Performance cum Achievement Report

on

Project entitled

"Utilization of recycled waste carpet for development of structural composites material"

(Project ID: K-12012/4/19/2020-21/R&D/ST)
Under Research & Development Scheme

Sponsored by

Office of the Development Commissioner (Handicrafts)
Ministry of Textiles, Government of India
West Block No. VII, R.K.Puram, New Delhi, India

Submitted by

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December 2021

DECLARATION

I declare that this written submission represents research project work and ideas in my own words. Where others' ideas or words have been included, I have adequately cited and referenced the sources. I also declare that no misrepresented or falsified any idea/data/fact/source in my project work submission.

18/12/2021

PROJECT
PRINCIPAL INVESTIGATOR
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(Signature)

Name of the Project Investigator : **Dr. Rajesh Kumar Verma**

Department: **Mechanical Engineering Department**

Date: / Sept / 2021

MADAN MOHAN MALAVIYA UNIVERSITY OF TECHNOLOGY
MACHANICAL ENGINEERING DEPARTMENT
GORAKHPUR-273010

CERTIFICATE

It is certified that a project team of Mr. Balram Jaiswal (Senior Research Expert), Mr. Rahul Vishwakarma (Senior Research Expert), Mr. Kuldeep Kumar (Junior Research Fellow), Mr. Kaushlendra Kumar (Junior Research Fellow) has carried out the experimental work presented in this report entitled "***Utilization of recycled waste carpet for development of structural composites material***". This work was performed at Department of Mechanical Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur. The project report embodies the result of original work and studies carried out under the R&D scheme project of the O/o the DC (Handicrafts), Ministry of Textiles, Govt. of India.

Signature

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Date: 18-12-2021

Acknowledgment

This project work entitled "***Utilization of recycled waste carpet for development of structural composites material*** " is possible due to the help of many.

To begin, my most profound sense of gratitude first goes to Almighty, who endowed me with health, grace, wisdom, patience, and direction to bring this work to completion. My deepest gratitude goes to the **Hon'ble Development Commissioner (Handicrafts**) **Shri Shantmanu**, **IAS**, who has given me this opportunity. I would like to express my warm gratification and indebtedness to **Ms. Mudita Mishra, Additional Development Commissioner (ADC), Shri Arun Kumar Yadav,** Director (HC), and **Ms. Pooja Venugopal J.**, Assistant Director (R&D), O/o Development Commissioner (Handicrafts) under the Ministry of Textiles Govt. of India, for their continuous support and direction to run this project. I deem it my privilege to work on this research project. I am also thankful to **Shri Ravi Kumar Gond**, Assistant Director and **Shri Sandeep Kumar Patel**, Assistant Director, for their kind support during this project.

I want to express special thanks to the Indian Institute of Technology (IIT) Roorkee, (Saharanpur Campus) and Birbal Sahni Institute of Palaeosciences (BSIP) Lucknow under the Department of Science and Technology, Govt India, for providing the advanced characterization and testing facility. Also grateful to the Central Institute of Petrochemicals Engineering and Technology (CIPET) Lucknow for giving us mechanical and morphological testing facilities.

I would like to express my sincere thanks to **Prof. J.P. Pandey,** Hon'ble Vice-chancellor, and **Prof. D. K. Singh,** Head of Department, Mechanical Engineering, M. M. M. University of Technology, Gorakhpur, for their generous support and continuously motivation during this project. I am fortunate to have their advice and support to express my thankfulness for their support and belief.

I would like to special thanks to my project team members Dr. Sanjay Mishra, Associate Professor (MMMUT Gorakhpur), Dr. Harshit K. Dave (SVNIT Surat) & Dr. Shravan Kumar Gupta (IICT Bhadohi) for their valuable support and for providing expertise info to complete this work.

Dr. Rajesh Kumar Verma

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List of abbreviations

CDF	*Carpet-Derived Fuel*
SiC	*Silicon Carbide*
Al_2O_3	*Aluminium Oxide*
FRP	*Fiber Reinforcement Polymer*
MMC	*Metal Matrix Composite*
CMC	*Ceramic Matrix Composite*
PMC	*Polymer Matrix Composite*
LDPE	*Low-Density Polyethylene*
MAh	*Maleic anhydride*
rPET	*Recycled Polyethylene Terephthalate*
SEM	*Spectroscopy Emission Method*
XRD	*X-Ray Diffraction*
ILSS	*Interlaminar Shear Strength*
IFSS	*Interlaminar Flexural Shear Strength*
FBBF	*Front Back-Back Front*
BFFB	*Back Front-Front Back*
NFC	*Nylon fiber-based composites*
OFC	*Olefin fiber-based composite*
PVA	*Polyvinyl Alcohol*
GFRP	*Glass Fiber Reinforcement Polymer*
POFA	*Palm Oil fuel Ash*
PVC	*Poly Vinyl chloride*
VARTM	*Vacuum Assisted Resin Transfer Moulding*
FTIR	*Fourier-Transform Infrared Spectroscopy*
G/CFRP	*Graphene/Carbon Fiber Reinforcement Polymer*
PP	*Polypropylene*
R	*Resin*
H	*Hardener*
NRC	*Nylon Reinforced Composites*
RWCA	*Recycled Waste Ceramic Aggregate*

WCF	*Waste Carpet fiber*
HSC	*High Strength Concrete*
NCA	*Natural Coarse Aggregate*
ASR	*Automotive Shredder Residue*
NFRC	*Nylon fiber Reinforced Concrete*
NFFRC	*Nylon fiber Fabric Reinforced concrete*
UCS	*Unconfined Compressive Strength*
SWF	*Ship Wool Fiber*
LWA	*Light Weight Aggregates*
HC	*Hessian Cloth*
CBC	*Carpet Backing Cloth*
GNP/MWCNT	*Graphene Nanoplate/Multiwall Carbon Nanotube*
ASTM	*American Standard Testing Materials*
UTM	*Universal Testing Machine*
FA	*Fly Ash*
TGA	*Thermogravimetric Analysis*
FRC	*Fiber Reinforced Concrete*

List of Symbols

m^2K/W	*Unit of Thermal Insulation*
gm/cc	*Unit of Density*
t	*Thickness of sample*
Wt.%	*Weight %*
w/w	*Weight by weight percentage*
v/v	*Volume by volume percentage*
Hrs	*Hours*
mPa-s	*Unit of Viscosity*
MPa	*Unit of Tensile/Flexural*
°C	*Unit of Temperature*
FS	*Flexural strength*
t_m	*Machining time*
w_i	*Initial weight*
w_f	*Final weight*
ρ	*Density*
%	*Percentage*
cm^{-1}	*Unit of Wave Number*

Project Sanction Letter

No. K-12012/4/19/2020-21/R&D/ST
Government of India
Ministry of Textiles
Office of the Development Commissioner (Handicrafts)
West Block No.7, R. K. Puram,
New Delhi-110066
Dated: 27.08.2020

To
The Pay & Accounts Officer
Central Pay & Accounts Office
Office of the Development Commissioner (Handicrafts)
R.K. Puram, New Delhi 110066.

Sub: - Grant-in aid to M/s Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur, U.P. for conducting study on "Utilization of recycled waste carpet for development of structural composites material" under Research & Development Scheme– reg.

Sir,

In exercise of the power delegated to the Development Commissioner (Handicrafts) as Head of Department vide Office of the DC (H) O.M. No. G-20013/42/DC[HC]/BGT/2004 dated 08.05.2015 and in terms of Ministry of Textiles (Integrated Finance Wing) order No. G20013/42/DC[HC]/BGT/2004 dated 05.05.2015 & 07.05.2015, I am directed to convey the sanction of the President of India for sanctioning an amount of **Rs. 13,53,000/- (Rupees Thirteen Lakhs Fifty Three Thousand Only)** as Non-Recurring grant - in – aid & releasing the first instalment of **Rs. 6,76,500/- (Rupees Six Lakhs Seventy Six Thousand and Five Hundred Only)** in advance being 50% of the Sanctioned amount to **M/s Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur, U.P.** for conducting study on **"Utilization of recycled waste carpet for development of structural composites material"** under R & D Scheme. The Financial Implications for conducting the above event are as under:-

Sl. No.	Components	Amount sanctioned	50% Funds to be released
1	Project Leader	NIL	NIL
2	Senior Research Expert @25,000/- p.m. per person (For 2 persons)	6,00,000/-	3,00,000/-
3	Junior Research Fellow@15,000/- p.m. per person (For 2 persons)	3,60,000/-	1,80,000/-
4	Investigator [Graduate]	NIL	NIL
5	Computer Operator	NIL	NIL
6	Documentation & Videography	90,000/-	45,000/-
7	T.A./D.A. @15,000/- p.m.	1,80,000/-	90,000/-

8	Miscellaneous	1,23,000/-	61,500/-
TOTAL		**13,53,000/-**	**6,76,500/-**

Mode of Payment:

The sanctioned amount will be released in two installments. The first installment (50% of the sanctioned amount) **Rs. 6,76,500/- (Rupees Six Lakhs Seventy Six Thousand and Five Hundred Only)** will be released on submission of the pre- receipted bill & acceptance of terms and conditions. Second and final installment in the shape of reimbursement after completion of the project & submission within stipulated time of sanctioning of the project & thereafter submission of final report indicating performance and follow up action to be taken duly agreed to, by the competent authority (six hard copies and two soft copies in CD Room and audited statement of accounts, auditor's report, utilization certificate in GFR 12-A in respect of the 1st installment of grant released and total expenditure incurred on the project on the letter head of Chartered Accountant duly verified and countersigned by the authorized signatory of the organization and acceptance of the reports, standard formulation regarding qualitative and quantitative targets along-with bills and vouchers.

Certified that no Utilization Certificate is pending against the organization in any scheme of this office.

Craft to be covered: - Reuse of Carpet waste.

Area to be covered: - Carpet and Textiles.

Duration of the project: - 12 Months.

Terms and Conditions:-

1. The organization shall interact periodically with Office of the Development Commissioner (Handicrafts) or their representative/experts for understanding the problems being addressed through this project and firming up the outputs.
2. Grant-in-aid/funds shall be utilized for the aforesaid study only.
3. The grantee/ organization shall maintain subsidiary accounts of the grants/ payments received from the Government.
4. The grantee/ organization shall maintain a register of assets in the prescribed form GFR-12-A. The assets acquired wholly or substantially out of Government Grants except those declared as absolute and unserviceable or condemned as per the procedure laid down in the General Financial rules shall not be disposed of without the prior approval of this office.
5. The grantee/organization shall submit performance-cum-achievement report physically and financially to DC (Handicrafts) Office, New Delhi and its concern Regional Office.
6. The amount so paid to the grantee/ organization shall be open to inspection by the Sanction Authority i.e. O/o DC(Handicrafts)/Internal Audit Party of the Chief Controller of Accounts, Ministry of Commerce and Textiles, New Delhi whenever the grantee/ organization is called upon to do so.
7. The grantee/ organization shall get its accounts audited from the Chartered Accountants.
8. The grantee /organization shall not divert the grants/funds and entrust execution of the scheme or work concerned to another Institutions or Organizations and shall

abide by the terms and conditions of the grant/funds. If the grantee /organization fail to utilize the grant/funds for the purpose for which the same has been sanctioned, the grantee /organization will be required to refund the amount of the grants/funds with interest thereon @ 10% per annum.

9. The selection of participants must be in transparency.
10. The grantee/ organization shall submit the utilization certificate in the from GFR-12-A and a list in respect of assets being created out of Government grant/funds, if any, duly signed by the Head of the Grantee/ organization Institution and audited by the Chartered Accountant within stipulated time from the date of completion of the project. The Utilization Certificate would indicate the achievements against the specified quantitative targets and also disclose whether the specified qualitative targets that should have been reached against the amount utilized were in fact reached ,and if not, the reasons therefore.
11. The grantee /organization agree to make reservations for scheduled castes and scheduled tribes in posts/services under its control on the lines indicated by the Government of India.
12. There is no reason to believe that the grantee/ organization are involved in corrupt practices.
13. The expenditure shall be incurred as per GFR provision and department of the expenditure guidelines.
14. The component-wise breakup of the sanctioned amount represents the permissible upper limit of expenditure and the admittance thereof shall be subject to actual.
15. **All the payments to the beneficiaries in respect of TA/DA/Honorarium/Wage/Stipend/Boarding/Lodging/Freight etc. must be paid as per Direct Benefit Transfer (DBT) guidelines. Further, the Implementing Agency will provide all the information related to Direct Benefit Transfer in pre-scribed Performa alongwith the report.**
16. **The implementing agency shall intimate the HSC as well as RDs concerned minimum 30 days in advance about the scheduled event content and material to be used for this programme & also list of resource persons, Hqrs. shall be informed at least 20 days in advance.**
17. **Preference may be given during the study the insurance, self reliant of artisans and entrepreneurship etc. which should be uploaded on website.**
18. **Video CD/soft copy of the event may be submitted with the report.**
19. **On Completion of the Study implementing agency must clearly indicate the outcome of the event & must submit performance-cum-achievement report.**
20. **All the payments should be made on Public Financial Management System (PFMS) to the beneficiaries.**
21. The existing exporters must be consulted and the names of those exporters must be reported with performance report.
22. It may be noted that the final report submitted by the organization should clearly mention the name of the sponsor on the cover page as reproduced below:-

Sponsored by Development Commissioner (Handicrafts),
Ministry of Textiles,
Government of India

The Accounts Officer (Hqrs.) Office of the Development Commissioner (Handicrafts), New Delhi is authorized to draw and disburse the amount in question.

The expenditure involved is debatable to the Major Head of account

2851.00.796.56.05.31 –**GIA- ST** – **General** and will be met within the sanctioned Budget for the financial year 2020-21, **where adequate funds are available.**

This issues with the approval of DC (H) vide **Dy. No. 37559 Dated: 26-08-2020.**

Entry has been made in the Grant-in-Aid register at **page No. 65** at **Sl. No. 06.**

27/08/2020

(Pooja Venugopal. J)
Assistant Director (R&D)

Copy to:-

1. **M/s Madan Mohan Malaviya University of Technology (MMMUT), Gorakhpur, U.P.-** with the request to submit the following documents immediately:-
   a. Stamped pre-receipt in triplicate on the letter head of the organization for an amount **Rs. 6,76,500/- (Rupees Six Lakhs Seventy Six Thousand and Five Hundred Only),** being the 1st installment, mentioning the sanction` number, with date, purpose, bank account number, name of the bank and branch.
   b. Acceptance of the enclosed terms and conditions of the project in triplicate on letter head of organization.
   c. Enclosed from dully filed for ECS payment.
   d. Prescribed Bond & Certificate on affidavit that no fund has been received from any Office/Department for the above Seminar/Workshop.
   e. **Undertaking regarding agency is using PFMS (EAT), Module and all the payments will be made through PFMS (EAT) as per Ministry of Finance Instruction.**
2. Deputy Secretary, IFW, M/o Textiles, Udyog Bhawan, New Delhi
3. Principal Accounts Officer, M/o Textiles, Udyog Bhawan, New Delhi.
4. Principal Director of Audit Economic and Services Ministries, I.P. Estate, AGCR Building New Delhi.
5. Regional Director (CR), O/o D C (Handicrafts), CRO, Lucknow.
6. Assistant Director (H), O/o D. C. (Handicrafts), HSC, Varanasi.
7. Accounts Officer, (B&A), O/o (Handicrafts) New Delhi.
8. Guard file/Computer Cell/Hindi Section for Hindi version.
9. Scientist D, National Informative Center (NIC), O/o (Handicrafts) New Delhi.
10. Dr. Rajesh kumar Verma, Associate Professor, MMMUTy – for kind information

Assistant Director (R&D)
27/08/2020.

Project Team

Name & Affiliation	Role & Responsibility
Dr. Rajesh Kumar Verma, MMMUT Gorakhpur	Project Principal Investigator
Dr. Sanjay Mishra, MMMUT Gorakhpur	CO-PI 1
Dr. Shravan Kumar Gupta, IICT Bhadohi	CO-PI 2
Dr. Harshit K, Dave, SVNIT Surat	CO-PI 3
Mr. Balram Jaiswal, MMMUT Gorakhpur	Senior Research Expert (SRE)
Mr. Rahul Vishwakarma, MMMUT Gorakhpur	Senior Research Expert (SRE)
Mr. Kuldeep Kumar, MMMUT Gorakhpur	Junior Research Fellow (JRF)
Mr. Kaushlendra Kumar, MMMUT Gorakhpur	Junior Research Fellow (JRF)

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Chapter 1
INTRODUCTION

In the 21st century, waste has become the primary concern for the manufacturing sector and industries. Waste management is a critical issue for controlling many types of waste, including solid, liquid, and gaseous forms. The numerous techniques used in industry, business, and institutions to control waste and resource development [1]. The manufacturing of carpets and their uses is a substantial source of waste. In this context, the many techniques employed for reusing carpet waste products. The manufacturing sector is generating waste from the initial product development to the end products. The generation of waste leads to the imbalance of the environmental conditions and hazardous effects on the ecology. The proper utilization and recycling of discarded products is a feasible solution for waste management [2], [3]. The principle of ***"waste to wealth"*** could be helpful for manufacturing industries and human beings. The waste generated from the carpet and textile industries is a matter of concern due to their bulky sizes and decomposition cost. Exploration for the production of discarded carpet polymer materials is in its early stages and requires greater interest from academia, research, manufacturing, and organizations. The present work highlights the fundamental introduction about the carpet sector and waste generated from carpet and textile products. A novel approach is presented to utilize the carpet waste for the generation of lightweight structural applications. An attempt has been made to overcome the limitations of the existing manufacturing methods by using the resin transfer molding method in a vacuum environment. This research work will provide a novel direction for reusing waste carpets into an appropriate composite form. This method will reduce the discarded carpet and a simultaneously environmentally friendly approach shall be helpful for the manufacturing sector.

1.1 Brief history

The carpet word is derived from the old French " CARPITE," and according to the dictionary, it first appeared in the late 13th century and meant "Coarse Cloth". It came to mean "Tablecloth or bedspread" until the 14th century. In some cases, the term "rug" can be used instead of " carpet". But the rug is generally considered to be smaller as compared to carpet. Usually, the carpet was prepared from wool before the 20th century. Still, after the 20th century, artificial fibers such as nylon, polyester, and polypropylene are commonly used because they are less expensive and have greater design flexibility than natural fibers [4].

The carpet industry in India is one of the oldest and most prevalent sectors. India has a long history of carpet weaving, a technique that draws on skills and expertise from worldwide, including Persia, China, and Afghanistan. Mughal Emperor Babar was displeased with the lack of amenities in India as compared to Persian luxuries, including carpets. He developed a carpet manufacturing industry (Agra) for the Persian carpet in India from 1580 onwards. Later, to speed up the production of Persian-styled carpets, Akbar established carpet weaving enterprises in Agra, Delhi, and Lahore. The main centers of the carpet industry experienced rapid growth in India north-western region (Kashmir, Jaipur, Agra, Bhadohi, and Mirzapur) [5]. Between the 1930s and 1990s, almost all carpets were made with synthetically colored wool. An embargo on Iran diverts significant exports to China, India, and Tibet in the 1980s. The use of organically colored wool in hand-knotted oriental rugs became popular in the 1990s.

1.2 Major carpet belts in India

Carpets have been utilized for various purposes, comprising tile or concrete floor insulating, crafting a floor area more decorative and comfortable for sitting, and sound insulation. Jaipur, Bikaner, Rajasthan, Bhadohi, Mirzapur, Agra, Kashmir, and their border areas are the primary industrial and manufacturing belt in the carpet and textiles sector.

1.2.1 Uttar Pradesh (Agra, Bhadohi, and Mirzapur)

Uttar Pradesh carpets are known all over the world for their distinctive colors and designs. Bhadohi, Mirzapur, and Agra are the three main carpet centers in Uttar Pradesh. Since Agra (Uttar Pradesh) was the capital of Akbar's kingdom, it was the first carpet center in Mughal India. This city is well-known for its Persian-style carpets. Furthermore, Abussan and Turkman designs with beautiful flower borders surround elegant and simple motifs.

