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Jayakumari M
Research Scholar, Department of Costume Design and Fashion, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India

Dr. G Manonmani
Assistant Professor, Department of Home Science,Mother Teresa Women's University, Kodaikanal, Tamil Nadu, India

Divya R
Assistant Professor, Department of Costume Design and Fashion, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India

Correspondence
Jayakumari M
Research Scholar, Department of Costume Design and Fashion, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India

Development of sound proof material with flame retardant property using natural and synthetic composites

Jayakumari M, Dr. G Manonmani and Divya R

Abstract
Today much importance is given to the acoustical environment. Noise control and its principles play an important role in creating an acoustically pleasing environment. The main objective of this study is to control excessive noise using natural fiber and synthetic non woven as sound absorbing material. Three different synthetic non woven materials were used (polypropylene: polyurethane: polyethylene) in three different ratios (3:1:1, 3:1:2, 3:1:3) as composite were prepared (belt calendaring process) for the analysis of sound absorption (impedance tube method). The best resulted sound absorption ratio material was selected to analyze flame retardancy with natural banana fabric material finishing (belt calendaring process) onto the higher thickness side of the composite. The sound absorption ability of the composite resulted that the ratio 3:1:3 possessed higher sound absorption ability when compared with other two ratios hence banana fabric was coated onto the polypropylene side of the composite. Flame retardancy test resulted that the sound absorption composite is a class I fabric where flame persisted above 7 seconds. As a final objective, this research describes sound absorption material can be made into large variety of sound absorption materials and acoustic partitions for reducing background noise.

Keywords: noise pollution, Banana fiber, Synthetic foam, Sound absorbing, Flame retardation

1. Introduction

"Noise is an unwanted sound and unfortunately most of the machines that have been developed for industrial purposes, for high speed transportation, or to make life more enjoyable are accompanied by noise" [1]. Most of the society is now aware that noise pollution apart from it has several grave effects like impulsive noise may cause damage hearing psychological and pathological disorders. Recent reports suggest that blood is thickened by excessive noise as well as optical system of human beings is also affected. Noise pollution also causes damage to the heart, brain, kidneys, liver and may produce emotional disturbance [2]. Noise is public nuisances which causes distractions, contributes to health problems, stress and eventually lower productivity. It is a series of longitudinal or compression waves that move through air or other materials which must have mass and elasticity. It is a mechanical vibration that travels through matter as a waveform. Sound does not travel in a vacuum or in outer space [3].

This paper focuses on the absorption of bio based materials. The materials and structures using sound absorption material to reduce ambient noise received much attention. Noise absorbing materials absorb unwanted sound by dissipating sound wave energy when it passes through and also by converting some of the energy into heat, making them very useful for the control of noise [4]. Noise control is a major factor in the planning, design, and construction of transportation corridors. Architects, acoustical engineers and transportation planners are searching for creative ways to eliminate or greatly reduce noise levels [5].

Mankind has been strongly dependent on plant fibers for all kind of purposes. Agricultural waste from banana are eco friendly which are found in abundance and can be used as an alternative materials for the production of home textiles, apparels, non-woven and industrial fabrics. Banana fiber is a natural fiber with high strength, which can be blended easily with cotton fiber or other synthetic fibers to produce blended fabric & textiles [6]. The two common materials for acoustic absorbers are open-cell urethane foams and fiberglass.

High-quality panels in urethane and fiberglass are of about the same acoustic effectiveness for the same thickness. Foams - Urethane foam has the advantage of being both tough and flexible, which makes it easier to handle and install than fiberglass. Urethane foams used in boats should be flame retardant, polyether and they should have protection against liquids and vapors, as the materials may age and crumble or become an oil ladened fire hazard if not so protected [7].

Polypropylene (PP) is one of the most successful commodity fibres. PP fibres belong to the newest generation of manufactured chemical fibres after polyester, polyamides and acrylics. Polypropylene (PP)] are a major type of thermoplastic used throughout the world. The large accumulation of these thermoplastic materials in the environment is an issue of increasing concern from the point of view of environmental safety [8]. The molecular configuration of PP can be altered to give three types of PP depending on the catalyst and the polymerization method used namely atactic, isotactic, and syndiotactic configurations. These advantages include: High toughness, High strength to weight ratio, Lighter weight, Corrosion resistance, Chemical resistance. Due to easy process ability PP has replaced conventional materials like wood, metal and glass as an efficient as well as cost effective material for the manufacture of articles with various colours, complicated shapes, and designs [9]. Polypropylene matrix can be recommended for application in building and automotive industry because of their good sound absorptive power as well as in packaging electronics due to their dielectric properties. They increase the sound absorption coefficient by about 20% in the frequency range above 3000 Hz [10]. Composites made from polypropylene and wood fibre are characterized by significantly higher stiffness than unreinforced polypropylene [11].

