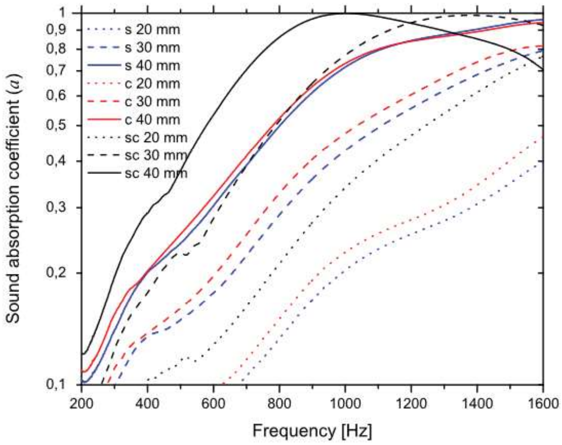

Fig. 5. Comparison of empirical and experimental results, sisal-(s), coconut husk-(c), sugarcane-(sc) [15]

Rubino et al., [16] investigates the performance of composite materials made from the use of fibers from recycled textile wastes,and building materials for sound absorption,showing better sound-absorbing properties. The experimentalconstituentswerepreparedwith 100% fibers of Merino woolin addition toChitosan and gum arabic, which were natural binders.

The computation of sound absorption wasexecutedwith transfer function methods. The absorption coefficients of the created fibrous specimens wereacquired. Also, variation of porosity, affecting air flow-resistivity of specimens, impacts acoustic performance. The extraporous specimens were categorizedthrough lower air flow-resistivity, exhibitedimproved sound absorption in mid and high frequency ranges (above 500 Hz).

Badida et al.[17] carried study focused on the utilization of new acoustic materials, produced from old materials from automobiles, e.g., foam, textile, rubber, and tires. The acoustic parameters, i.e., sound absorption coefficient, transmission loss, were tested, and acoustic properties of materials were laterenhancedbasedonthe tested values.

Three materials consisting of Ekomolitan, recycled rubber &Nobasil, with their diversemixtures, were used inthe creation of various test specimens. Based on measurements of the reduction index R of tested materials, Nobasil gave the greatest outcomes, trailed by recycled rubber and Ekomolitan.

Gil-Lopez et al. [18] studied to determine and evaluate the use of a mixture of shredded palm tree pruning waste with dampened topsoil in the construction of noise barriers. There were 12 diverse material specimensexamined, varying in thickness, composition, and quantity of water added. To findthe most appropriateratios for achieving greater soundproofing.

The specimen exhibiting the greatest sound insulationwas found to havea ratio of 50% soil and 50% chippings. It exhibits totalsound insulation of in excess of 23 dB. The environmental cost is almost zero, given that effluentproduced by the apparatus is used to create a barrier. Also, these materials can helpenrichthe topsoil for gardening after the completion of barrier life.

Del Rey et al. [19] designed and tested novel green sound-absorbing materials, used in the creation of noise barriers. These reprocessed textile constituents and nontoxic binder fibers were used inthe productionof eco-materials. The different ratios of reprocessed materials, having diversefractions, were studied. It was found that samples with matching ratiosvary in density and thickness.

Toportray acoustic performance of materials, togetherwith the evaluation of sound absorption coefficient, according to standard ISO 10534-2:1998, at normal incidence and airflow-resistivity for each of these constituents. Noise barriers evaluated in such study were metal structures having drilled metal plate at their side visible to noise source, with eco-materials, used in internal partof the barrier. Thus, novel sound absorbing materials from textile wastes without toxic resins can be utilized as interior materials for the noise barriers.

Tengku Izhar et al. [20] investigated Noise Reduction Coefficient (NRC) boardpanels, made of coconut coir fiber, rice husk and sawdust, as shown in Fig. 6.

Fig. 6. Raw Materials: Coconut Coir, Rice Husk & Sawdust [20]

Six specimens were createdemploying two dissimilar binders. The parameters used to estimate NRC are frequency, speaker intensity, and distance from the speaker atdiverse distances. The outcomepresented that NRC changes linearly with changes in sample distance from the speaker,frequency, and speaker intensity. It was also realized that sawdust and coconut coir fibers, both natural materials, can be used inthe creationof board panels with considerable noise attenuation properties.