1.2.2 Kashmir

Kashmir is the epicenter of the Indian oriental carpets and rugs, given their popularity worldwide. Hand-knotted woolen and silk carpets are known for their quality and artistic expertise. Most of India's carpet-producing centers are located in Kashmir, and these are famed for their traditional hand-knotted silk carpet weavers. Kashmir's conventional silk carpets can be traced back to the Mughal Empire. Kashmir’s carpet's look and design are based on a Persian carpet layout and pattern.

1.2.3 Rajasthan

Rajasthani carpets have been long noted for their high-quality hand-knotted woolen fibers. Jaipur, Ajmer, and Bikaner are the prominent locations for this craft in Rajasthan. During the Mughal Empire, Jaipur was another major carpet weaving center. Artists from Afghanistan arrived in Rajasthan's royal ateliers in the 17^{th} century, and they have really flourished carpet production in Rajasthan.

1.3 Carpet manufacturing techniques

There are various types of carpets available in India. Every type of carpet in India has a unique design that attracts different spectators and buyers. Carpet weaving utilizes multiple techniques, including some Mughal period procedures, which are still in use today. Some specific methods have been outlined here for better understanding as follows.

1.3.1 Hand-knotted carpets

The Mughals pioneered this technique. This carpet has potential because workers hired by the ruling elite made it. The patterns have initially been Turkish and Persian in origin but were eventually Indianized. Kashmiri art incorporated many of the techniques and designs.

1.3.2 Hand-tufted carpets

In this method, a backing material is pumped into the carpet pile using a tufting gun and then attached to a secondary backing fabric with a latex solution for stability. The design is then completed with the usage of the third backdrop cloth. Tufted carpets can be made with either a loop pile or a cut pile.

1.3.3 Hand woven carpets

It is a combination of hand-knotted carpets and flatweave carpets. When compared to walking on a bare concrete floor, rugs can be utilized for various commercial and domestic purposes, including room decoration, creating a comfortable location to sit, walk, etc., and sound absorption. They have a lot of design flexibility in terms of fiber morphologies, color, and fiber length.

1.4 Historical hierarchy of advancement in carpets

There are changes in the textile era and development in various carpets with a unique design. As the following outline shows, some specific types of carpets have been used.

1.4.1 Antique carpets

Antique carpets have been weaved for longer than a century (before the 1920s). They are traditional woven carpets with natural dyes before introducing synthetic dyes (during 1860-the 1870s).

1.4.2 Semi-antique carpets

Semi-antique carpets were made in the early to the middle part of the 18th century, from around the 1800's up to about 1900's. In this era, the carpet industry saw a revamp. The rise of new, less costly carpets did away with the need for hand-woven carpets in the market following the economic depression and the short-lived post-depression market period.

1.4.3 Modern carpets

Modern carpets are woven from the 1900's to till today are recognized as modern carpets. Western preferences and needs are generally accepted to have affected these rugs. Carpets woven before the 17th century are extremely rare and can only be found in Encyclopaedic and Historical Museum collections.

1.5 Classification of carpet

The following are the most common types of carpet available.

1.5.1 Tufted carpets

As illustrated in Figure 1.1, tufted carpets are still manufactured today. Tufting is the stitching of face yarns onto a backing material with multi-purpose machinery. The fibers are secured to the pre-woven backing by a thick latex coating. An additional backing can be employed for added dimensional stability.

Figure 1.1 Tufted carpet [6]

1.5.2 Woven carpets

These carpets are woven on large looms in the same way that any other cloth is woven. They could have loops and stacks that are cut and uncut. On the carpets, a range of bright yarns is utilized to create various patterns and designs. The woven carpet is illustrated in Figure 1.2.

Figure 1.2 Woven carpet [7]

1.5.3 Non-woven carpets

Non-woven carpets are made in a different way than tufted and woven carpets. Non-woven carpets are made from polypropylene fibers. Needle punching creates a web from the strands, which is then thermally fused to create the rug. They are most commonly used in automotive applications and for short-term uses such as exposition halls and foot-mats, as shown in Figure 1.3.

Figure 1.3 Non-woven carpet [8]

1.6 Other types of carpets

The carpets are made in various methods, materials, and designs that are classified as follows.

1.6.1 Flatweave carpets

Figure 1.4 displays a flatware carpet that is used as a floor covering in a specific location. Interlocking warp and weft threads are used to achieve this significance. Oriental flatwoven carpets include kilim, soumak, plain weave, and tapestry weave. This is very common in Asian countries, such as Japan.

Figure 1.4 Flatweave carpet [9]

1.6.2 Needle felt carpets

The needle-felt carpet is significantly better in terms of technology, as shown in Figure 1.5. Individual fibers are attracted to one another by electrostatic attraction, resulting in a one-of-a-kind carpet with exceptional durability. In commercial and industrial applications such as hotels and high-traffic areas, a needle felt mat is used.

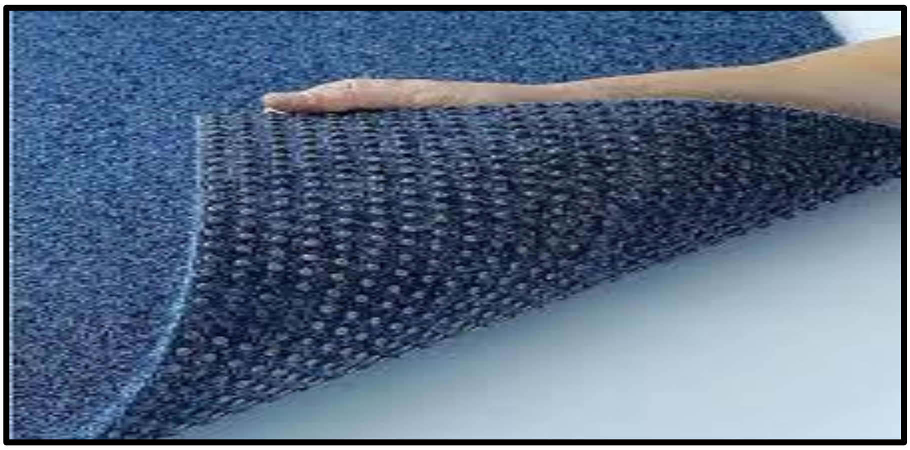

Figure 1.5 Needle felt carpet [10]

1.6.3 Velvet carpets

Velvet rugs (Figure 1.6) are incredibly soft and have a uniform color; they are delicately twisted, and their rich appearance makes them ideal for formal rooms.

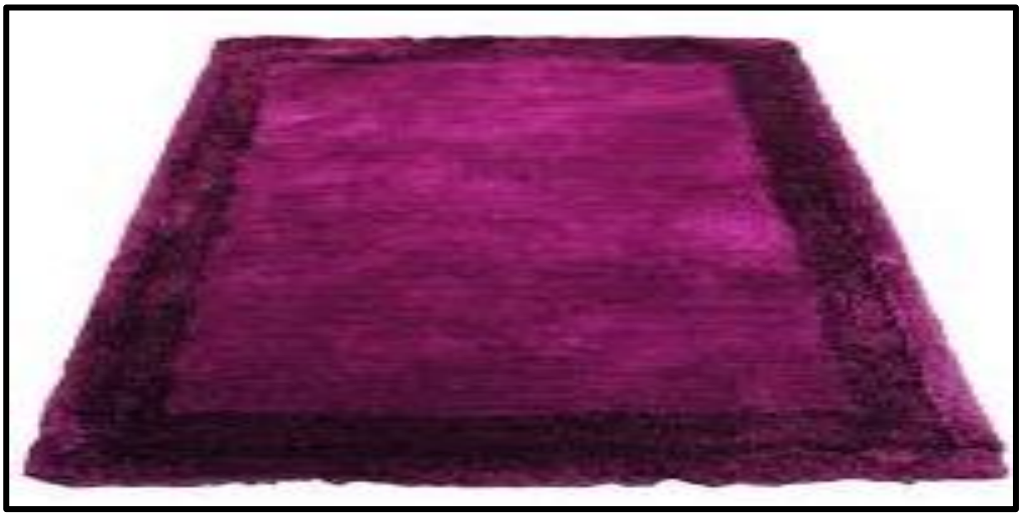

Figure 1.6 Velvet carpet [11]

1.6.4 Handwoven carpets

Hand-knotted and hand-woven carpets and rugs (Figure 1.7) are treated in the same way. Floor coverings that are handwoven or knotted, on the other hand, differ slightly. There is no pile on flatweaves. They are woven on a particular sort of loom with very precise weft and warp placement.

Figure 1.7 Handwoven carpet [12]

1.6.5 Fiber type carpet

As shown in Figure 1.8, this type of fiber used to make carpet affects its durability, appearance, and cost. The most common fiber kinds include nylon, olefin, polyester, acrylic, wool, and blends.

Figure 1.8 Fiber type carpet [13]

1.6.6 Nylon carpet

The nylon type (Figure 1.9) is the most common fiber used in carpets. Nylon is a durable, long-lasting material that can withstand environmental factors. When exposed to direct sunlight for an extended period, it develops a static electricity conductor that fades.

Figure 1.9 Nylon carpet [14]

1.6.7 Olefin carpet

The olefin carpet is modern, as displayed in Figure 1.10. This fiber is ideal for outdoor carpeting since it is mold and mildew-resistant.

Figure 1.10 Olefin carpet [15]

1.6.8 Polyester carpet

As shown in Figure 1.11, polyester is gaining popularity as a less expensive alternative to other textiles. It has a smooth feel when combined with a thick cut-pile construction. Because it is less resilient and prone to breakage and fading than nylon fiber, it is unsuitable for high-traffic areas.

Figure 1.11 Polyester carpet [16]

1.6.9 Acrylic carpet

Acrylic carpet is not a popular material, but it mimics the look and feels of wool-based carpets for a fraction of the price. It is mold and mildew resistant, but it does not have a higher electrical conductor carrying capacity. Figure 1.12 depicts the acrylic carpet.

Figure 1.12 Acrylic carpet [17]

1.6.10 Wool carpet

Figure 1.13 shows the wool materials carpet is the only natural fiber used in carpet production and the most expensive carpet material available today. It provides a lovely feel against bare feet and is quite long-lasting. It is stain-resistant, but when exposed to direct sunlight, it fades swiftly.

Figure 1.13 Wool carpet [18]

1.6.11 Blends carpet

As shown in Figure 1.14, the blend material carpet with these fiber blends has a better overall look and feel and more excellent durability. Wool and nylon are the most prevalent combinations.

Figure 1.14 Blends carpet [19]

1.7 Application of carpet

As listed below, there are numerous applications for carpets in daily life.

1.7.1 Residential use carpets

Carpets for domestic use are accomplished worldwide, with the major markets being the United States and Western Europe. The Indian subcontinent and China are emerging as major carpet-producing regions. Figure 1.15 depicts the use of carpets in daily life.

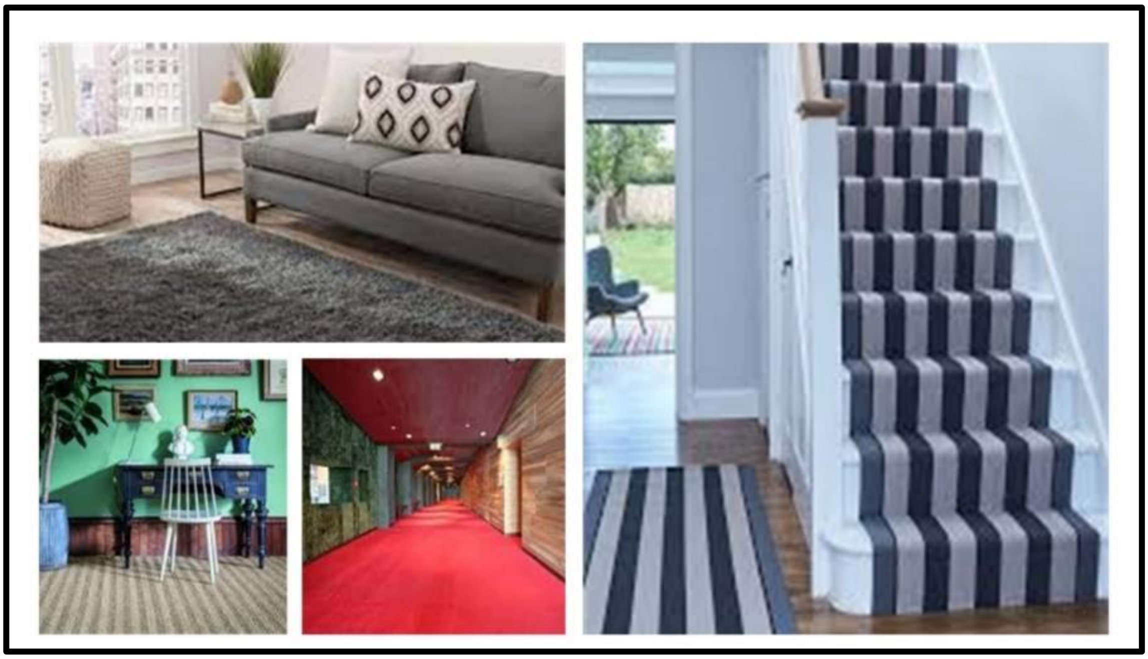

Figure 1.15 Daily life application of carpet

1.7.2 Thermal insulation carpets

Carpets are exceptional thermal insulators, and a suitable underlay provides that characteristic. When used with traditional heating systems, carpet and underlay's insulating properties can effectively reduce heat loss through the floor. Depending on the construction and specification, the carpet can have a thermal insulation rating of 0.1 m^2K/W to 0.3 m^2K/W. When under-floor heating is used, it is assumed that the carpet acts as a heat transmitter to the airspace above. Figure 1.16 shows the application of thermal insulation carpet.

Figure 1.16 Thermal insulation carpet [20]

1.7.3 Acoustic insulation

In three different methods, carpets can provide acoustic insulation. The properties of this are material characteristics that impact sound absorption and acoustic absorption. This is concerned with sound is conveyed into the chamber below, such as a footfall or a dropped object. The carpet pile absorbs impact energy, transforming a high-frequency thud into a low-frequency thud with far less effect on the ear.

1.8 Generation of carpet waste

Nowadays, carpet waste is a considerable concern for the environment and the economy due to the costs involved in the deposal of waste carpets. Only a small fraction of it gets recycled every year compared to carpet waste produced worldwide [21], [22]. Carpets are widely used worldwide for floor covering, homes, offices, commercial centers, decorative purposes, etc. In our daily lives, almost all of us see carpet in various forms near our surroundings. Since India is the world's second-largest country after China, with a population of around 130 crores. Such a large population generates a large amount of carpet waste every year [23]. Carpet waste of about 40,000 tons is sent to a landfill in the UK itself [24]. Due to this, it has become a global concern. Only a small percentage of the amount of carpet waste that is produced every year gets recycled. Carpet waste recycling requires multiple steps of processing, which makes it difficult and expensive [25]. Considering carpet waste as landfilling options becomes uneconomic due to its non-biodegradable nature and increment in charges of landfilling. It is a type of solid waste that is causing environmental issues. Thus, it becomes essential to find some solution to convert such solid waste into a useful form with several applications. The burning of this fibrous waste releases high toxic fumes, which result in danger to human health [26]–[28]. Carpet waste can be collected in two forms, depending on its source of origin [29], [30].

1.8.1 Pre-consumer waste

Figure 1.17 demonstrates the trimmed carpet waste which is collected from manufacturing firms or factories. These are collected from garbage piles or dustbins. Pre-consumer carpet waste includes the trimmed scrap generated at the time of manufacturing or production of carpets per customer needs and demands, such as in cinema halls, households, educational or institutional complexes [31], [32]. For making a suitable design according to requirement, carpet is trimmed out, and this trimmed part cannot be utilized further at the same place. This generated waste has a shrunken and irregular shape and cannot be used further directly. About 10% of the total carpet waste is generated as scrap [33], [34].

Figure 1.17 Trimmed waste (Pre-consumer carpet waste)

1.8.2 Post-consumer waste

Postconsumer waste comprises carpet waste generated after it becomes useless in households and commercial buildings [35]–[37]. Figure 1.18 depicts the waste carpet after it has been used by consumers and thrown into dustbins. The users directly throw these carpets as waste. The carpet waste management hierarchy is depicted in Figure 1.19.

Figure 1.18 Useless carpet waste (Post-consumer carpet waste)

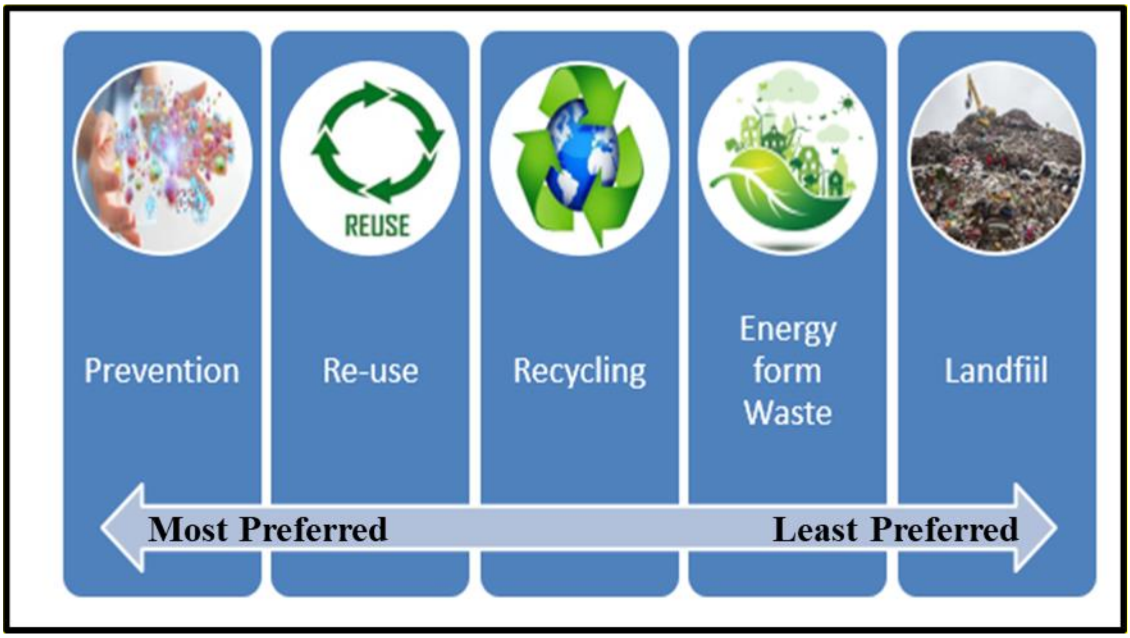

Figure 1.19 Carpet waste management hierarchy

1.9 Recycling of waste carpet

Green manufacture, waste management, application, and environmental development are the most important things to keep in mind in the manufacturing sector in the modern era. With the generation and increasing of carpet wastes from many fields, its re-utilization has become a matter of concern to convert this waste into a valuable product to maintain waste material [38]–[40]. Many research works have been conducted to recycle carpet waste. Various recycling processes have been proposed based on the methodology applied and production of product quality. The following categories have been presented for carpet waste recycling.

1.9.1 Primary recycling

Primary recycling (de-polymerization) is mainly concern with chemical approaches. This involves detaching the face fibers from its backing. This can be done manually or by a particular designed machine.

1.9.2 Secondary recycling

Secondary recycling requires recouping the individual components of a polymeric mixture without necessarily breaking them down to the monomeric form. This category includes various extraction.

1.9.3 Tertiary recycling

Tertiary recycling or melt blending is a physical methodology. It is a widespread procedure due to its flexibility and simplicity [41], [42]. This process involves chopping of carpet into simpler pieces and then blends by melting. This blend of carpet constituents is utilized to manufacture secondary plastic materials.

1.9.4 Quaternary recycling

Quaternary recycling involves the incineration of carpet waste to obtain thermal energy. While burning, this has higher ash content than that of coal. The problems with incineration or the generation of carpet-derived fuel (CDF) increase air pollution containing NOx emissions.

It has become clear that a new method is required to develop carpet recycling to reduce the problems generated through conventional techniques. Therefore, this work has conducted an approach toward the reutilization of discarded carpet, which is quite different from the above recycling process. This study focuses on fabricating composite by utilizing the waste carpet, which can be used in low structural applications. So, before we get into the details of fabrication, it is important to realize the basics of composites.