Polyurethane foams are one of the most important classes of cellular plastic used in the manufacture of such materials as foam mattresses, pillows, furniture, cushioning materials for automobiles, packing, recreation, shoes, resilient floor coverings etc. polyurethane has been a growing demand for durable and high hardness characteristic (i.e. high compression resistant) foam at low cost [12]. Flexible polyurethane foams are open cell materials that allow free movement of air between the foam cavities. They are commonly available in density of 13 - 80 kg m^{-3}. Composite materials obtained by introducing textile waste in rigid polyurethane foam matrix have sound absorption properties much improved compared to the 100% rigid polyurethane foam. The 60-RPF material has the best capacity to absorb noise, reaching a value of minimum 0.4 of sound absorption coefficient on the whole analyzed frequency ranges. The developed materials can be used both in the outdoor and in the indoor environment [13].

Polyethylenes are semi-crystalline materials with excellent chemical resistance, good fatigue and wear resistance, and a wide range of properties. They have a higher impact strength, but lower working temperatures and tensile strengths than polypropylene. They are light in weight, resistant to staining, and have low moisture absorption rates. Poly-olefins are of two types such as low density polyethylene (LDPE) and high density polyethylene (HDPE) [14]. These are used in underlay and walls for houses, offices etc. The product developed from such foam sheets are used to prevent noise entering or leaving a specific area or room (especially low frequency waves).

Flame retardants are key components in reducing the devastating impact of fire. The commercial flame retardant finishing agent, Ecoflame CT 6 was used. They are added to or treated potentially as flammable materials including textiles and plastics. These flame retardants are added to different materials or applied as a treatment to materials to prevent fires from starting, limit the spread of fire and minimize fire damage. Flame retardant ability of the composite was determined by using auto flame chamber method. This way treated materials achieve material recovery and takes effect of environmental protection [15].

This research is to develop multifunctional composite in order to improve sound absorption with natural woven fabric (banana fabric) and synthetic foam (PP/PU/PET) planks and to rebound resilience properties were evaluated. As banana peduncle are dumped on road side or burnt which causes environmental pollution. The main aim of this study is to compare the sound absorbing/flame retarding properties of the nonwovens and the composites made of them as well as to determine the dependence of the composite fibers. This approach will reduce noise Pollution to a great extent using the agricultural waste also it prevents the waste deposition which will surely help in solving the environmental problems.

2. Experimental Procedure

Sources of Raw Materials

Banana fiber was purchased from TNAU, Coimbatore. Polyethylene, Polyurethane and Polypropylene fiber were purchased from PSG COE, Neelambur, Coimbatore. Banana fiber were processesed in to fabric through handloom weaving, Erode. Flame retardant finishing agent, Ecoflame CT 6 was purchased from ecostar unit, Tiruppur, Tamil Nadu.

Processing of Fibers [16]

Alkali treatment was chosen for pretreatment of fibers. Fibers were treated with 5% NaOH (w/v) at 100 ºC for one hour (pH 12). Later cooled, rinsed for 10 times with distilled water and dried at 50 ºC for 45 min in oven. The procedure was repeated if the fibers were not processed properly.

Handloom Weaving

Weaving is done by intersecting the longitudinal threads, the warp, i.e. "that which is thrown across", with the transverse threads, the weft, i.e. "that which is woven". The major components of the loom are the warp beam, heddles, harnesses or shafts shuttle, reed and take up roll. In the loom, yarn processing includes shedding, picking, battening and taking-up operations which are the principal motions.

Foam Composite Preparation (Belt Calendaring Process) [17]

Belt calendaring is a modified form of hot roll calendaring. The two main differences are time in the nip and the degree of pressure applied. In belt calendaring, the time in this nip is 1-10 seconds. The pressure applied is about 1/10th of the pressure applied in the hot calendaring process. The selected synthetic foams were heat bonded by running in-between the roll and the blanket. Pressure was applied by varying the tension on the blanket against heated roll and the pressure on the exit guide rolls inside the rubber blanket.

Measurement of Fibre Strength and Elongation [18]

Strength and elongation of fibers as well as PP, PU, PET was calculated using Vibroscope & Vibrodyn using [18] standard. Measuring range of force 0-1000 cN, measuring range of elongation max. 1000% at 10 mm gauge length, gauge length 5-50mm, tension weight 100 mg and testing speed of 0.5 to

300 mm/min. An average of 30 readings was taken at random and the mean value was calculated.

Measurement of Sound Absorption [19]

The measurement of sound absorption was based on the method of ASTM E 1050-98: Standard Test Method for impedance and absorption of acoustical properties using a tube, two microphones and a digital frequency analysis system. A measuring instrument was used for testing within the frequency range 0–6.4 kHz. This instrument includes Type 4206 Impedance Tube, PULSE Analyzer Type 3560, and Type 7758 Material Test Software. The frequency range to be tested depends on the diameter of the tube. A large tube (100 mm diameter) is set up for measuring sound absorption in the low frequency range from 50 Hz to 1600 Hz. A small tube (29 mm diameter) is set up for testing the material sound absorption in the high frequency range of 500–6400 Hz.