Hosseini Fouladi et al.[21] studied utilizing natural fibers as a sound absorber for their application in acoustic panels. Various natural fibers, corn, sugarcane, and grass were selectedfor the estimation of acoustic absorption properties. Selected fibers displayedimproved absorption coefficient in their frequency spectrum, compared to synthetic materials (carpet, Plywood, Drapery) having the same thickness, except, fiberglass.

Yang and Li, 2012 [22] studied the acoustic properties of natural fibers and their reinforced composites. Sound absorption coefficients of three different natural fibers, which include ramie, jute, and flax fibers and their mixtures, were quantified by the two-microphone transfer function method in the impedance tube, shown in Fig. 7.

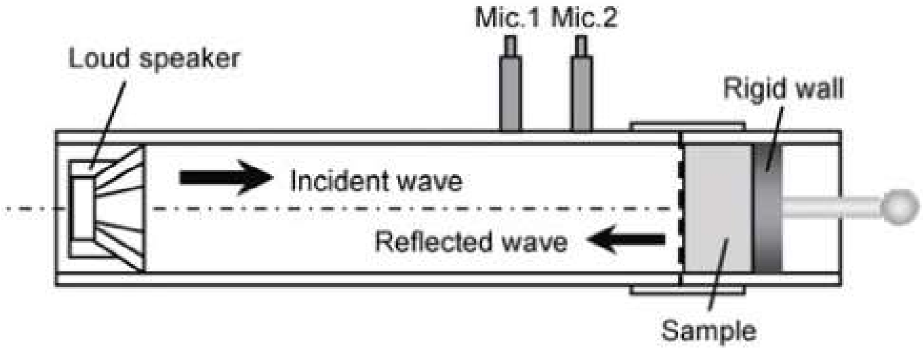

Fig. 7. Schematic diagram of Impedance Tube Setup [22]

Natural fiber reinforced composites also possessed better acoustic absorption behavior than synthetic fiber reinforced composites, especially at high frequencies, shown in Fig. 8 and Fig.9.

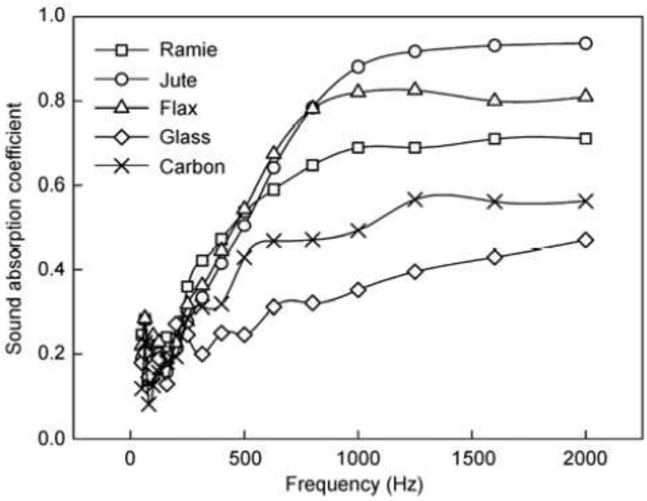

Fig. 8. Sound absorption coefficients for natural and synthetic fibers [22]

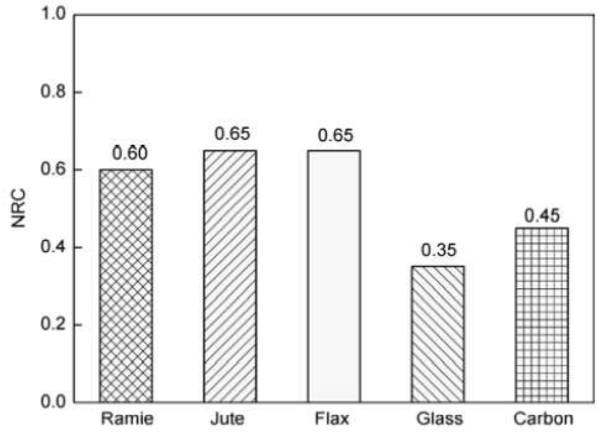

Fig. 9. Noise reduction coefficient (NRC) comparison of natural and synthetic fibers [22]

Zulkifli, Rozli et al.[23] carried out experimental tests on coconut coir samples, showing good acoustic properties at low and high frequencies. They can be considered asan alternative replacement for synthetic-based products. With the application of porous layers and a perforated plate supporting coconut-coir fiber, panels display decent potential foran ecologically responsive product.