1.10 Composites

The term composite is defined as "Composites are material systems that are multifunctional and have properties that differ from discrete phases *viz.*, matrix phase and reinforced phase. In other words, two or more materials are physically combined to form a cohesive structure with improved properties." Composite materials are primarily composed of two phases mentioned above, which are described in the following order.

1.10.1 Matrix phase

The matrix is a primary phase with a continuous character. It has a more ductile nature and a softer phase. The role of the matrix phase is to keep the secondary phase (reinforcement) in the desired shape and share the load with it.

1.10.2 Reinforcement phase

These phases have a discontinuous form entrenched in the matrix in specific ratios to enhance the physical and mechanical properties. These are less ductile and stronger than the matrix. It is also called as reinforcing phase.

1.11 Classification of composites

Composite materials have been classified mainly on two bases. The first classification is based on matrix material type composites, and the second is based on reinforcing material type composites. These types are depicted in Figure 1.20 and Figure 1.21, respectively.

1.11.1 Classification based on matrix materials

- **Polymer matrix composites (PMC)**

These are composed of matrix derived from polymer-based materials like thermoset or thermoplastic [43]. The materials which come under thermoset are unsaturated polyester, epoxy, etc., and that which comes under thermoplastic are polycarbonate, polyvinylchloride, nylon, polystyrene, etc. Others that could be considered include PMCs, embedded glass, carbon, etc. PMC consists of fibers as reinforcing material which is comparatively much stiffer and more robust than the matrix. It also becomes attractive due to its lightweight properties, which can be modified for any particular application.

- **Metal matrix composites (MMC)**

A metal matrix composite is a composite material made up of at least two constituent elements, one of which must be metal and another metal, ceramic, or organic ingredient. A hybrid composite consists of three or more materials.

- **Ceramic matrix composites (CMC)**

These are comprised of a ceramic-based matrix with embedded fibers of any ceramic materials or other material in the dispersed phase. Reinforcement in CMC can be short (discontinuous fiber) or long fiber (continuous fiber). Silicon carbide (SiC) is mainly preferred as a reinforcing material because of its high strength and stiffness. It is used in high-temperature applications, but it has poor tension and shear properties. Figure 1.20 depicts the classification of composite based on the matrix phase.

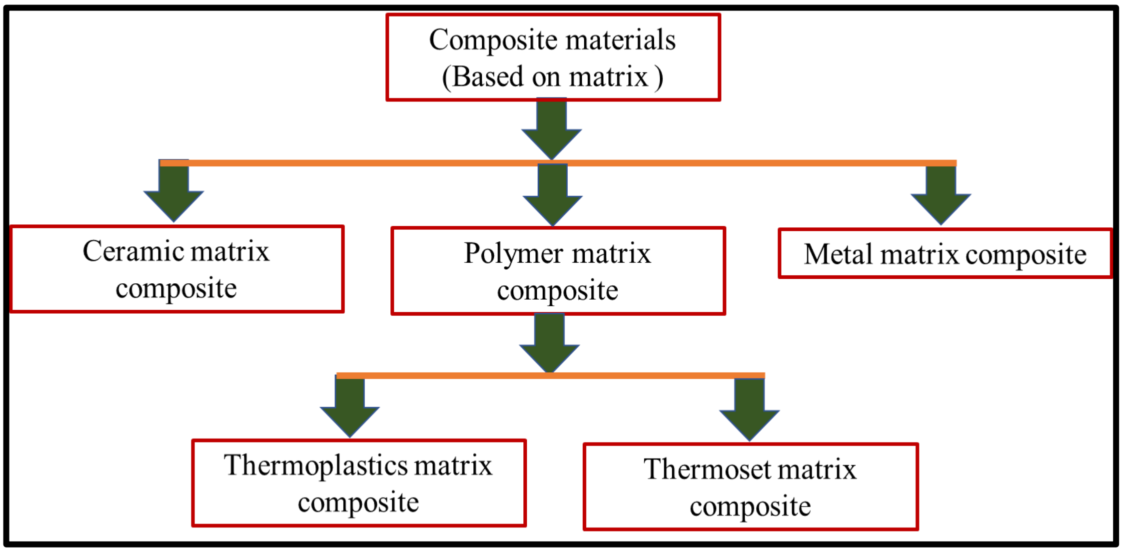

Figure 1.20 Types of composite materials based on matrix

1.11.2 Classification based on reinforced material

- **Particulate composites**

The name suggests that the reinforcement in such a composite is a particle in nature. The particle in this composite can be cubic, spherical, tetragonal, or any other regular or irregular shape, but the condition is approximately equiaxed. These particles help enhance properties of composites such as creep, wear, and abrasion resistance, etc.

- **Fibrous composites**

Fibrous materials are distinguished by having lengths that are significantly greater than their cross-sectional area. However, the dimension of the reinforcement determines its contribution to the composite's properties. Fibers significantly improve the matrix's fracture resistance because their long size discourages crack growth. The surface area of the fiber matrix is kept as large as possible for better load transfer to the fiber composite.

- **Structural composites**

Structural composites are layered composites that are generally low-density composites and used in applications requiring structural integrity, high tensile strength, high stiffness, etc. These composites are strong and lightweight. The properties of composites are dependent on constituents and the geometrical design of the structural element. Figure 1.21 depicts the reinforcement-based classification of composite materials.

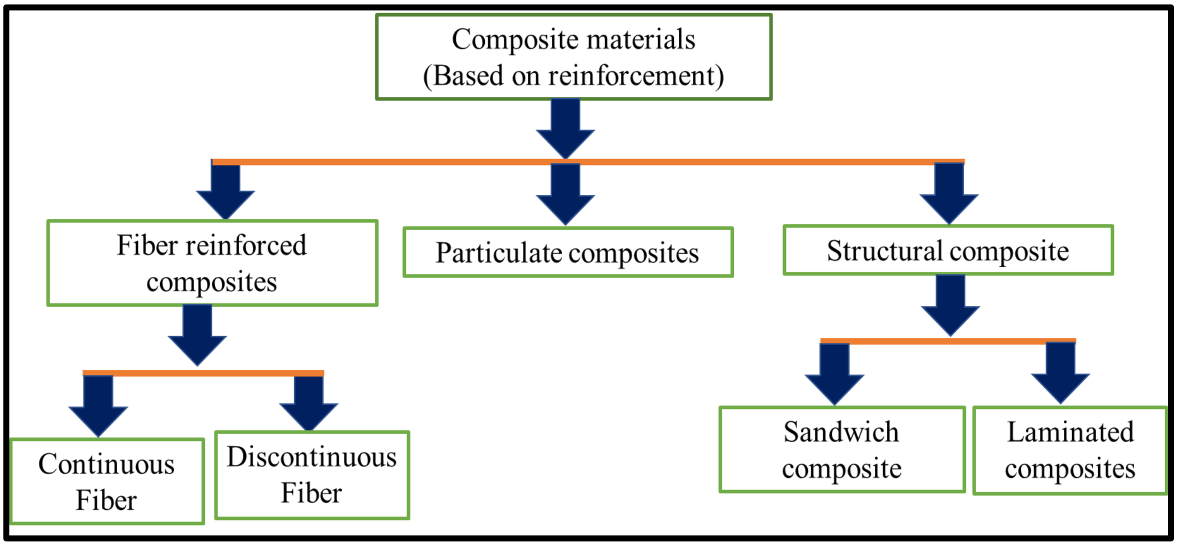

Figure 1.21 Classification of composite materials based on reinforced

Summary

This chapter provides a brief history of carpet origins, major belts in India, carpet advancement generation, classification, and application potential. Later, the development of carpet waste and its recycling technique are discussed. At last, a brief description of composite materials, their classification, and similar critical functions in engineering fields.

Following a brief overview of carpet materials' applications, waste utilization in engineering, the significance and challenges for the development of polymer composites are described. The importance of recycling techniques for the development of discarded polymer composites materials is discussed in the following chapter, including a literature survey of current and previous work related to fabrication and characterization.

Chapter 2

LITERATURE SURVEY

Waste re-utilization provides a feasible way for the development of cost-effective products and reduces environmental hazards. Very limited studies exist on the reuse of carpet for composite development and waste management. Nowadays, various types of carpet waste are available in garbage piles that are difficult to recycle. Several pioneering experiments have been conducted in order to utilize such waste in some appropriate form. An increase in the proper utilization of this waste can eliminate its concerns. Continuous research has been conducted to manage such wastes and could provide an alternate solution.

Some of the preliminary research work was performed by eminent scholars for the reuse of solid waste generation from manufacturing industries. In this series, ***Bateman et al. [44]*** utilized the carpet waste by converting it into a functional product. The author was concerned about waste carpet and low-density polyethylene in this study (LDPE). Maleic anhydride (MAh) PE copolymer as a compatibilizer was taken in small amounts. This study used carpet fibers to reinforce polythene and concluded that it could be composite. ***Atakan et al. [45]*** fabricated valor designed automotive carpets using recycled waste to improve abrasion resistance. This author took recycled polyethylene terephthalate (rPET) taken from PET bottles and concluded that molded carpets made of rPET had improved mechanical and fastness properties. ***Haines et al. [46]*** utilized the shredded post-consumer carpet waste as fuel material in cement kilns that exhibit high heat value similar to low-grade coal. They were found a negligible rise in carbon monoxide and other un-burnt substances. They found a significant increase in nitrogen oxide (NO) due to nylon fibers. ***Rushforth et al. [47]*** investigated the soundproof performance of material prepared from recycled granulated carpet tiles. It has better sound insulation quality and acoustic properties that are influenced by sieving granulated waste. ***Karaduman et al. [48]*** studied the comparative behavior of dry and water absorption carpet waste jute-reinforced polymer composites. They revealed that the impact strength of wet composite increased by 30%, while the flexural strength and modulus decreased by 40% and 65%, respectively. ***Kocak et al. [49]*** were carried experiments by combining carpet waste with cement and water in various ratios. They conducted flexural and impact tests, and the results revealed that the flexural strength increased with density while their impact strength remained constant. Additionally, the material is resistant to moisture and termites. These properties thereby enhanced the ductility of concrete with more significant absorption of energy and modified crack distribution. Hence this novel prepared concrete can be utilized in constructing building material and structural bodies.

Sotayo et al. [50] were made composites with a variation of wool face fiber and synthetic face fiber to convert these wastes into valuable composites. They utilized composite as an alternate for timber and PVC material in posts and rails for fencing purposes. It was reported that the average flexural strength for the new composite was twice the tensile strength. ***Alrshoudi et al. [51]*** performed experiments to utilize the waste in construction. They have observed an excellent combination between polypropene carpet material and palm oil fuel ash. It reflects that the interaction between the matrix and the fiber was made to enhance flexural and tensile strengths, elasticity, energy absorption, and impact resistance. Despite this, the inclusion of carpet fibers did not affect compressive strength. ***Dayiary et al. [52]*** experimentally analyzed the compression behavior of cut-pile carpet by the theoretical model with various fibers such as PP, acrylic spun, etc., based on energy storage under constant compressive stress and concluded that the proposed theoretical model shows a good relationship with experimental results.

Awal et al. [53] fabricated a novel composite, carpet fiber reinforced concrete from polypropylene waste carpet fiber and plain concrete. They were found that incorporating carpet fiber into concrete significantly decreased the workability and concrete density and enhanced the flexural and splitting tensile strengths of concrete. A relation of decreasing modulus of elasticity with the increase of fiber amount was found. The author also reported that the shrinking strain of fabricated composite was higher than ordinary plain concrete to improve soil cohesion and reinforcement. ***Miraftab et al. [54]*** studied to provide green and sustainable development by incorporating waste nylon carpet fiber into the clayey soils. The author reported that this combination had better load-bearing capacity, internal cohesion, shear, and comprehensive strength than the ordinary clayey or substandard soils. Soil moisture content plays a vital role in improving the above properties. Fiber type, fiber length, soil nature, and environmental conditions can also affect the results of such prepared composite to enhance the properties of glass fiber reinforced polymer (GFRP). ***Wang [55]*** studied improve FRC properties by incorporating the recycled nylon fibers from industrial carpet waste. The results revealed improvement in shatter resistance, ductility, and energy absorption compared with virgin polypropylene (PP) fibers used earlier. ***Gowayed et al. [56]*** prepared the composite material by taking PP carpet waste fabric as reinforcement and polyethylene (PE) waste as matrix material. They reported that fabricated composite revealed enhanced mechanical and chemical properties than that of pure polyethylene. ***Jain et al. [22]*** executed structural composites from the waste carpet through the vacuum-assisted resin transfer molding (VARTM) technique. Two types of carpets, such as nylon and olefin-based, were used for fabrication purposes. This paper included characterization such as flexural test and SEM of composites and their applications, including a low-cost container, civil infrastructure components, and materials for impact protection, etc. This technique obtained an improved mechanical property of carpet composites compared with other recycled carpet-based materials. ***Islam et al. [2]*** developed insulation materials made from recycled textiles for acoustic and thermal applications. This played an important role in energy savings and the reduction of environmental pollution. One sector which produces a large amount of waste is the textile sector, though these wastes contain valuable fiber products. These wastes can be recycled to make various products for several applications, including thermal and acoustic applications mentioned above. This recycling process helped in the reduction of waste and fight against severe environmental issues. ***Xanthos et al. [51]*** fabricated a low-cost thermoplastic composite with consistent properties by taking nylon-6 fibers from used carpets and thereby used them for building applications. It can be used as a replacement for wood thermal barriers used in steel-based stud assembly. Flexural strength, modulus, and strength of LDPE decreased by the presence of Automotive shredder residue (ASR). Strength and strain at break decreased, but modulus of LDPE in tensile and flexural loading increased by the addition of carpet residue. Carpet residue-based composite shows better results than ASR-based thermal barrier in terms of higher density, reduced creep rate, thermal conductivity, leachates, and flammable properties. ***Zareei et al. [57]*** investigated the change in tensile, compressive as well as flexural strengths when recycled waste ceramic aggregate (RWCA) and waste carpet fiber (WCF) were combinedly utilized in high strength concrete (HSC). It was found that when RWCA replaced 40% natural coarse aggregate (NCA), it increased the compressive, tensile, and flexural strength by 13 %, 15%, and 3%, respectively. WCF was added to the same mixture. It increased the tensile strength up to 21%. Combinedly showed an increase in water absorption by 48%. ***Miraftab and Mirzababaei [58]*** summarized almost all possible theories, which could be provided as a bunch of information collected. The area of topics that he covered started with the introduction, which included generation and concern of carpet waste. This paper had different pieces of information were the categories of carpets in which post-consumer carpets were focused more. Now, the challenging work related to recycling of such waste carpet were explained. Future scope, sources, government role, and consumers regarding carpet waste as a matter of concern were all discussed. ***Thakur and Thakur [59]*** fabricated polymer composites based on cellulose fibers of different varieties. The use of cellulose fibers as reinforcement components in other polymers helps develop specific properties into the product.

The reason behind this to be the attraction for the researcher is its ease in availability, friendliness to the environment, ease in the processing of having applications in the field from automotive to medical. ***Kumar et al. [60]*** fabricated structural composites from the post-consumer carpet using the VARTM process. This effort was made to convert such waste into an application form. In this paper, such composites used as structures act as a noise barrier in the form of the noise absorption coefficient. For a range of frequencies, it was found that the noise absorbed by fiber composite was better than conventional for a range of frequencies.

Gowayed et al. [61] fabricated composite by using waste fabrics and plastics. The composite synthesized was an environmentally benign fiber composite material. A polypropylene "PP" was chosen as reinforcing material, and polyethylene "PE" was selected as matrix material. These were chosen due to their abundant availability. It was found that an average tensile modulus initially for pure ethylene was 0.15 GPa and its average tensile strength was 9 MPa. Chemical treatment of the fabrics of "PP" was done for the promotion of "wetting" characteristics of "PP" for enhancing the surface compatibility between PP fabrics and PE resin. Fabrication of composite panels was done by compression molding machine and tested for different mechanical properties.

Researchers have shown their interest in using carpets and other wastes that could be utilized in any form. They have tried to use scraps because of their availability and wanted to convert them into a usable manner by various methods. Some have mixed fibers of the carpet with other things, some other have done fabrication and characterization of composites which somehow helps in the utilization of waste.

Chapter 3

METHODOLOGY

This study relates to the re-utilization of waste carpets for developing the lightweight structural polymer composite. Generally, the life of any carpet is typically 10 to 15 years, after which it is discarded as carpet waste [62], [63]. There are generally two types of carpet waste, post-consumer carpet waste, which includes carpets from end-of-life waste streams. Pre-consumer carpet waste includes scraps or off cuts generated during their manufacture and installation. There are numerous types of carpet materials such as nylon, wool, polyester, and polypropylene. Carpet wastes are generated by households, hotels, cars, buses, furniture, movie theatres, etc. These various carpet waste materials are used as reinforcement and epoxy resin as a matrix for the structural composite material. Epoxy improves the interfacial adhesive characteristics between reinforcement and matrix of the composites material. The composites are developed through the Vacuum-assisted resin transfer molding (VARTM) technique, which ensures the voidless infusion of the matrix in the carpet. This discloses the productive and cost-effective approach for the utilization of carpet waste into the composite material.

Additionally, this method refers mainly to the management of solid carpet industry waste and post-consumer carpet waste. This chapter explains the precise fabrication procedure of composite material from waste carpets. The flow chart of methods and processes elaborate in Figure 3.1

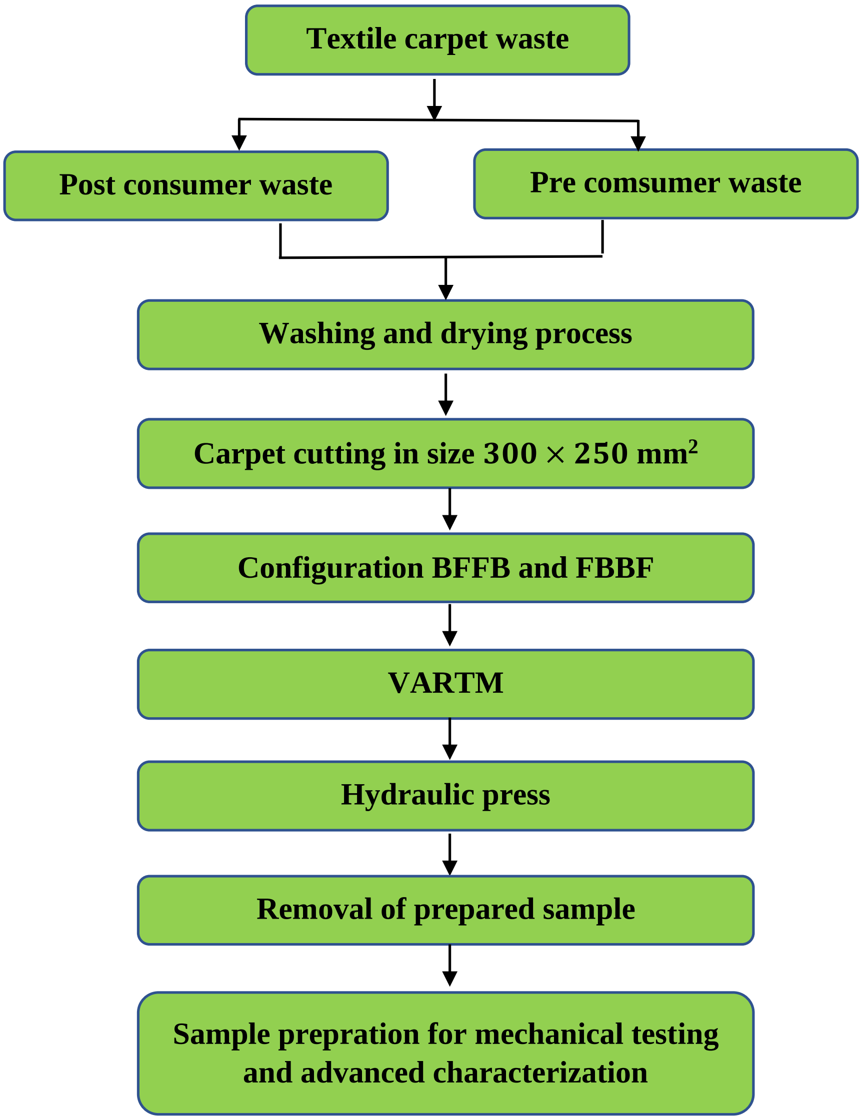

Figure 3.1 Flow chart for the proposed methodology

3.1Material selection

3.1.1 Waste carpet

For the development of composite, the waste carpet mainly has been collected from different sources of pre-consumer scraps from the Bhadohi carpet industry, and post-consumer like households and automobile waste both the carpet waste are shown in Figure 3.2 and Figure 3.3.