Flame Retardancy Testing (Auto chamber method)

The commercial flame retardant finishing agent, Ecoflame CT 6 was used for finishing the banana fabric. The finished fabric sample was tested for the flame retardancy properties using auto flame chamber method. The flame retardant finished fabric/foam was tested for the efficiency to finish using auto flame chamber inclined at 45°. The samples were taken in 5 X 15 cm. A dried specimen was inserted in a frame and inserted in the auto flame chamber at an angle of 45°. A standardized flame was then applied to the surface of the sample near the lower end for 5 seconds. Finally the time required for the flame to proceed up the fabric for a distance of 127 mm was recorded. The flammability of the fabrics was measured as the length of char in mm [20].

3. Results and Discussion

Fiber Composition and Identification

Three synthetic fibers Used in this study are identified as polyethylene, polyurethane and polyester fibers. The natural fiber used in this study was identified as banana fiber and was developed in to fabric. These natural and synthetic fibers are used in this research to study the acoustic absorption performance. Initially, after pre-treatment the synthetic foams and banana fiber were processed for identification. The processed fiber was identified by microscopic and chemical method (Table – 1) and the samples were thus identified and are used for further studies.

Table 1: Fiber composition (Microscopic and chemical method)

Identification of fiber	Units (%)
Banana fiber	100
Polyethylene	100
Polyurethane	100
Polyester	100

Fiber composition: Authentication and percentage of purity**.**

Physical Properties

Single Strength

After identification, the fiber and foams were subjected to testing physical properties such as the measurement of single strength and elongation break of fiber. The results are represented in Table - 2. Strength is very often the predominant characteristic for every material. Elongation break of polypropylene (21.6%) was considerably more than polyester (17.3%), polyurethane (14.1%) and banana fiber (12.5%). The single thread strength of polypropylene (61.1%) is considerably more than polyester (56.1%), polyurethane (50.9%) and banana fiber (53.2%). This can be seen from the fact that nature produces countless types of fibers, most of which are not use alone in the textile material because of inadequate strength [16]. So the natural fiber combines with synthetic foam and increase the value of the textile material to be produced. The polypropylene foam has maximum strength and so the ratio taken for the study was higher when compared to other foams.

Table 2: Single strength [18]

Name of the test	Units	Measurement of fiber/foams			
		Banana fiber	Polyurethane	Polyester	Polypropylene
Single thread strength	CV (%)	53.2	50.9	56.1	61.1
Elongation at break	CV (%)	12.5	14.1	17.3	21.6

Measurement of Fibre strength and elongation [18], Single Strength [18]

Sound Absorption Property

Authenticated samples were processed for fabrication. The synthetic foams were processed for composite preparation – sandwich model by hot calendar process. Three different ratios (3:1:1, 3:1:2, 3:1:3) of composites were prepared i.e polypropylene: polyurethane: polyethylene respectively. These three composites were analyzed for its sound absorption property by impedance tube method (Table – 3). The performance of sound absorbing materials in particularly is evaluated by the sound absorption coefficient (α). Alpha (α) is defined as the measure of the acoustical energy absorbed by the material upon incidence. If 55 percent of the incident sound energy is absorbed, the absorption coefficient of that material is said to be 0.55.

It was observed from results that the best sound absorption ratio was 3:1:3 the high thickness side of the foam which is polypropylene. Hence polypropylene was maintained constant while polyurethane and polyethylene samples were analyzed with different ratios. For the 3:1:1 at the maximum frequency (2000 Hz) the sound absorption coefficient was 0.34, for the other ratio 3:1:2 the sound absorption coefficient is 0.43 and for the final ratio 3:1:3 there was maximum sound absorption was attained for 0.59. In this study the average sound absorption co efficient ratio was obtained to which natural fiber banana fabric (natural fiber) with flame retardant property was coated to analyze sound absorption coefficient. From these obtained results, it is evident that 3:1:3 ratios have the maximum average sound absorption coefficient, also it has a major role in sound absorbing property. In 2014 Prabhakaran and co workers observed the similar results, stating that altering the different foam ratios results in better sound absorption property [17]. The average absorption is usually described in terms of the NRC (Noise Reduction Coefficient) factor, defined as the arithmetic average of the NAC at the frequencies 250, 500, 1000 and 2000 Hz, to which the human ear is mostly sensitive [21].

Table 3: Different ratios of polypropylene, polyurethane and polyethylene for sound absorption property.