Mahzan et al.[24] investigates the acoustic properties of composites from coconut coir with a combination of recycled tube tyre particles for sound absorption material. The composite is built at givenfractions of fillers and polyurethane as resin. The proportions of coconut coir and reprocessed rubber composites are found to give high sound absorption coefficient in broader frequency range, which results in high sound absorption applications.

Joshi et al.[25] reviewed life cycle assessment (LCA) comparing natural fiber composites and glass fiber composites. LCA studied ecological facets and possible influences all over the product life since its raw material procurement to production, usage, and end-of-life managingopportunities,for example, recycling, incineration, and disposal.

Figures 10 and 11 displaythe lifecycle phases of componentsformulated from glass-fiber reinforced material and natural fiber material separately. The study evaluates Natural Fiber Reinforced (NFR) composites and Glass Fiber Reinforced (GFR) composites. The results showed NFR composites are superior to GFR composites.

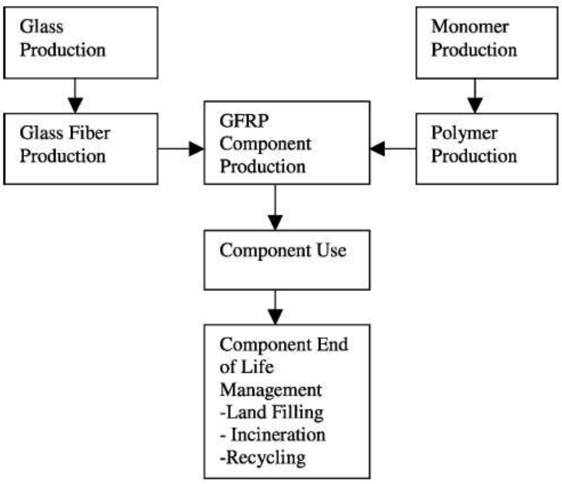

Fig. 10. Lifecycle of glass-fiber reinforced component [25]

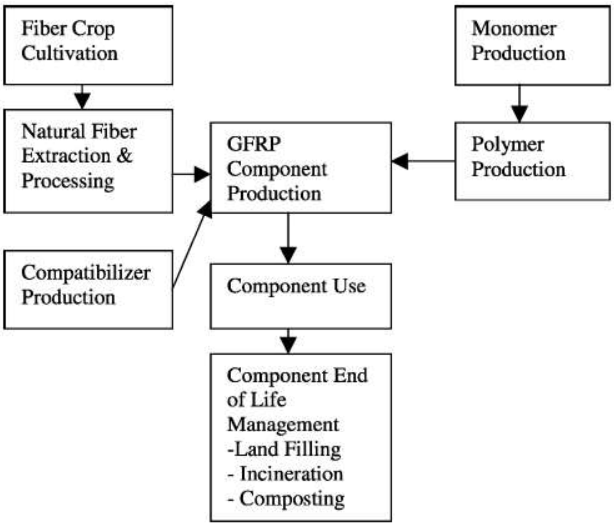

Fig. 11. Lifecycle of natural fiber reinforced component [25]

3. Conclusion :

Noise pollution from highways remains a significant environmental and societal concern,particularly in areas near residential zones, schools, hospitals, and other sensitive regions. While traditional noise barriers made from synthetic and inorganic materials, for example, glass-wool, polystyrene, stonewool, and rock wool have proven effective in mitigating noise, their environmental impact andnon-biodegradability necessitate the exploration of sustainable alternatives.

This study highlights the potential of using natural and recyclable materials, such as coconut fibers, sugarcane bagasse, bamboo charcoal, sawdust, plastic waste, and other eco-friendlyoptions, inthe creation of sustainable noise barriers. These materials offer environmentalbenefits and also present an opportunity to reduce the carbon footprint of noise barrierproduction. However, challenges remain in improving their acoustic performance and ensuringcost-effective scalability for practical applications.

Forth coming investigations will emphasize enhancing acoustic properties of sustainable materials, such as increasing sound absorption coefficients, also evaluating long-term durability and feasibility in large-scale highway projects. By integrating sustainability into the production of noise barriers, transportation engineering can pursue environmentally responsible solutions that complement global labor to battle environmental alteration, which encourages sustainable development.

This paper provides a comprehensive overview of existing literature and identifies gaps that require further investigation.It servesasa basis for future innovations in the design and executionof sustainable noise barriers for highway noise mitigation.

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