Figure 3.2 Pre-consumer textile waste carpet

Figure 3.3 Post-consumer textile waste carpet

3.1.2 Epoxy and hardener

The epoxy material is a thermoset resin, widely used in polymer composites for load distribution to reinforcement applications (Figure 3.4). The epoxy has significant advantages like fabrication at room temperature, excellent composite performance at elevated temperature, superior interlaminar shear strength properties, low shrinkage, resistance to a corrosive environment, and robust mechanical properties. For the fabrication of composites samples in this project, epoxy was used as a polymer phase. For matrix materials, a solvent-free low viscosity, bisphenol-A-based epoxy resin (Araldite GY-257), and hardener (Araldite HY-951) were used. The epoxy and hardener were taken from M/s. Universal Enterprises (Polymer Division) 78/44 Latouche Road Kanpur-2008001 India. The properties of epoxy resin have dissipated in Table 3.1.

Table 3.1 Specification of Epoxy resin (Araldite GY-257)

Parameters	Value
Density	1.15gm/cc
Viscosity	450-650 mPa.s at 25^{0}C
Curing	25^{0}C 20-30 hrs.
Specific gravity	1.8

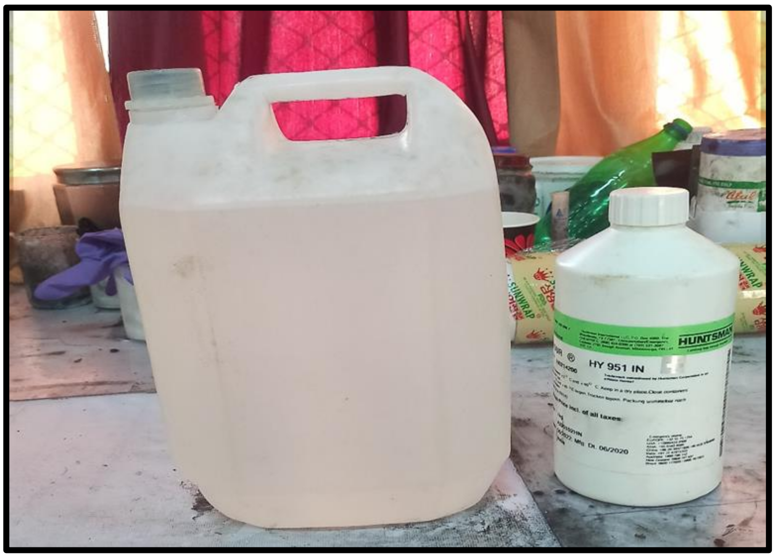

Figure 3.4 Epoxy resin and hardener

There are certain items and tools are required for the fabrication setup, such as vacuum bag (Figure 3.5), mesh (Figure 3.6), peel ply (Figure 3.7), spiral tube (Figure 3.8), clamp, and resin tube (Figure 3.9), sealant tape (Figure 3.10), vacuum pump, etc. which shown below. The release agent, silica gel spray, was utilized to remove the developed specimen simply from the bottom surface. These carpet piles provide mechanical strength, whereas epoxy resin acts as a binding material and distributes the reinforced composite load. Polymer composite fabrication was done with the waste carpet (300×250 mm^2) in FBBF and BFFB configuration by the infusion of thermosetting epoxy resin.

Figure 3.5 Vacuum bagging

Figure 3.6 Resin distribution mesh

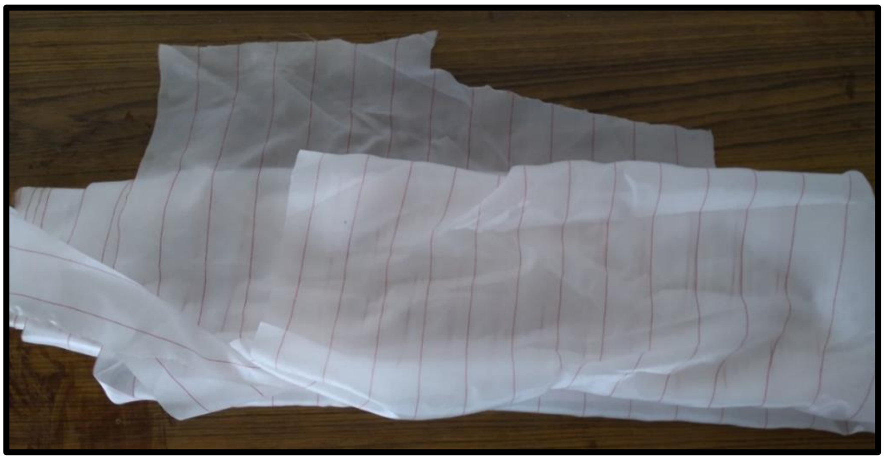

Figure 3.7 Peel ply

Figure 3.8 Spiral tube

Figure 3.9 Clamp and resin tube

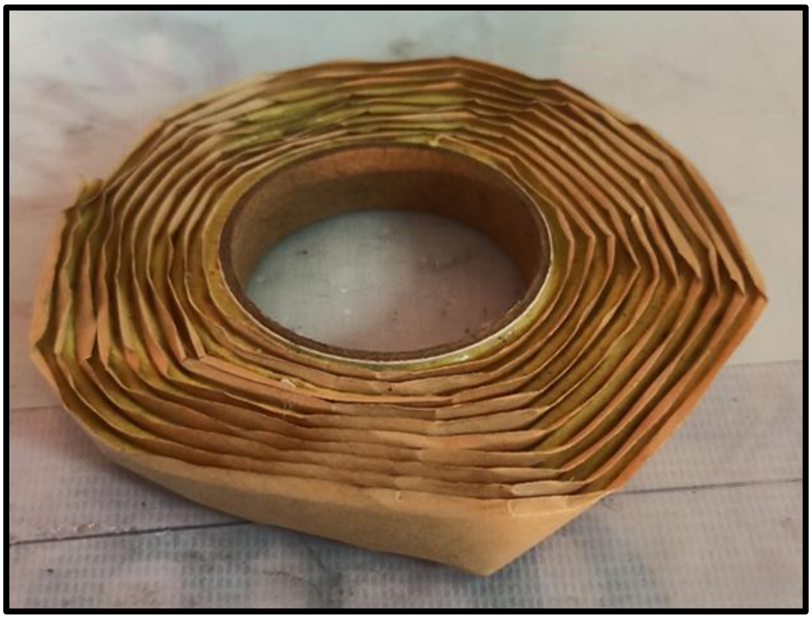

Figure 3.10 Sealant tape

3.2 Fabrication procedure of composite through VARTM technique

The VARTM technique has been used for the polymer composite fabrication, which has the advantage of the uniform resin flow and minimum porosity while preparing the sample. The fabrication setup and block diagram are shown in Figures 3.11 and Figure 3.12. Initially, the acquired waste carpets are gently washed and remove all the dust particles. Cleaned carpets are dried in the open sunlight for 24 hrs. After the dying process, the carpet is cut in the dimension of 300×250 mm^2. The epoxy resin is used as a polymer matrix for the composite development of epoxy diglycidyl Bisphenol-A (Araldite GY 257) low-viscosity Tri-ethylene-tetra-amine (Araldite HY 951) used as a curing agent. The ratio of epoxy and the hardener is 10:1 ratio by weight. The carpet pile was laid down in a vacuum bag into both configuration BFFB and FBBF separately and airtight mold prepared with the help of tacky tape, polyethylene sheet, inlet, and outlet pipe, as demonstrates in Figure 3.11 and Figure 3.12. The vacuum pressure is applied with the vacuum pump of -0.85 atm pressure for the proper infusion of resin in the carpet pile through the spiral wrap. After appropriate infusion from the carpet pile, both the inlet and outlet pipe are clamped tightly and leave 30 hours for proper curing. All the processes are conducted at a room temperature of (approx. 25 ^{o}C). The fabrication work of composite by VARTM was performed at ***Materials & Morphology Laboratory, Department of Mechanical Engineering, Madan Mohan Malaviya University Technology, Gorakhpur, Uttar Pradesh 273010 India*** (displayed in Figure 3.13).

Description of Figure 3.11

- Vacuum bag
- Inlet valve
- Sealant tape
- Outlet valve
- Vacuum box
- Vacuum pump
- Clamp
- Air pressure gauge

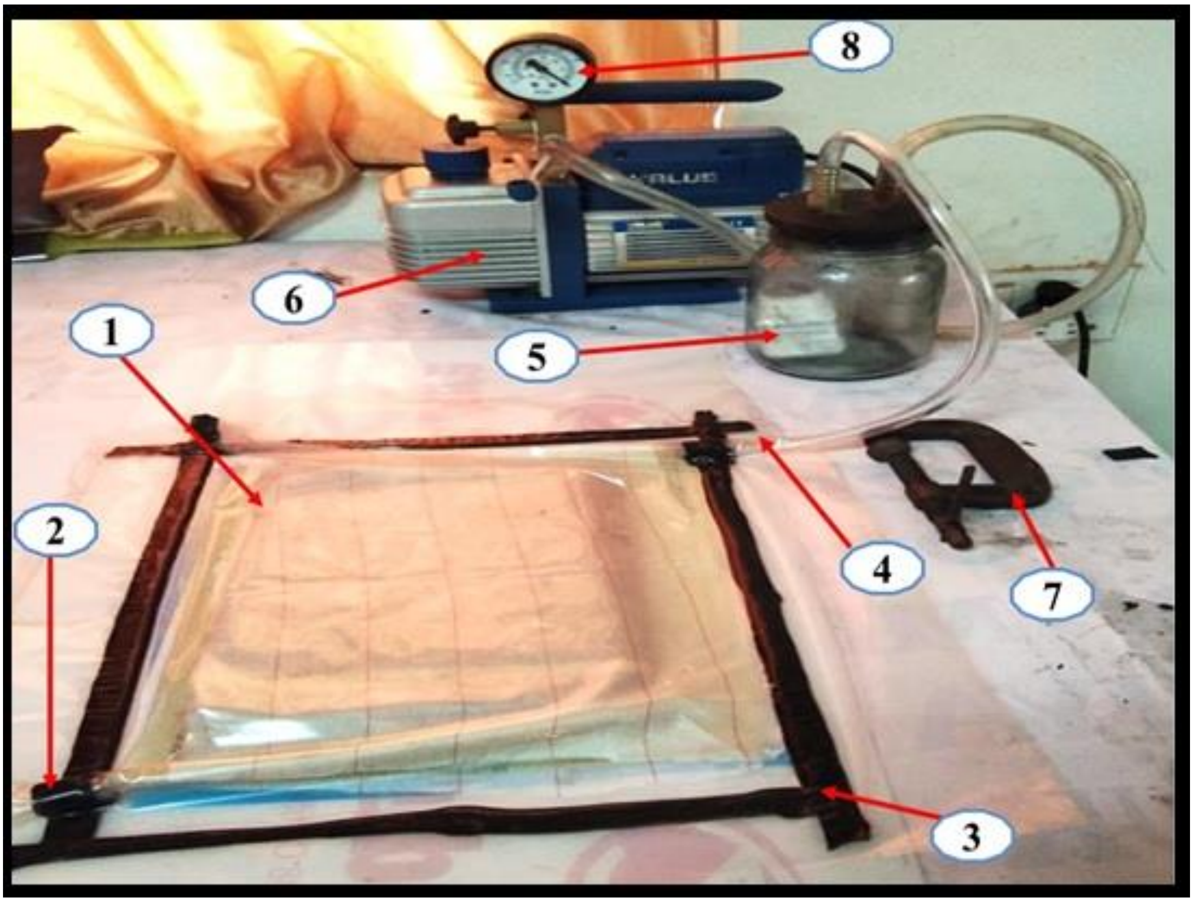

Figure 3.11 Fabrication setup for the development of waste carpet composite

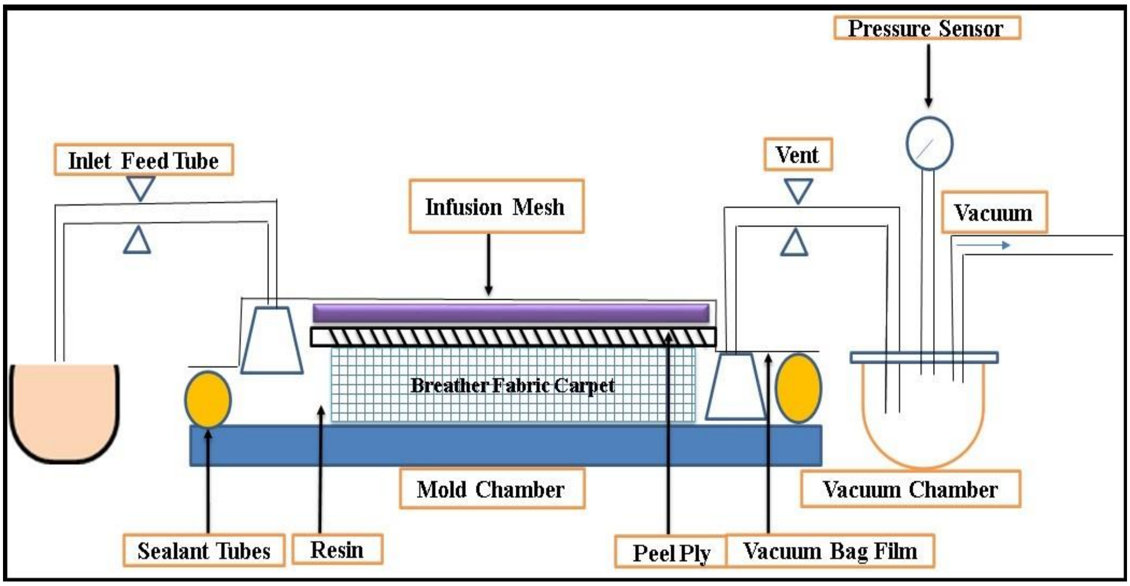

Figure 3.12 Block diagram of VARTM setup

Figure 3.13 Fabrication processes at Materials & Morphology Lab., MMMUT Gorakhpur

The fabricated sample (wool, nylon, polyester, and polypropylene) has been shown in Figure 3.14. The waste carpet was resized to 300×250 mm^2 and then combined their backings to obtain the FBBF configuration and fiber to fiber to obtain BFFB configuration.

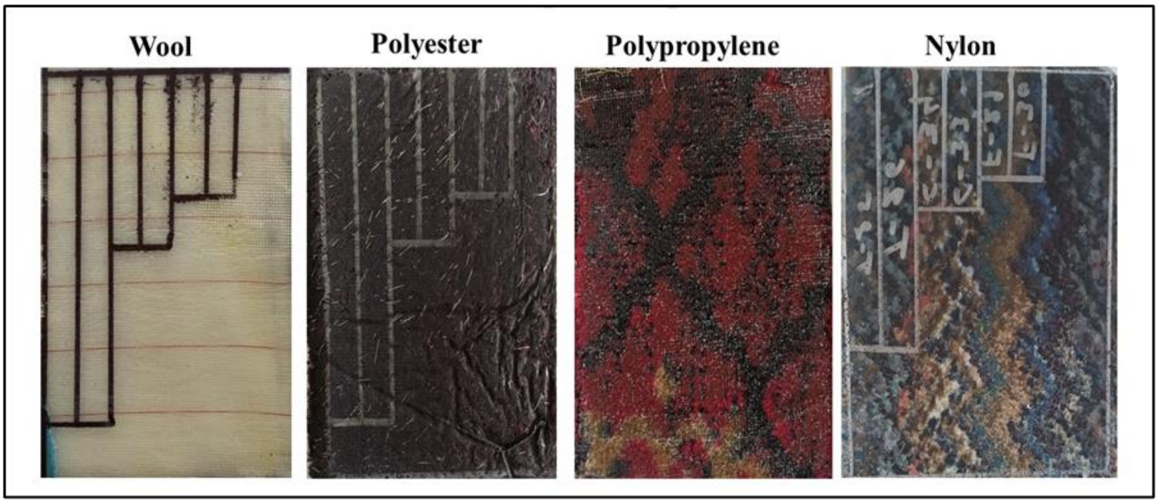

Figure 3.14 Fabricated sample from the different carpet waste material

The processing of carpet wastes and sample preparation techniques are addressed in this chapter. Later, the selection of carpet waste materials for the development of composites was discussed. Epoxy and hardener, which has used as a matrix material for the proposed composite. After that, the VARTM technique was briefly described for the fabrication of the sample.

Chapter 4

MECHANICAL AND MORPHOLOGICAL CHARACTERIZATION

4.1 Mechanical characterization

Mechanical characterization mainly performs to examine the properties of the material in static and dynamic force conditions. Their testing results ensure that material capacity and its suitability for the planned mechanical applications. This affects the mechanical strength and overall efficiency of the proposed material to be molded in an appropriate shape and size. This also includes the physical property evaluation of functional characteristics of structural composite material. Mechanical characterization of the proposed composite samples was done by the tensile test and flexural test analysis from the face BFFB (Back Front-Front Back) and FBBF (Front Back-Back Front).

4.1.1 Tensile test

The various polymer composites study compares the outcomes based on tensile data such as strength, modulus, and elongation at break. The specimen resists elongation during the test, and it is detected by the load cell the sample preparation and testing condition having a significant impact on the tensile strength value. The tensile properties of all materials are determined from the uniaxial tension and specimen prepared according to the ASTM D3039. Figure 4.1 shows the various dimensions specified as per ASTM D3039 standard for carpet/epoxy composite tensile specimen. Universal Testing Machine (UTM-WDW-5) was used to test the prepared samples.

Tensile test procedure

The tensile specimen is placed between the grips of a UTM as shown in Figure 4.2, and the load is given gradually until the specimen fails. An average test speed for testing standard test specimens is 2 mm/min. The universal testing equipment is connected to a computer, and experimental data are acquired using software that calculates deformation and tensile strength. Testing in multiple orientations (BFFB and FBBF) is evaluated depending on the reinforceme nt and type of composites. This test was repeated for all the specimens chosen for the test.

Figure 4.3 shows the tensile test samples before testing, and Figure 4.4 shows the tensile test samples after testing.