3:1:1		3:1:2		3:1:3	
Frequency (Hz)	**Sound absorption coefficient (α)**	**Frequency (Hz)**	**Sound absorption coefficient (α)**	**Frequency (Hz)**	**Sound absorption coefficient (α)**
250	0.06	250	0.06	250	0.07
500	0.09	500	0.09	500	0.13
1000	0.16	1000	0.17	1000	0.29
2000	0.34	2000	0.43	2000	0.59
Avg.	0.16	Avg.	0.19	Avg.	0.27

Flame Retardant Test [20]

The resulted best ratio i.e. 3:1:3 was selected for the product development of product. To this material, chemical finished banana fabric having flame retardant property was attached like sandwich model. Flame retardancy test was carried out with the standard procedure of ASTM D 1230/94. The chemically finished banana fabric resulted as class I fabric which in turn the flame persisted above 7 seconds (Table – 4). This suggests that the chemically finished banana fabric has higher retardancy towards flame. It is also evident from the previous studies, Flame retardant performance of banana fiber is observed to be highly flame resistible. The ignition period of banana fabric was above 7 seconds which in turn banana fabric is considered to be a class I fabric. There are other two categories of flame retardant properties namely class II which was investigated to ignite below 7 seconds while class III is immediately ignitable [22]. The reason being, the treatment of banana fibers for flame retardant might change its fiber structure in such a way that it absorbs sound better than untreated banana fibers. It is Possible that treatment increases surface voids on the fibers which might later entrap more sound [20]. Chemically finished banana fabric has been confirmed to be a flame retardant belonging to class I category.

Table 4: Flame retardant testing

Fabric samples	**Flammability of apparel textiles ASTM-D_1230/94**	
Chemically finished banana fabric	Above 7 sec	Class I

Table 5 represents depicts different parameters investigated for the synthetic foams namely polyurethane, polypropylene and polyester. The observed data reveals that density of polyurethane is 4.0 LB/cubic Ft. while polyester and polypropylene is 2.2 LB/cubic Ft and 1.7 LB/cubic Ft. Water absorption increases with increases with fiber addition. It is evident that percentage of water absorption is higher for composites. In case of thermal resistivity all the three foams possess the similar heat stability. Compressive stress of polyurethane foam is found to be slightly higher with 14.5 LB/In.Sq.

The experimental results were also found to be similar with zulkifli [23] which exhibited the coir fiber with perforated panel shows higher coefficient index compared to plain coir fiber was in the range of 0.7 to 0.85 while for the coir fiber without panel was around 0.8. In reports of banana samples exhibited an average absorption coefficient equal to 0.85 in the 500-5000 Hz range and equal to 0.65 in the 100 -5000 Hz range, while for the recycled polyester and polyurethane possessed measured mean values are respectively 0.63 and 0.71 [24]. Pure *Arenga pinnata* fiber is a good absorber at frequencies. The optimum sound absorption coefficient, 0.88, was obtained at high frequency from *Arenga pinnata* from 40 mm thickness. The fiber thickness has influence to sound absorption coefficient of the material. Generally, the thicker material exhibits a maximum sound absorption coefficient at high frequencies [25].

Table 5: Physical data of synthetic foams

Property (ASTM D 3575)	**unit**	**polypropylene**	**polyester**	**polyurethane**
Density	LB/cubic Ft.	1.7	2.2	4.0
Colour		White	white	Pale yellow
Compressive Strength (25%)	LB/In.Sq	7	7	8
Compressive Strength (50%)	LB/In.Sq	12	14	14.5
Compression creep	(%)	5	6	6
Water absorption	LB/Sq.Ft.)	0.06	0.04	0.06
Thermal stability	(%)	<2	<2	<2
Electrostatic decay (EIA 541)	Time (sec)	<2	<2	<2
Surface resistivity (EIA 541)	ohms	>1.00x10*5<1.00x10*12	>1.00x10*5<1.00x10*12	>1.00x10*5<1.00x10*12

4. Conclusion

In this study, alternative sound absorbing material using synthetic foams was developed and flame retardant property with banana fabric was analyzed. The observations results ensured good activity with 3:1:3 when compared with other different composites which were analyzed for its sound properties and flame retardancy with the banana fabric. Hence from the obtained results it is obvious that the combination of banana fiber material and composite possess acoustic properties equivalent to those of commercially available products. The pressing process of composites made it possible to obtain equally thick thermoplastic sound absorbing property which increases the sound absorption coefficient of material.

Sound-absorbing/flame-retarding composite plank prepared in this study has better sound absorption property even at high-medium frequency than commercial PU foam. Even though this composite plank had higher sound-absorption, at high-frequency it was slightly lower, and possessed better cost superiority than the commercial sample due to usage of recycled materials. Therefore, sound-absorbing/flame-retarding composite plank can be applied in music halls and audio-visual rooms [25].

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