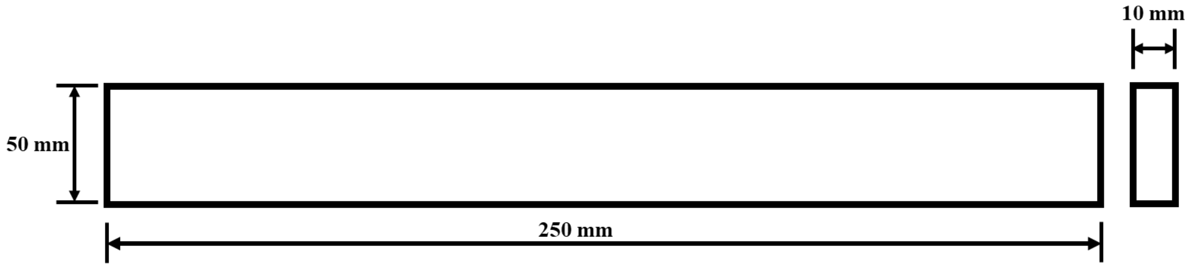

Figure 4.1 Specimen of the tensile test (ASTM D3039)

Figure 4.2 Tensile testing on UTM machine at CIPET, Lucknow

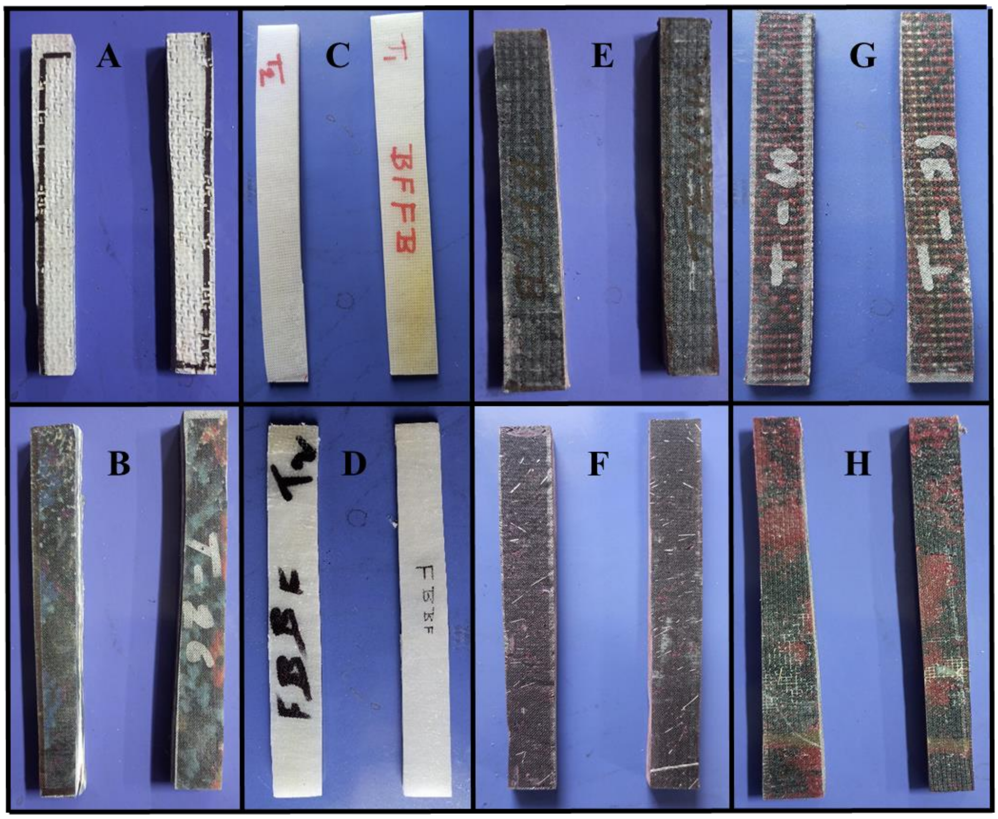

Figure 4.3 Samples of tensile test (A) Nylon BFFB (B) Nylon FBBF (C) Wool BFFB (D) Wool FBBF (E) Polyester BFFB (F) Polyester FBBF (G) Polypropylene BFFB (H) Polypropylene BFFB

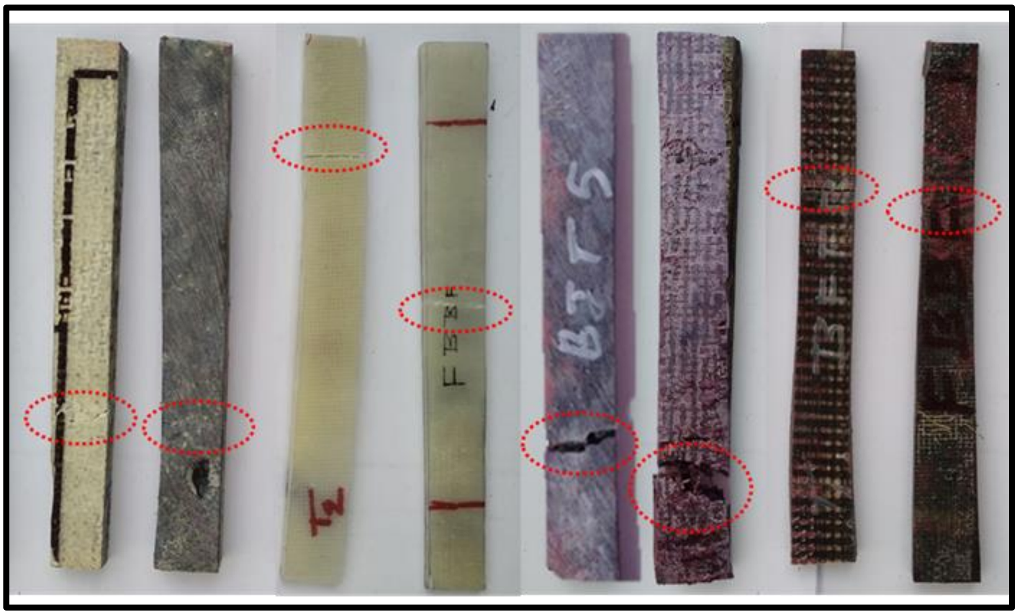

Figure 4.4 Tested samples (Tensile)

4.1.2 Flexural test

Flexural testing determines a sample's flexural stiffness and bending strength by testing its ability to withstand both 3-point and 4-point bending. This research utilizes the UTM machine to carry out a 3-point bending test. The flexural strength is defined as the material's ability to resistant the bending action against an applied force vertical to the longitudinal axis. The generated stress is a combination of tensile and compressive stress. Flexural strength is also known as rupture modulus, bending strength, or fracture strength. It is a mechanical property that is defined as the ability to resist deformation when being loaded. The bending test in transverse is most frequently used where a specimen with either a rectangular or circular cross-section is bent until fracture. The ASTM D790 standard is commonly used in the polymer and composite sectors and is often quoted for bending strength measurement. The obtained flexural strength of the material and allows users to select the materials that do not fail when supporting the loads required for the application.

Flexural test procedure

A three-point bend fixture conducted flexural tests on the universal testing machine, as shown in Figure 4.5. The UTM was connected with a computer so that the experimental values were taken. The flexural strength and the flexural modulus were obtained directly from the computer. The dimension of the specimens was considered according to ASTM D790 standards, as shown in Figure 4.6. A schematic diagram of the flexural test setup is represented in Figure 4.7. Adjust the support span length with the standard determined length. Place the test specimen on the three-point bend fixture and begin the test on the universal testing machine by applying the load gradually. The bending load was applied to the specimen until it delaminated and broke. This delamination indicates the failure of the sample. Figure 4.8 shows the flexural test samples before testing, and Figure 4.9 shows the flexural test samples after testing.

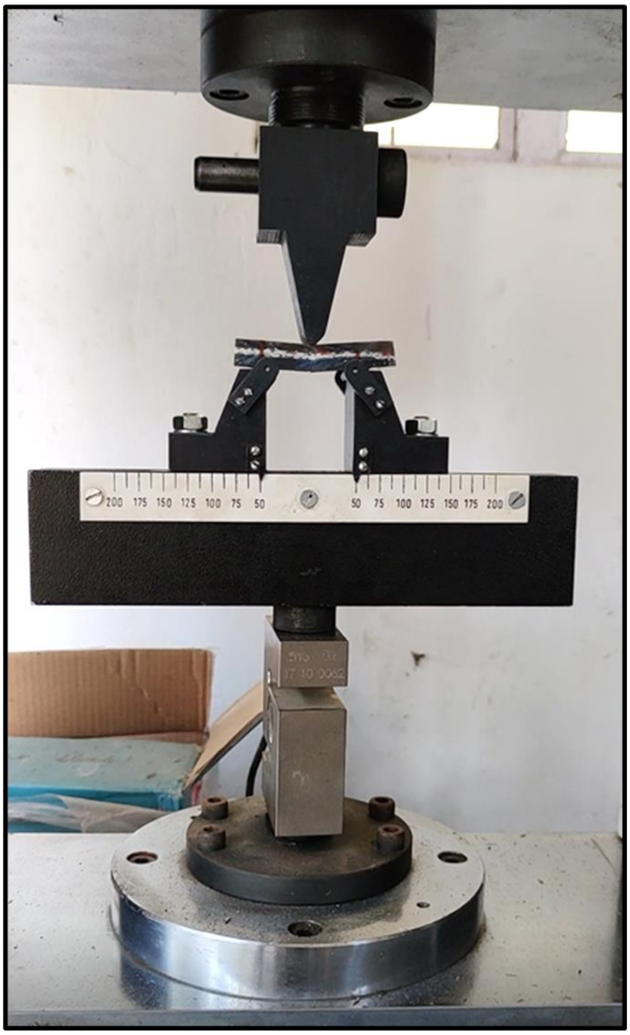

Figure 4.5 Flexural test specimen on UTM

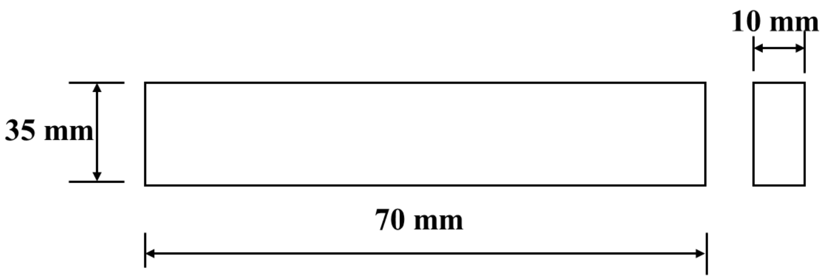

Figure 4.6 Specimen of the flexural test (ASTM D790)

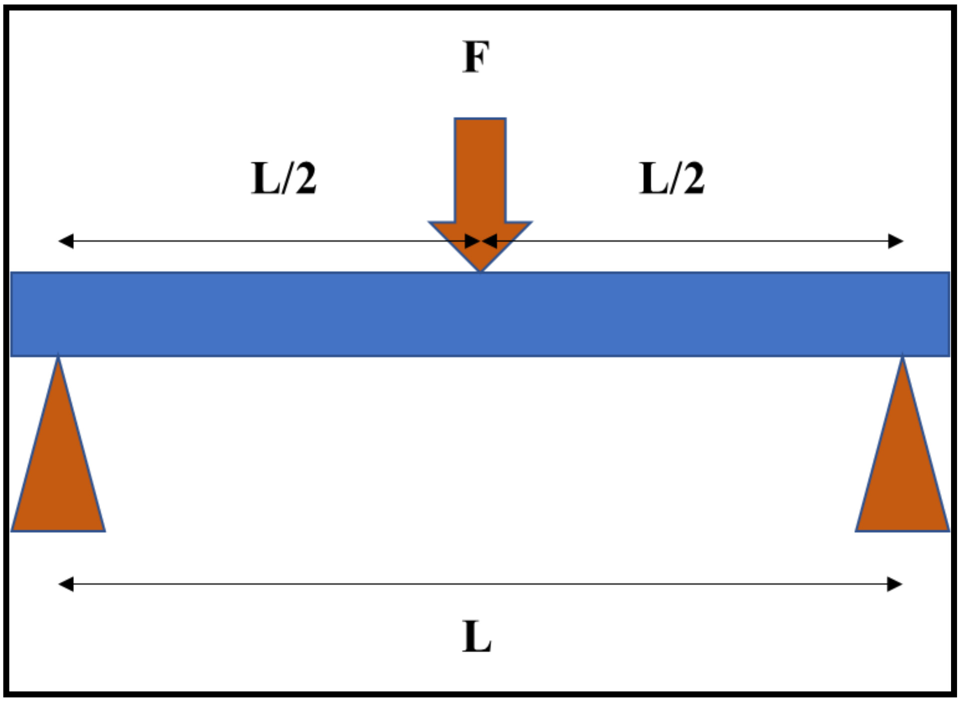

Figure 4.7 Schematic diagram of the flexural test setup

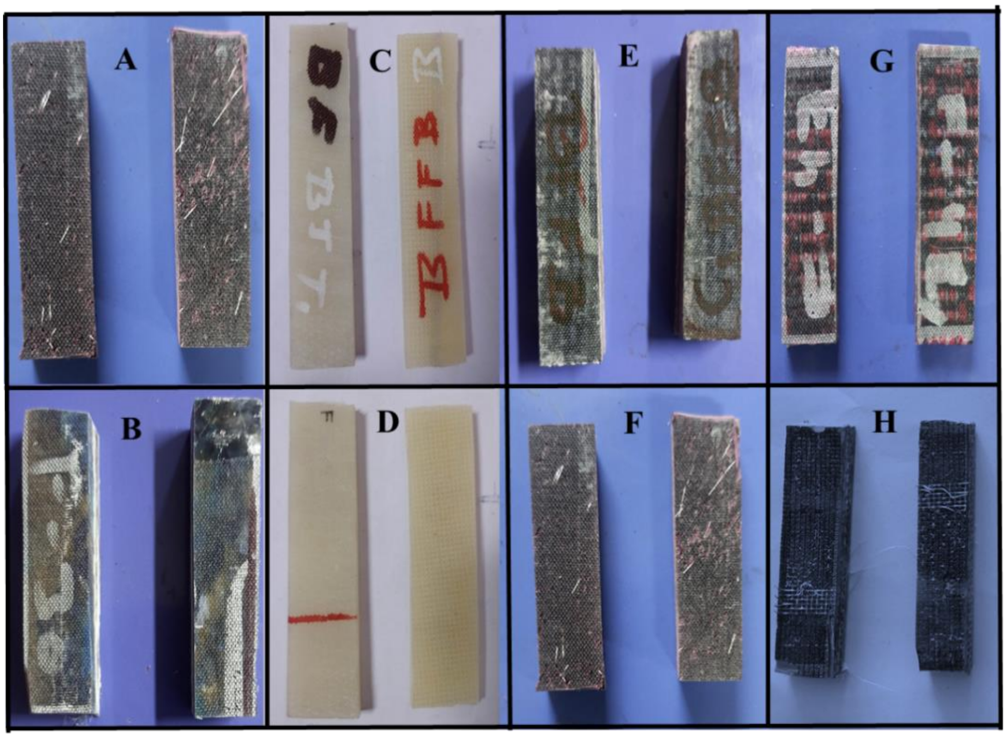

Figure 4.8 Samples of flexural test (A) Nylon BFFB (B) Nylon FBBF (C) Wool BFFB (D) Wool FBBF (E) Polyester BFFB (F) Polyester FBBF (G) Polypropylene BFFB (H) Polypropylene FBBF

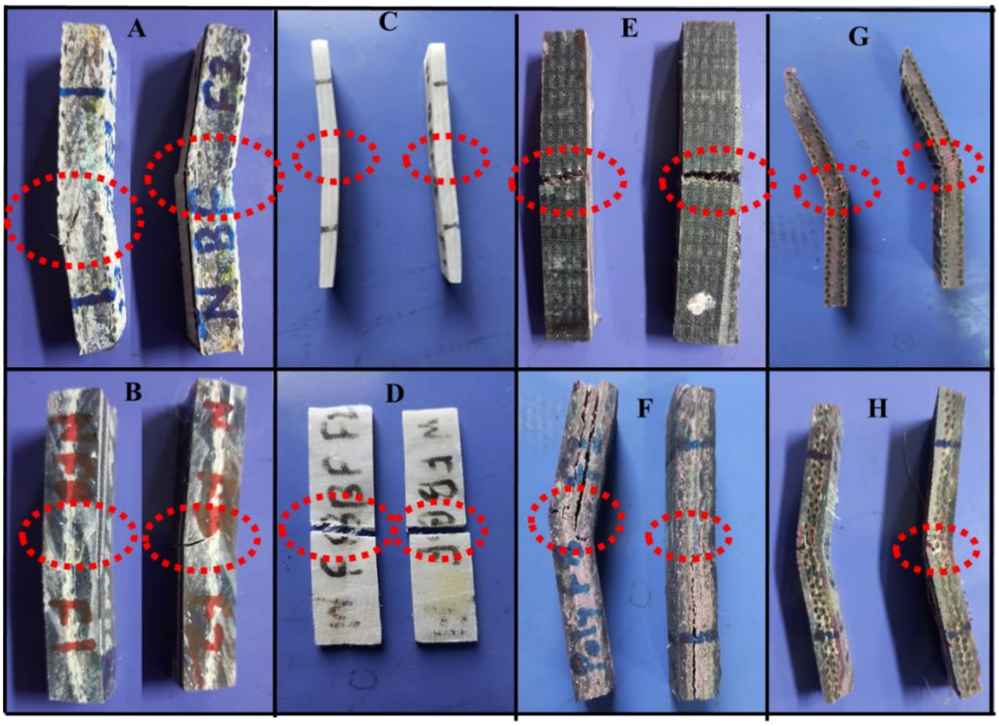

Figure 4.9 Tested samples of flexural test

4.2 Morphological characterization

The microstructure and metallurgy of substrates, particularly at the surface, are usually required to be well understood in high-value production since they influence the safe loading conditions and longevity. Morphological characterization of the developed composite has been performed to characterize based on thermal properties of the material, microstructural analysis. In this work, the chemical composition of the material, phase of the material, and crystallinity of the discarded composite samples are also investigated.

4.2.1 Thermal gravimetric analysis (TGA)

Figure 4.10 shows TGA 55 machine was used for thermal analysis of the developed carpet waste structural composites at the Indian Institute of Technology Roorkee (IITR) Saharanpur Campus lab. Thermogravimetric analysis, often known as thermal gravimetric analysis (TGA), is a thermal analytical technique that determines the mass of a sample as temperature changes over time. In particular, this study gives information on physical phenomena like the transitional phase, absorption, and desorption of substances.

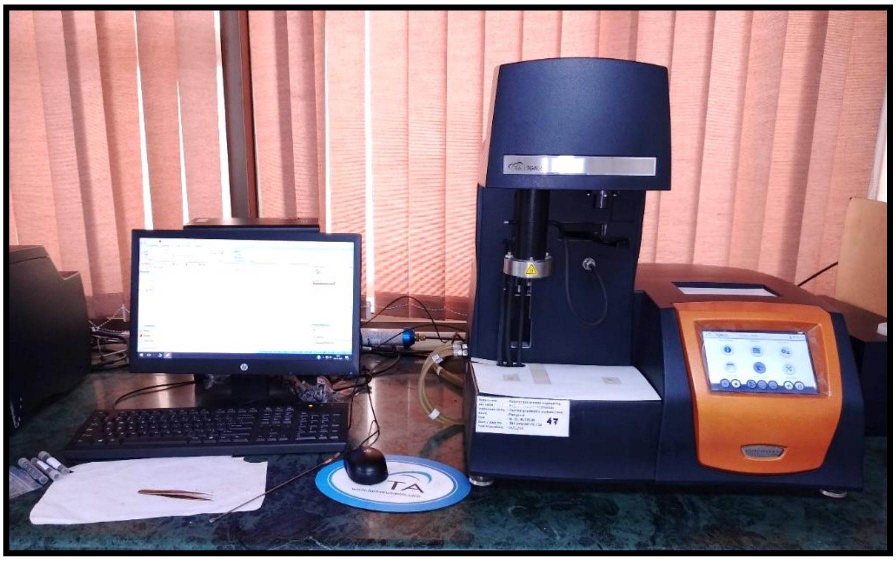

Figure 4.10 Thermogravimetric analyzer

4.2.2 X-ray diffraction (XRD)

Fully automated optical alignment under computer control Ultima-IV machines shown in Figure 4.11 was used to X-ray diffract the developed carpet waste structural composites. XRD is an advanced technique for characterizing the structure, phase, crystal direction, and other structural parameters, such as average kernel sizes, crystallinity, strain, and crystal defects. XRD peaks are created by a monochromatic X-rays beam dispersed off each set of lattice planes at specified angles. The atomic locations dictate the maximum intensity of the lattice planes.

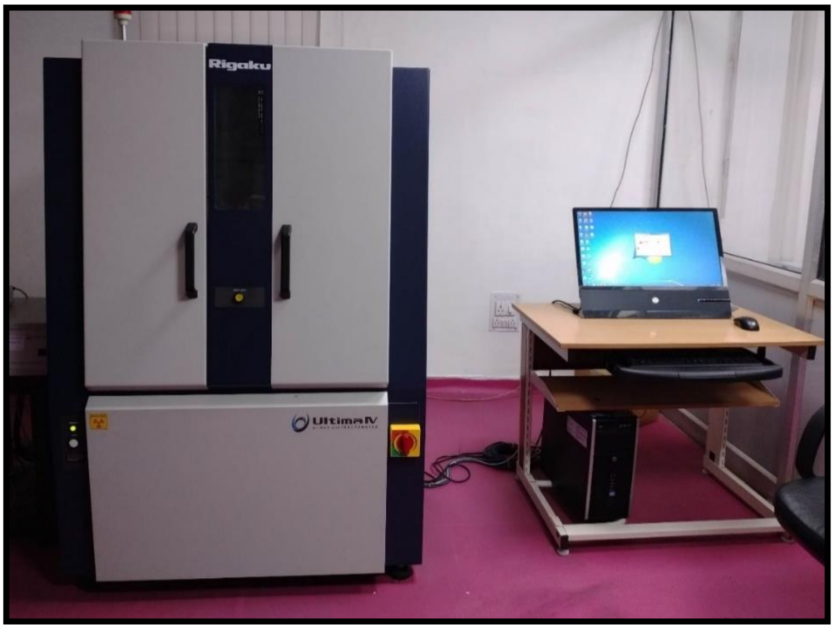

Figure 4.11 X-ray diffraction analyzer

4.2.3 Fourier transform infrared (FTIR) spectroscopy

FTIR spectrometer shown in Figure 4.12 was used for spectroscopy analysis and identify chemical compounds of the developed carpet waste structural composites. For both organic and inorganic materials, FTIR delivers quantitative and qualitative studies. By generating an infrared absorption spectrum, FTIR can identify chemical bonds in a molecule. The spectra provide a sample profile, a unique chemical fingerprint that may be used to screen and scan samples for various components. FTIR is a useful analytical tool for identifying functional groups and analyzing covalent bonding information.

Figure 4.12 Spectrum-2 FTIR spectrometer

Chapter 5

RESULTS AND DISCUSSIONS

In previous chapters, carpet waste/epoxy composite fabrication, mechanical characterization, and morphological characterization have been done. Now in this chapter, the results of mechanical and morphological testing have been analyzed and discussed.

5.1 Tensile strength of developed carpet waste composites

Tensile tests were performed on carpet waste composite materials of wool, polypropylene, nylon, and polyester. All the composite materials were laminated using the two ways back front-front back (BFFB) and front back-back front (FBBF) techniques. The tensile strength of the specimens is shown in Table 5.1 and plotted stress-strain curves are shown in Figure 5.1.

Table 5.1 Tensile strength of composite material

Material	Tensile Strength (MPa)	
	FBBF	**BFFB**
Wool	18.2	16.4
Poly Propylene	8	7.7
Nylon	7.3	11.5
Polyester	11	12

The stress-strain plots show that for wool (FBBF), composite stress increases almost linearly with the strain before fracture of the specimen. It shows the brittle nature of the wool FBBF composite. In the same way, the wool (BFFB) composite shows a linear rise in the curve but with small yielding before the fracture point. Tensile strength of the wool composite was found 18.20 MPa in FBBF laminate and 16.40 MPa in BFFB laminate. It can be observed that the wool composite strength of FBBF laminate is greater than BFFB laminate.

The tensile strength of the polypropylene composite was determined to be 8 MPa for the FBB F laminate and 7.7 MPa for the BFFB laminate. The stress-strain curve of polypropylene composite shows several peaks without fracture for both laminate FBBF and BFFB, which present the toughness of the composite. It was observed for the polypropylene composite, the strength of FBBF laminate is almost equal to BFFB laminate.

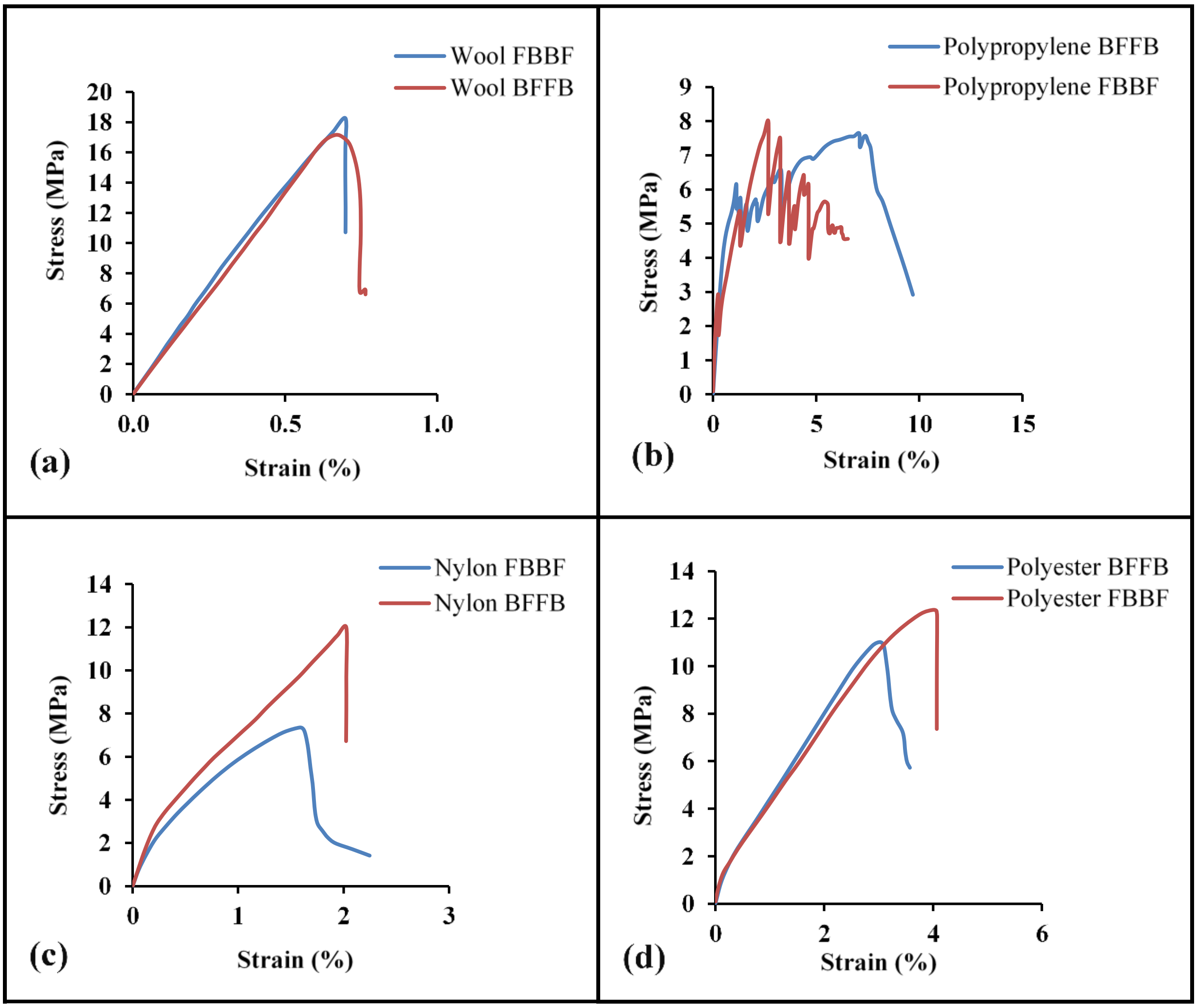

Figure 5.1 Stress-strain (tensile) curves of epoxy-based carpet waste composite (a) Wool (b) Polypropylene (c) Nylon (d) Polyester

The tensile strength of the nylon composite was found at 7.30 MPa in FBBF laminate and 11.50 MPa in BFFB laminate. The stress-strain curve of the nylon composite rises linearly up to the elastic limit. After that, it shows yield point and then rises linearly with strain. It presents the ductile nature of nylon composite. It was observed for the nylon composite, the strength of FBBF laminate is smaller than BFFB laminate.

For the polyester composite, both curves of BFFB and FBBF show very low elastic limits. After that, stress rises linearly with strain. The curves present the ductile nature of polyester composite material. Tensile strength was found 11 MPa in FBBF laminate and 12 MPa in BFFB laminate. It was observed for the polyester composite, the strength of FBBF laminate is smaller than BFFB laminate.

5.2 Flexural strength of developed carpet waste composites

Flexural strength is defined as the material's ability to resist bending action against an applied force vertically to the longitudinal axis. Flexural tests were done of composites made from various waste carpet materials such as nylon, polypropylene, polyester, and wool. The flexural test is performed to evaluate the specimen's bending strength and flexural stiffness by 3-point bending test. The generated stress is a combination of tensile and compressive stress. The ASTM D790 standard was followed in preparing the sample. All composite materials were laminated using the two-way back front-front back (BFFB) and front back-back front (FBBF) techniques (FBBF). The flexural strength of discarded carpet/epoxy composite material is shown in Table 5.2. According to the table, the flexural properties of wool/epoxy composite BFFB laminates have the highest flexural strength. Polypropylene (BFFB) and nylon (FBBF) composites have the best flexural strength after wool (BFFB). In comparison, wool (FBBF) has the lowest flexural strength of the developed structural composite material. The enhancement in flexural properties is clearly due to the recycled waste carpet's ability to withstand the composites' bending force. The polyester/epoxy composite materials BFFB and FBBF, both laminate was subjected to resist with the highest load.

Table 5.2 Flexural strength of composite material

Material	**Flexural strength (MPa)**	
	FBBF	**BFFB**
Wool	23.00	34.40
Poly Propylene	30.64	34.00
Nylon	33.19	25.47
Polyester	28.23	26.61

Figure 5.2 demonstrates the typical load-displacement curves attained after performing the flexural test on the four samples, which have been shown in Figure 5.2 (a), 5.2 (b), 5.2 (c), and 5.2 (d), respectively. Each graph contains two curves for the same material but different (BFFB & FBBF) configurations. In Figure 5.2 (a), the wool/epoxy BFFB composite exhibits a quick and sharp load rise, indicating a higher load (strength) than the wool/epoxy FBBF sample, but it also has low displacement suggesting that it is brittle. On the other hand, the maximum load of wool/epoxy FBBF sample is less than the BFFB sample, but yield displacement is high, showing this composite's ductile nature. Figure 5.2 (b) shows the load-displacement curves for polypropylene carpet/epoxy composite. In this graph polypropylene/epoxy FBBF sample has

a higher flexural load and maximum yield displacement. This shows the toughness of the material. However, the polypropylene carpet/epoxy BFFB sample has a small rise in load with higher displacement and exhibits the material's ductile property. Figure 5.2 (c) shows the load-displacement curves for nylon/epoxy composite. The nylon FBBF sample has a steep load rise with small displacement showing the composite's brittle nature. The nylon BFFB sample, on the other hand, exhibits a moderate rise in load with considerable displacement, indicating the material's ductile nature. Figure 5.2 (d) shows the load-displacement curves for polyester/epoxy composite. Both the BFFB and FBBF curves exhibit a sharp rise in load until they reach the elastic limit, after which they display displacement with distinct peaks that demonstrate the materials' toughness.

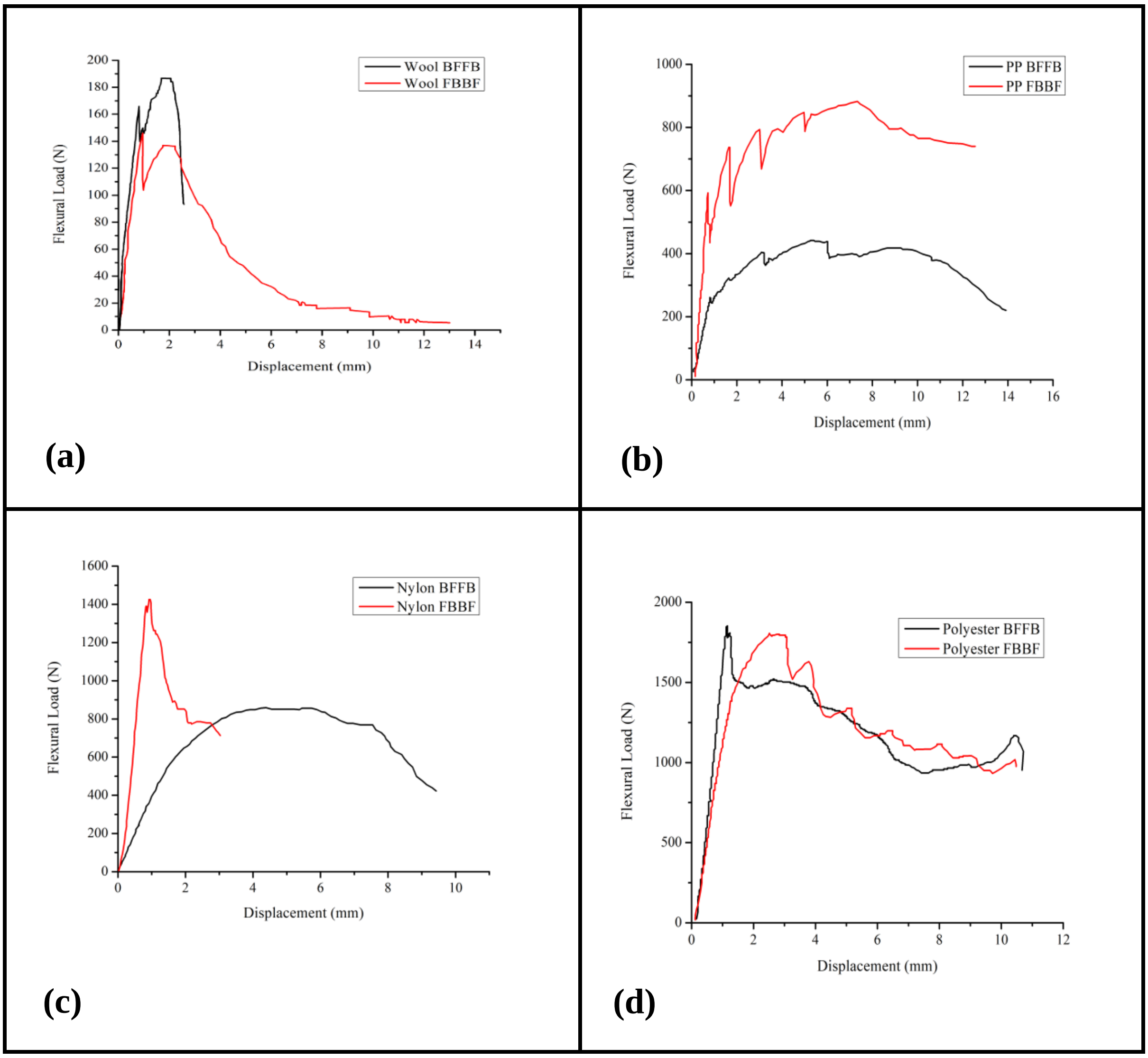

Figure 5.2 Load-displacement (flexural) curves of epoxy-based carpet waste composite (a) Wool (b) Polypropylene (c) Nylon (d) Polyester

5.3 Thermogravimetry analysis of the developed composites

In this test, the thermal stability was investigated in terms of weight loss as a function of temperature in a nitrogen atmosphere. Thermogravimetry analysis (TGA) of the epoxy-based waste carpet composite material is illustrated. From Figure 5.3 (a), there are three primary reaction stages of degradation. The first stage shown at 248˚C was caused by loss of water or decomposition of impurities. Figure 5.3 (a) shows the loss of weight fraction was around 6.76%. The second degradation step, associated with the polymeric fraction's decomposition, is composed of the prominent peak. After this point, there was massive thermal degradation related to the deterioration of the polymeric fraction. A temperature rises of about 109°C is equivalent to the highest amount of weight loss: resin was decomposed. The decay of the resins ended approximately at 600°C, with a 77 % weight loss. Finally, around 800°C, it degrades about 91.77% weight loss of the whole sample.

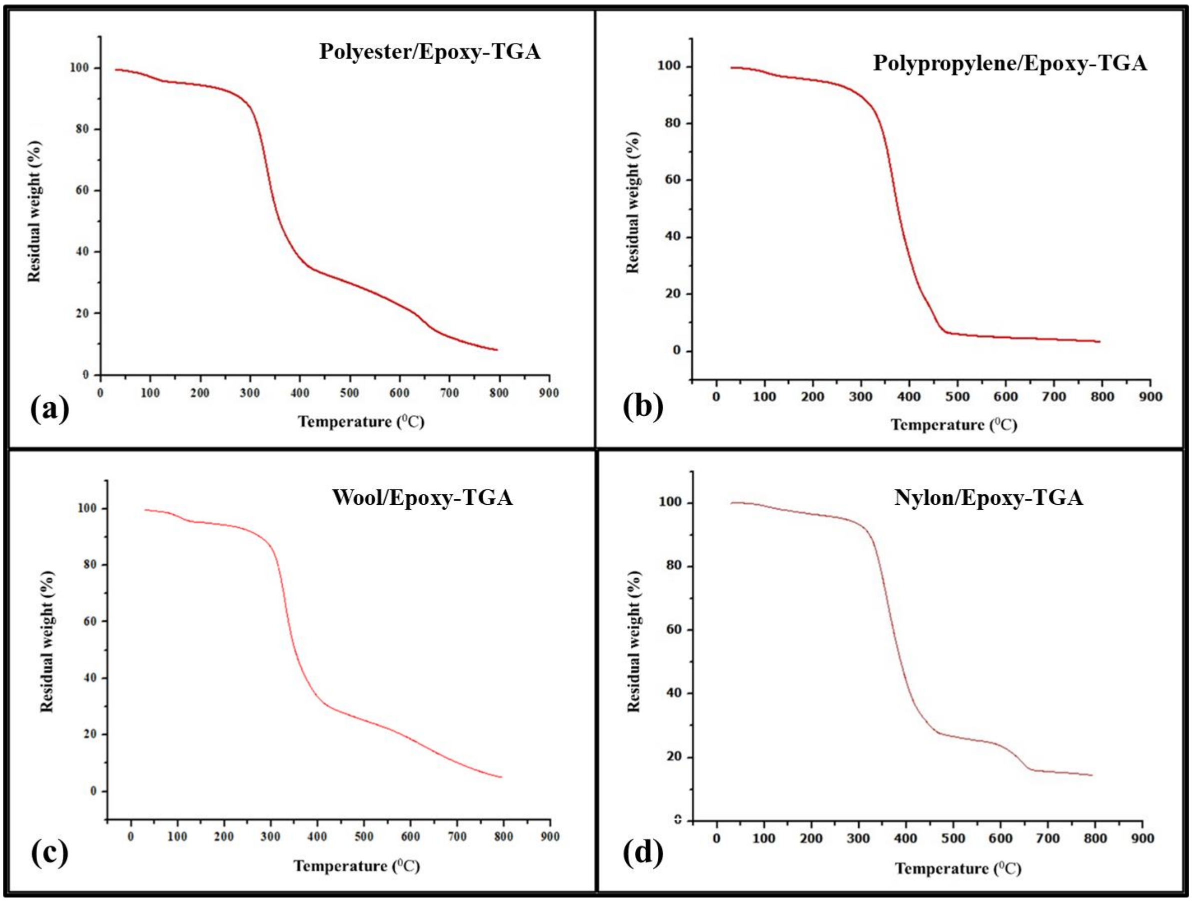

Figure 5.3 TGA analysis of epoxy-based carpet waste composite (a) Polyester (b) Polypropylene (c) Wool (d) Nylon

Figure 5.3 (b) showed the TGA curves of the epoxy-based carpet (polypropylene) waste composite. During the first step, a slight weight loss was detected at the temperature of 100°C due to the evaporation of moisture and other volatiles. The loss of weight fraction in the first step was around 10%. The actual decay occurs in the second step at 300°C, which is caused by the thermal degradation of propylene. Following this stage, there was a massive amount of thermal degradation due to the degradation of the polymeric fraction. The decay of the resins ended approximately at 470°C, with 93.86 % weight loss. Finally, around 800°C, it degrades about 97.84% weight loss of the whole sample.

Figure 5.3 (c) showed the TGA curves of the epoxy-based carpet (wool) waste composite. During the first step, a slight weight loss was detected at the temperature of 100°C due to the evaporation of moisture and other volatiles. The loss of weight fraction in the first step was around 10%. The actual decay occurs in the second step at 290°C, which is caused by the thermal degradation of wool. After this point, there was massive thermal degradation of polymeric material occurs. The decay of the resins ended approximately at 550°C, with 84 % weight loss. Finally, around 800°C, it degrades about 96.84% weight loss of the whole sample.

Figure 5.3 (d) shows the TGA curves of the epoxy-based carpet (nylon) waste composite. During the first step, a slight weight loss was detected at the temperature of 100°C, which was due to the evaporation of moisture and other volatiles. The loss of weight fraction in the first step was around 8%. The actual decay occurs in the second step at 320°C, which is caused by the thermal degradation of nylon. The temperature rises up to 600°C, and the resin was decomposed. The decay of the resins ended approximately at 650°C, with 84 % weight loss. Finally, around 800°C, it degrades about 91.80% weight loss of the whole sample.

5.4 X-Ray diffraction of a different material of polymer composites modified by discarded carpet

X-ray diffraction test was performed for epoxy-based waste carpet composite of different materials and illustrated. For the polyester material in Figure 5.4 (a), it is observed that all of the spectra contained three peaks that are mainly well established for the polyester reinforced with epoxy. The ordinate depicts the XRD pattern maximum refractive intensity, and the abscissa indicates the diffraction angle. This identified the existence of the polyester reinforce epoxy with its higher peaks at $2\theta = 24°$ and the low peaks at 28°, and 43°.

In epoxy, the XRD characterization method is primarily used to determine the degree of epoxy and polypropylene reinforcement. The presence of high peaks at 2θ=19.5° degree and lower peaks at 2θ=17°,19°, and 23°, Figure 5.4 (b) confirms the existence of polypropylene in epoxy.

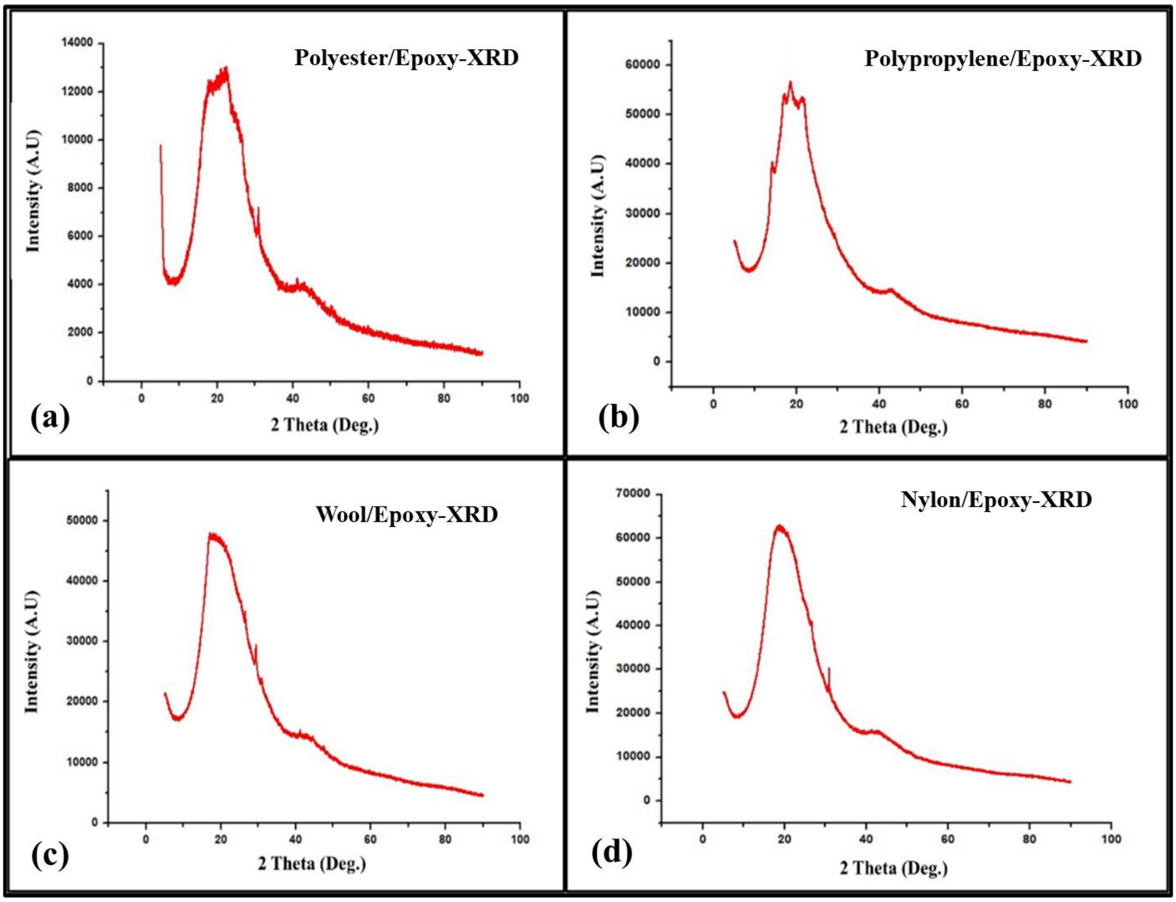

Figure 5.4 XRD analysis of epoxy-based carpet waste composite (a) Polyester (b) Polypropylene (c) Wool (d) Nylon

The XRD output of wool reinforcement in epoxy is shown in Figure 5.4 (c). The wool and epoxy peak are visible in the fabricated composite of wool reinforced with epoxy, as shown in Figure 5.4 (c). According to the figure, a solid solution was produced by mixing wool and epoxy, resulting in the formation of wool reinforcement in epoxy, and finally, the composite's peak can be seen. The crystalline characteristics of nylon/epoxy composite are clearly visible in the diffractogram at 2θ =30°, as shown in Figure 5.4 (d). In the X-ray pattern and at 2θ = 25.1° peaks, wool reinforcement in epoxy peaks can be seen. This demonstrates the presence of wool reinforcement in epoxy composite particles in the fabricated composite.

5.5 Fourier-transform infrared spectroscopy of different material polymer composites modified by discarded carpet

FTIR spectra of polymer (epoxy) composite modified by discarded carpets are shown in Figure 5.5 (a). The assignments and wavenumbers of FTIR transmittivity bands were summed up in Table 5.3. At a wave number of 3340 cm^{-1}, the existence of the ≡C-H groups was detected in the stretching vibrations. The bonding of hydrogen between polyester samples is more likely to happen from this standpoint as mentioned above. The C-H group weak stretching vibrations such as $-CH_2$ and $-CH_3$ are described by the transmittivity bands in the range 2900–3100 cm^{-1}. After curing the polyester with epoxy, the transmittivity bands of the stretching vibrations of the C-H groups had virtually the same transmittivity bands.Transmittivity was examined at 1716 cm^{-1} during the infrared spectrum investigation due to the significant stretched vibrations of the C=O aldehyde group. The spectra of carpet (polyester)/epoxy-based composites exhibit subtle changes, resulting to a shift towards higher frequencies. Weak bands found in the cured polyester spectrum at 1508 cm^{-1} can be assigned to the aromatic ring C= C. The strong band at 1243 cm^{-1} that appears in the polyester spectrum is due to C-O-C group vibrations. From the graph, it can be concluded that the C-OH group at 1034 cm^{-1} and has good stretch interactions. One intensive band at 752 cm^{-1} attributed to C-Cl strong stretching vibrations in the polyester/epoxy composite spectrum. After 752 cm^{-1} wavenumbers, halogen groups are observed to appear continuously until wavenumbers of 500 cm^{-1}.

Table 5.3 Assignment of main infrared transmittivity of wave numbers

Wave Numbers (cm^{-1})	Assignment
3340	≡C-H Strong Stretch
2925	-C-H weak
2874	-C-H aldehyde Variable
1716	C=O aldehyde Strong
1508	C=C aromatic weak
1243	C-O-C stretch strong
1034	C-OH stretch strong
752	C-Cl strong
500	C-I strong

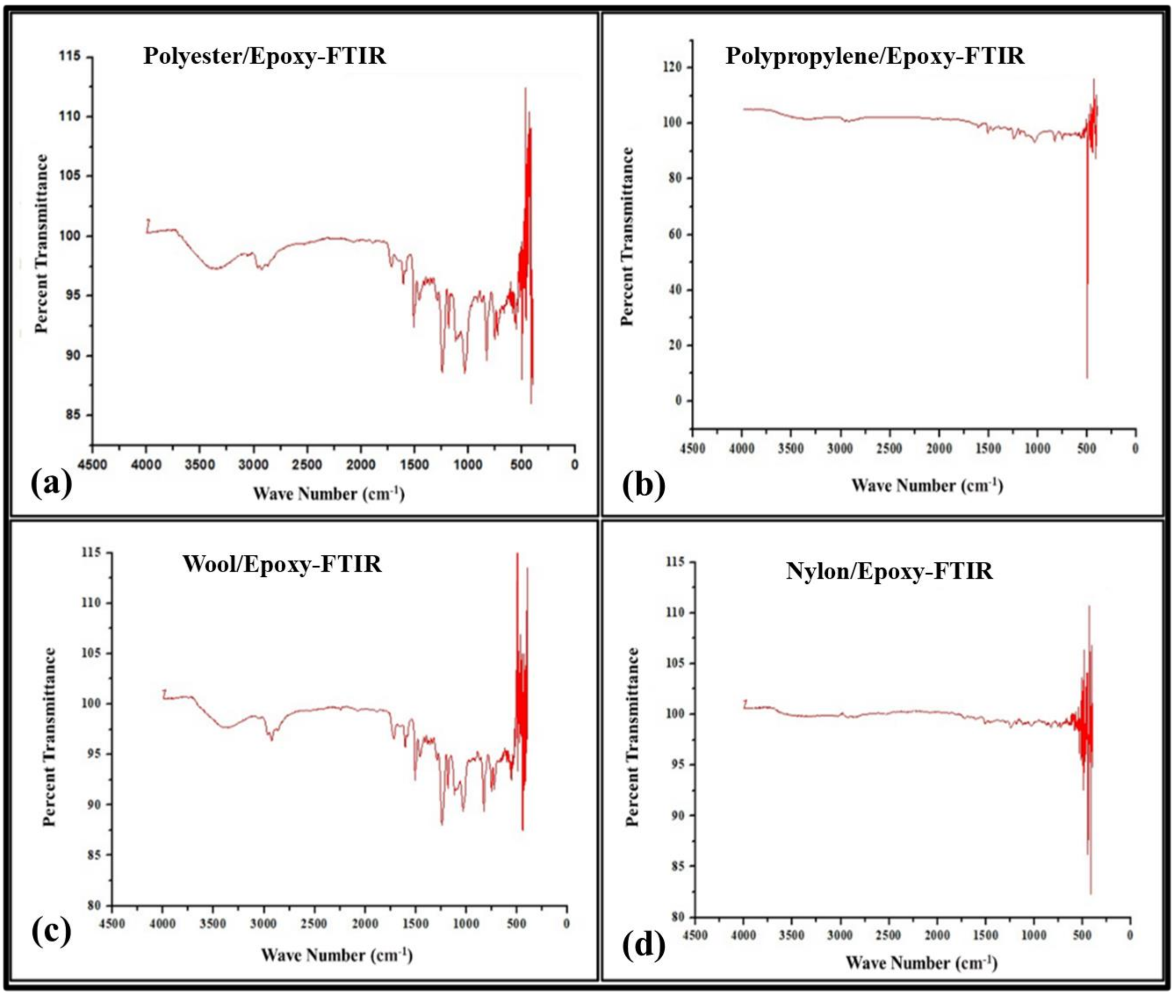

Figure 5.5 FTIR analysis of epoxy-based carpet waste composite (a) Polyester (b) Polypropylene (c) Wool (d) Nylon

Figure 5.5 (b) shows no peaks found in a single bond area (1700-4000 cm^{-1}). No broad absorption band was noticed, notifying there is no hydrogen bond in the material. There is some very small absorption that can be shown in the range of 500-1500 cm^{-1}. Small peaks were identified at 1626 cm^{-1} medium stretching of C=C, 1380 cm^{-1} medium stretching of C-H, 1125 cm^{-1} strong stretching of C-O, and 870 cm^{-1} bending of C-H. A sharp bond at about 500 cm-1 indicates the stretching of the C-I halogen compound.

In Figure 5.5 (c) for the wool composite higher wavenumber region, O-H stretching vibration band occurred in the range 3200-3550 cm^{-1}. At the 3000 cm^{-1} weak O-H stretching occurs. It can be seen from the spectra of epoxy-based carpet (wool) waste the stretching vibrations of the N-O group of the epoxy resin at 1500 cm^{-1}. In the spectra, the band at 1250 cm^{-1} corresponds to the stretching of aromatic ester C-O. Similarly, a prominent band at 1085 cm^{-1} corresponds to the aliphatic ether C-O. The band at 500 cm^{-1} indicates the stretching of the C-I halogen compound. At the 750 cm^{-1} strong C-H bending occurs. A sudden sharpness in the peak at 500 cm^{-1} region reveals a stretching of the C-I halogen complex.

Whereas, for the nylon composite, shown in Figure 5.5 (d), there are no peaks in a single bond area (1500-4000 cm^{-1}). The lack of any broad absorption band illustrates that the developed Nylon based composite material is bereft of hydrogen bonds. Band range of 500-600 cm^{-1} is related to halogen compound that is stretching of C-I.

Chapter 6

CONCLUSION

As mentioned at the outset, the present study is based on '*Utilization of recycled waste carpet for development of structural composite material*'. Carpet industries are expanding day by day due to the enhancement of their demand; as a result, the generation of waste carpets is also growing simultaneously. The usage of carpets and rugs has been expanded to a number of different purposes, *viz.*, for decoration in malls, commercial buildings, and floor covering in houses and hospitals, airports, etc. Waste management of the carpet is the biggest challenging job because the average life span of carpets is 4-6 years. Beyond this duration, it began to deteriorate and became a solid waste. Most people who use carpets refuse their carpets and don't properly dispose of them, burdening waste filling or garbage sites. Carpet wastes are generally disposed of the landfills and rivers, which harms humans and animals. It also creates environmental pollution after burning or landfilling and creating smells in the environment, etc.

In this project, to reduce the global concern of carpet waste due to its vast amount, an effort has been made by fabricating composites using such carpet waste. Only a small fraction of it gets recycled every year compared to carpet waste produced worldwide. The overall conclusion based on the obtained findings can be drawn as follows:

- The carpet waste was successfully utilized to fabricate composite material through the VARTM technique due to its proper infusion and indefectibility.
- VARTM technique is suitable in fabricating any carpet composite due to the infusion of resin uniformly in the carpet fibers. The epoxy resin serves as the composite's matrix, while the carpet waste serves as reinforcement.
- Carpets of four different materials were used in this project: wool, polypropylene, nylon, and polyester. Two samples of each material with different configurations were fabricated: FBBF and BFFB. Flexural and tensile tests were used to characterize the mechanical properties of the fabricated carpet waste composite samples.
- Wool material composite has a higher tensile strength of both laminate FBBF (18.2 MPa) and BFFB (16.4 MPa) among the developed composites.

- Flexural strength of wool BFFB (34.40 MPa) sample is higher than FBBF (23 MPa) sample.
- Polypropylene FBBF (30.64 MPa) sample has lower flexural strength than BFFB (34 MPa)
- Flexural strength of nylon FBBF (33.19 MPa) sample is higher than BFFB (25.47 MPa) sample.
- Flexural strength of polyester FBBF (28.23 MPa) sample is higher than BFFB (26.61 MPa) sample.
- Thermogravimetric analysis (TGA) has been performed on the fabricated samples to analyze the thermal stability of the developed composite.
- The crystallographic structure and chemical content of the developed composite were determined utilizing X-ray diffraction (XRD) on fabricated samples.
- The interaction between the epoxy and carpet materials was revealed using Fourier transform infrared (FTIR) spectroscopy, which improved the thermomechanical characteristics of the composites.

The project outcomes revealed a cost-effective and feasible solution to carpet wastes management, the same for the development of structural composites. The findings of the present work show a feasible solution for lightweight structural materials. The application of the efficient VARTM method proposed a functional composite material development. The concept of "Waste to Wealth" is proven useful in this study. As the waste generated from the carpet sector is very massive and environmentally hazardous. Limited data exist on the resue of carpet waste. The proposed work could become a novel direction for the management of discarded carpet waste. As a scope of future work, the proposed structural composite strength and other mechanical properties could be improved and explored by introducing different carbon-based nanomaterials (CBNs) and different hardener materials. It could be characterized by functional characteristics, barrier properties, thermal and mechanical properties.

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CURRICULUM VITAE (CV) OF PROJECT STAFF

• Senior Research Expert (SRE)

Balram Jaiswal
Senior Research Expert
(Ph.D. Scholar)
Department of Mechanical Engineering
(A state Govt. Technical University)
Contact No. +918932853158
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Career Objectives

To work in a challenging environment demanding all my skills and adapt myself in the field of Plastic Processing & waste management in an organization with impressive performance and encourage creativity and work in the research area on cutting-edge teaching technologies. And explore job opportunities in an organization that provides me an arena to enhance my technical knowledge. In addition, I pursue my area of interest to contribute to the research and growth of the firm with the best of my abilities and get the full experience to develop my potential and talent.

Education Qualification

DEGREE	INSTITUTION	YEAR	SPECIALIZATION	% MARKS
Ph.D.	Madan Mohan Malaviya University of Technology Gorakhpur	Pursuing from Sep 2020	Composite Materials from Carpet waste	Pursuing
MTech	Central Institute of Petrochemicals Engineering and Technology (CIPET) Lucknow	2018	Plastic Engineering	73
B. Tech	Institute of Technology and Management, Maharaj Ganj	2016	Mechanical Engineering	72.36
12^{TH}	DAV Narang Inter college	2012	PCM	65.80
10^{TH}	DAV Narang inter college	2010	Science	61.50

Work Experience

- ITM College of Polytechnic Chehari, Maharajganj U.P. as Lecturer 03/08/2018 to 03/09/2020
- Senior Research Expert on project entitled “Utilization of Recycled Waste Carpet for Development of Structural Composite Material” from 15 Sept. 2020 to 14

Sept.2021 under R&D Scheme, sponsored by O/o DC (Handicrafts) Ministry of Textiles, Govt of India.

Industrial Training/Internships: -

- Loco Frame Shop, Sheet Metal Shop & Planning Production Control Office DLW Varanasi Duration 4 Week 2014.
- Plastics Waste Management, Allahabad 2016.
- Mechanical Workshop North-eastern Railway, Gorakhpur, Duration- 4 Week 2013.

Academic Achievements: -

- Participant in **Robotics** in the event **"Electra 2014"** organized by **Jhunjhunwala P.G. College Faculty of Engineering and Technology,** FAIZABAD.
- Mechanical Workshop North-eastern Railway, Gorakhpur, Duration- 4 Week 2014

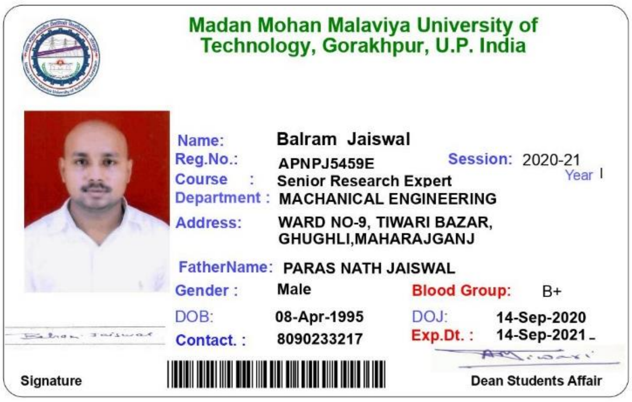
Extra-Curricular Activities

- Participant in College level event "**TECHBUZZ"** in 2012-13.
- Life Membership Card of ACADEMY OF MICROSCOPE SCIENCE AND TECHNOLOGY

Personal Information

Name	Balram Jaiswal
Date of Birth	08-04-1995
Father's Name	Paras Nath Jaiswal
Father's Occupation	Business
Marital Status	Single
Nationality	Indian
Present Address	Ward no 9, Gandhi Nagar Ghughli Maharajganj.U.P.273151

I hereby declare that the information given above is correct to the best of my knowledge & belief.



Place: Gorakhpur

Date:18-12-2021 Balram Jaiswal

- **Senior Research Expert (SRE)**

Rahul Vishwakarma
Senior Research Expert
(Ph.D. Scholar)
Department of Mechanical Engineering
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Career Objectives

To encourage creativity and work in the research area on cutting-edge teaching technologies. and explore job opportunities in an organization that provides me an arena to enhance my technical knowledge. In addition, pursues my area of interest to contribute towards research and growth of firm with the best of my abilities and get maximum experience to develop my potential and talent.

Education Qualification

DEGREE	INSTITUTION	YEAR	SPECIALIZATION	% MARKS
PhD	Madan Mohan Malaviya University of Technology Gorakhpur	Pursuing from Sept 2020	Composite material	Pursuing
M.Tech	Madan Mohan Malaviya University of Technology Gorakhpur	2018	Manufacturing Engineering.	7.84
B. Tech	Institute of Technology and Management, Gorakhpur	2015	Mechanical Engineering.	69.50
12^{TH}	Govt. jubilee inter college	2011	PCM	70.50
10^{TH}	Govt. jubilee inter college	2009	Science	61.50

Work Experience

- Senior Research Expert on project entitles “Utilization of Recycled Waste Carpet for Development of Structural Composite Material” from 15 Sept. 2020 to 14 Sept.2021 under R&D scheme sponsored by O/o DC (Handicrafts) Ministry of Textiles, Govt. of India.
- Working as a Guest faculty in Mechanical Engg. Dept. of Madan Mohan Malviya University of Technology Gorakhpur, Uttar Pradesh, India from July 2019-Apr 2020
- Working as a Assistant professor in Mechanical Engg. Dept. of Madan Mohan Malviya University of Technology Gorakhpur, Uttar Pradesh, India from Aug 2018-May 2019

Patent publication

1. Rajesh Kumar Verma, Balram Jaiswal, **Rahul Vishwakarma**, Kuldeep Kumar, Kaushlendra Kumar, Jogendra Kumar, Shivi Kesarwani. Patent Application No.:IN 2021/ 202111032430 A.
   Method of fabrication of a polymer composite from polyester carpet
2. Rajesh Kumar Verma, Jogendra Kumar, Shivi Kesarwani, Prakhar Kumar Kharwar, Kaushlendra Kumar, Balram Jaiswal, **Rahul Vishwakarma**, Puranjay Pratap, Devendra Kumar Singh, Kuldeep Kumar. Patent Application No.:IN 2021/202111025285A. *Graphene Oxide and Carbon Fiber Reinforced Composite Material*.

Industrial Training/Internships: -

- Workshop on Centra Institute of tool design, CITD Hyderabad 2013.
- Mechanical Workshop North-eastern Railway, Gorakhpur, Duration- 4 Week 2014

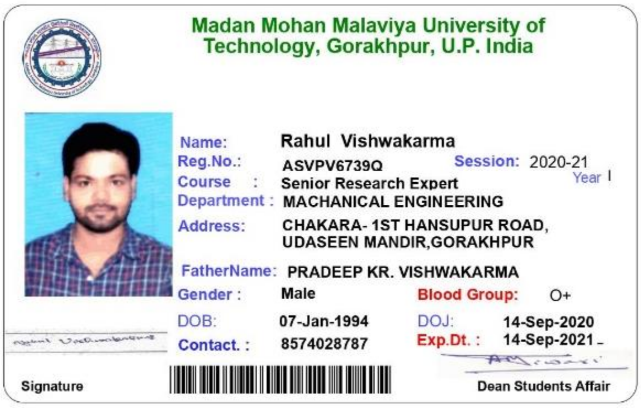
Skill Sets: -

- MINITAB 18
- AUTOCAD, CREO

Personal Information

Name	:	Rahul Vishwakarma
Date of Birth:	:	07 Jan 1994
Father Name:	:	Mr. Pradeep Vishwakarma
Mother Name:	:	Mrs. Nirmala Devi
Language proficiency	:	English and Hindi
Marital Status:	:	Unmarried
Nationality:	:	Indian

I hereby declare that the information given above is correct to the best of my knowledge & belief.



Place: Gorakhpur
Date:18-12-2021

Rahul Vishwakarma

- **Junior Research Fellow (JRF)**

KULDEEP KUMAR
Junior Research Fellow
(Ph.D. Scholar)
Department of Mechanical Engineering
(A state Govt. Technical University)
Mob. No. +91-8178434001,853629573
Email id- ***kuldeepjrfme@mmmut.ac.in***

Career objective: -

To promote innovation and collaboration in the field of structural composite development using carpet waste. And to look for job opportunities in an organization that will allow me to expand my technical knowledge and pursue my area of interest while also allowing me to contribute to the firm's research and growth to the best of my abilities while also allowing me to gain far more experience in order to maximize my potential and talent.

Educational qualifications: -

DEGREE	INSTITUTION	YEAR	SPECIALIZATION	% MARKS
PhD	Madan Mohan Malaviya University of Technology Gorakhpur UP	Pursuing from Sep 2020	Composite Material	Pursuing
M.Tech	Madan Mohan Malaviya University of Technology Gorakhpur UP	2020	Manufacturing Engineering	7.33
B. Tech	Dr. A.P.J Abdul Kalam Technical University Lucknow	2016	Mechanical Engineering	66.00
12^{TH}	U.P BOARD	2012	PCM	56.40
10^{TH}	U.P BOARD	2009	Science	53.50

Work experience: -

- Junior Research Fellow in the project entitled "Utilization of Recycled Waste Carpet for Development of Structural Composite Material" from 15 Sept. 2020 to 14 Sept.2021 under R & D schemes sponsored by O/o DC (Handicrafts) Ministry of Textile, Gov. of India.
- Working as an Assistant Lecturer in Department of Mechanical Engineering (Diploma & Graduate) at Indraprastha Institute of Management and Technology, Saharanpur India, from July 2016 to June 2018.

Academic project work: -

M.Tech:

- Minor Dissertation on PCA-TOPSIS hybrid approach in Electrical Discharge Machining of Inconel-X 750: Experimental Investigation & Multi-objective Optimization.

- Major Dissertation on Fabrication and Investigation on Machining of MWCNT Doped Epoxy/GFRP nanocomposite: Some Case Experimental Research

B.Tech:

- Optimization of Process Parameter for Dissimilar Joining of Al-alloys by Underwater Friction Stir Welding.

Industrial training/Internships: -

- Workshop on MATLAB conducted by E & ICT Academy, IIT Kanpur 2019.
- Mechanical Workshop North-eastern Railway, Gorakhpur, Duration- 4 Week 2015

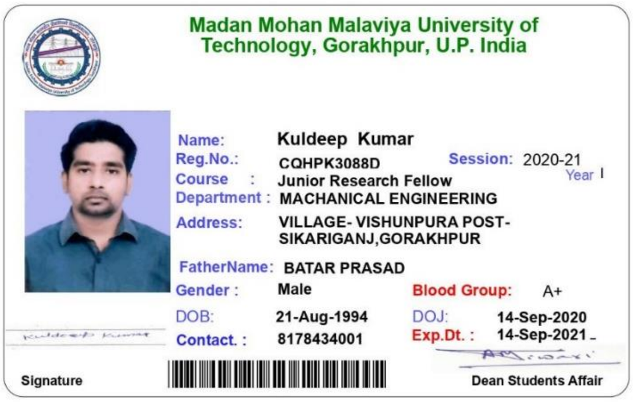
Skill sets: -

- MINITAB 18
- MATLAB 15.2

Personal information: -

Name	Kuldeep Kumar
Date of Birth	21 August 1994
Father Name	Mr. Batar Prasad
Mother Name	Smt. Kalavati Devi
Language proficiency	English and Hindi
Marital Status	Unmarried
Nationality	Indian
Blood Group	A^+

I hereby declare that the information given above is correct to the best of my knowledge & belief.



Place: Gorakhpur

Date: 18-12-2021

Kuldeep Kumar

- # Junior Research Fellow (JRF)

Kaushlendra Kumar
Junior Research Fellow
(Ph.D. Scholar)
Department of Mechanical Engineering
(A state Govt. Technical University)
Contact No. +917355133876
Email ID- kkjrfme@mmmut.ac.in

Career Objectives

To encourage creativity and work in the research area on cutting-edge teaching technologies. and explore job opportunities in an organization that provides me an arena to enhance my technical knowledge. In addition, pursues my area of interest to contribute towards research and growth of firm with the best of my abilities and get maximum experience to develop my potential and talent.

Education Qualification

Degree	University/board	Institution	Year	Specialization	Division
PhD	Madan Mohan Malaviya University of Technology	Madan Mohan Malaviya University of Technology	Pursuing from Sep 2020	Composite Material	Pursuing
M. Tech	Madan Mohan Malaviya University of Technology	Madan Mohan Malaviya University of Technology	2020	Manufacturing Engineering	First
B. Tech	Dr. A P J Abdul Kalam Technical University Lucknow	NIET, Greater Noida	2016	Mechanical Engineering	First
Intermediate	U. P. Board	Gov. Jubilee Inter College	2011	Maths & Science	First
10^{th}	U. P. Board	St. Theresa High School	2009	Science	First

Areas of Interest

- Advanced Machining process
- Manufacturing Engineering
- Engineering Mechanics
- Strength of Materials
- Theory of Machines

Research work experience:

Junior Research Fellow on project entitled "**Utilization of Recycled Waste Carpet for Development of Structural Composite Material**" from 15 Sept. 2020 to 14 Sept.2021 under R & D schemes sponsored by O/o DC (Handicrafts) Ministry of Textile, Gov. of India.

Academic Project Works

- Stress Analysis of Orthotropic Bone using Numerical method.
- Crash Analysis of tube under Impact Loading.

- Design analysis and Fabrication of Helical Gear.

Skill Sets

- Minitab 18
- Origin 8
- MATLAB 15.2
- Microsoft Word/Excel/PPT
- ANSYS (WORKBENCH)
- AutoCAD
- SOLIDWORKS
- MIMICS Medical

Patent publication

1. Rajesh Kumar Verma, Balram Jaiswal, Rahul Vishwakarma, Kuldeep Kumar, **Kaushlendra Kumar**, Jogendra Kumar, Shivi Kesarwani. Patent Application No.:IN 2021/ 202111032430 A. *Method of fabrication of a polymer composite from polyester carpet.*
2. Rajesh Kumar Verma, Jogendra Kumar, Shivi Kesarwani, Prakhar Kumar Kharwar, **Kaushlendra Kumar**, Balram Jaiswal, Rahul Vishwakarma, Puranjay Pratap, Devendra Kumar Singh, Kuldeep Kumar. Patent Application No.:IN 2021/202111025285A. *Graphene Oxide and Carbon Fiber Reinforced Composite Material*.

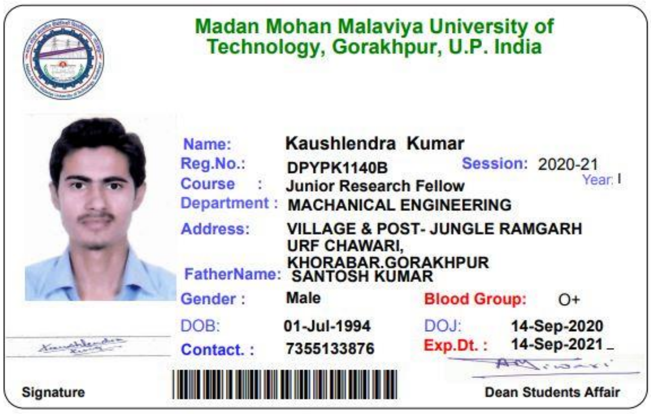
Other activity

- GATE qualified in 2016 and 2017
- Participated in the course "Materials Behavior and Characterization under Dynamic Loading" held at MNNIT Allahabad by GIAN.

Personal Information

Name	:	Kaushlendra Kumar
Date of Birth:	:	01 July 1994
Father Name:	:	Santosh Kumar
Mother Name:	:	Manorama Devi
Language proficiency	:	English and Hindi
Marital Status:	:	Unmarried
Nationality:	:	Indian
Blood Group:	:	O+

I hereby declare that the information given above is correct to the best of my knowledge & belief.



Place: Gorakhpur
Date: 18-12-2021

Kaushlendra Kumar

OUTCOMES FROM PROJECT WORK

- **Research Publications from present work**

ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Study on polymer (epoxy) composite using carpet waste for lightweight structural applications: A new approach for waste management

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ARTICLE INFO

Article history:
Received 8 December 2020
Received in revised form 8 December 2020
Accepted 15 December 2020
Available online xxxx

Keywords:
Carpet
Waste
Composite
Fiber
VARTM

ABSTRACT

In sites around the world, annually more than millions of tons of carpet are discarded. This gives rise to substantial concerns about economic and environmental degradation. Feasible pre-consumption carpet waste is thus imperative for high-value applications in engineering. Carpet waste management has become a subject of concern to reduce the increased burden on landfill sites, as it releases methane (CH_4), carbon dioxide (CO_2) and other pollution concerns. However, the proper disposal of carpet wastes is still a challenge and its harmful effect can be controlled only through its re-utilization. This study reports the utilization of the waste carpet for the development of composite material using the vacuum-assisted resin transfer molding (VARTM) process. The mechanical characterization and surface morphology investigations were done to check the feasibility of proposed composites in lightweight structural applications. For the experimentation regards, two types of composites samples were fabricated, Back-Fiber-Fiber-Back (BFFB) and Fiber-Back-Back-Fiber (FBBF), respectively. The study demonstrates that BFFB samples possess more flexural strength than FBBF and the tensile strength of FBBF was higher than BFFB samples. The SEM analysis reveals a higher density for FBBF samples, while in the case of BFFB samples, the gap due to the non-uniform flow of resin has been observed. This paper also explores the waste management method of carpet and its utilization according to their properties in some structural applications in a cost-effective way.

1. Introduction

In the 21st century, green production, waste management, re-utilization and sustainable development are the most demanding and challenging issues globally. Most manufacturing industries try to control the waste and re-utilize the products for the nation's sustainable development. Solid waste management reduces greenhouse gas emissions mainly methane and carbon dioxide gas and helps to scale down air pollution's hazardous impact on public health [1]. The adverse effect of waste generation is more severe in low-income countries and with rapid urbanization, the integrated impact of waste generation has increased exponentially. Waste management also helps to save energy, expenditure, and an unavoidable workforce of the manufacturing sectors. The textile industry plays a primary role in individuals' and countries' lives because this sector is associated with our society's basic needs. The carpet is also a part of the textile industry and it can be either handmade or developed through handloom and machine [2,3]. As the generation carpet wastes from various fields are increasing at a remarkably high rate, its re-utilization or reprocessing into the desired product has become a subject of concern. The average life span of carpet is 3–5 years beyond which it becomes a type of solid waste, or it can also be utilized as filler material. In most countries, it is either reused, dumped in the landfills[4], equestrian surface application[5], generation of energy through incineration[6], plastic processing [7,8]. In developing countries, most of the solid waste is disposed of in landfills. Due to its low bulk density, the carpet waste occupies a large landfill area, which further aggravates its disposal problem. Carpet is a fibrous structure fabricated through three main elements, i.e., fibers, filler material and backing material [9] In the structured carpet, the fibers may be arranged in the form of a cut-pile or loop type [10,11]. Pile yarns are perpendicularly incorporated in the backing material and thus forms the carpet surface. Since carpet material is generally subjected to compressive loads, the carpet's compression behavior is a matter

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https://doi.org/10.1016/j.matpr.2020.12.681
2214-7853/

Please cite this article as: B. Jaiswal, Vijay Kumar Singh, S. Mishra et al., Study on polymer (epoxy) composite using carpet waste for lightweight structural applications: A new approach for waste management, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.12.681

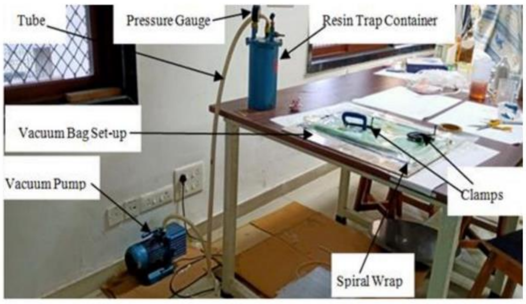

Fig. 1. VARTM setup.

Table 1
ASTM standard for the sample with their dimension.

	Tensile test	Flexural test
ASTM Standard	D3039	D790
Sample dimension (L×B×H) (in mm)	60×20×10	60×20×10

of concern from a design point of view. Carpets and rugs have been utilized for various purposes, such as floor covering in houses, for decoration in parties, malls, hospitals, commercial buildings, airports, etc. The carpet and rugs have the durability of almost three to five years and after that, it began to deteriorate and tore at various places and sometimes it is thrown as waste. Most of the users of carpet throw waste carpet in large amounts, which creates a burden on waste filling or garbage sites and simultaneously, it also creates health hazards, environmental pollution, bad smells, etc. Hence, there is an urgent need for an alternative way to convert these carpet wastes into useful or valuable products to reduce this waste material's upsurge. The carpet consists of non-biodegradable polymeric material; it is not easy to decompose due to high cost. The carpet waste can be used in bricks kiln, sugar mill, peppermint extraction mill, etc. for combustion purposes[12,13] But the challenges include heavy air pollution, global warming, smog formation, etc. Hence it is not feasible and also a violation of the pollution act. This study focuses on utilizing waste carpet by preparing a composite useful for various applications based on their characterization. The present article demonstrates the fabrication and characterization of polymer composites for lightweight structural use.

From comprehensive literature appraisal demonstrates that carpet waste materials have become a matter of global concern. The direct decomposition of non-biodegradable carpet waste in the form of landfill, fuel application and burning is very harmful to environmental concerns. Eminent scholars did ample work for the re-utilization of carpet waste for the development of hybrid cement material, fuel source, incineration, etc. but very limited data exist on the fabrication of epoxy/polymer composites through the waste carpet. For preparing the composite samples, the VARTM method was used. In this method, waste carpet material is utilized to fabricate the composite directly with simple dry cleaning or washing. The mechanical behavior and interlaminar structure of carpet waste samples are analyzed to find the application of fabricated composite. For this, the tensile test and flexural test was conducted. The microscopic behavior of developed samples was tested by Scanning Electron Microscopy (SEM). The microstructural investigation was done to check the dispersion level and aspect ratio of the proposed composites. The mechanical behavior is predicted for waste reinforced fibrous material impregnated with epoxy resin with two configuration arrangements. The inter-fiber behavior of the composite was analyzed under a constant strain rate. An attempt has been made to develop a feasible composite material. The present work also focuses on reducing carpet waste in some useful form to reduce landfill, pollution issues, and ecology balance.

2. Materials and method

2.1. Sample preparation

For the fabrication of composite samples, the waste nylon layer of waste carpet and hardener was used as reinforcing material into the epoxy matrix. The cut-pile nylon fibers were attached to polyvinyl chloride (PVC) backing material, which consists of some impurities. Initially, the waste carpets were simply washed with normal water, followed by the open drying process. The epoxy was used as a polymer matrix and Tri-ethylene-tetra-amine as a hardener in the fabrication of composites using VARTM method. The epoxy material and hardener were mixed in a fixed ratio of 10:1 by weight. Both materials were purchased from M/s. Anjanadri Engineering Service, Bengaluru India. This study focused on the fabrication of polymer samples in two configurations, i.e., Back-Fiber-Fiber-Back (BFFB) and Fiber-Back-Back-Fiber (FBBF). In FBBF, the fiber to fiber face was combined and in BFFB, the fiber to fiber back was combined.

2.2. Fabrication procedure

This study employed the VARTM method, which has an advantage of resin's uniform flow, minimum porosity, and bubbles

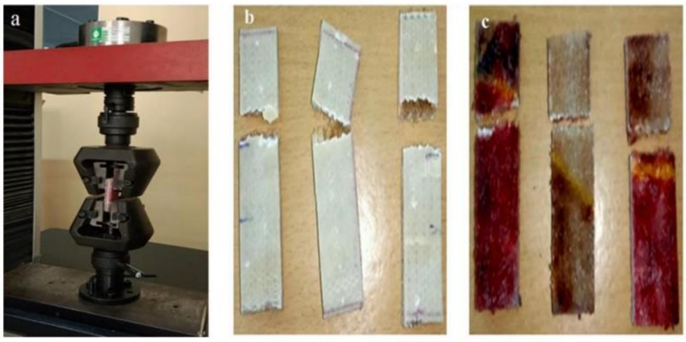

Fig. 2. (a) UTM Machine holding sample; (b) BFFB sample fractured at top grip; (c) FBBF ruptured sample.

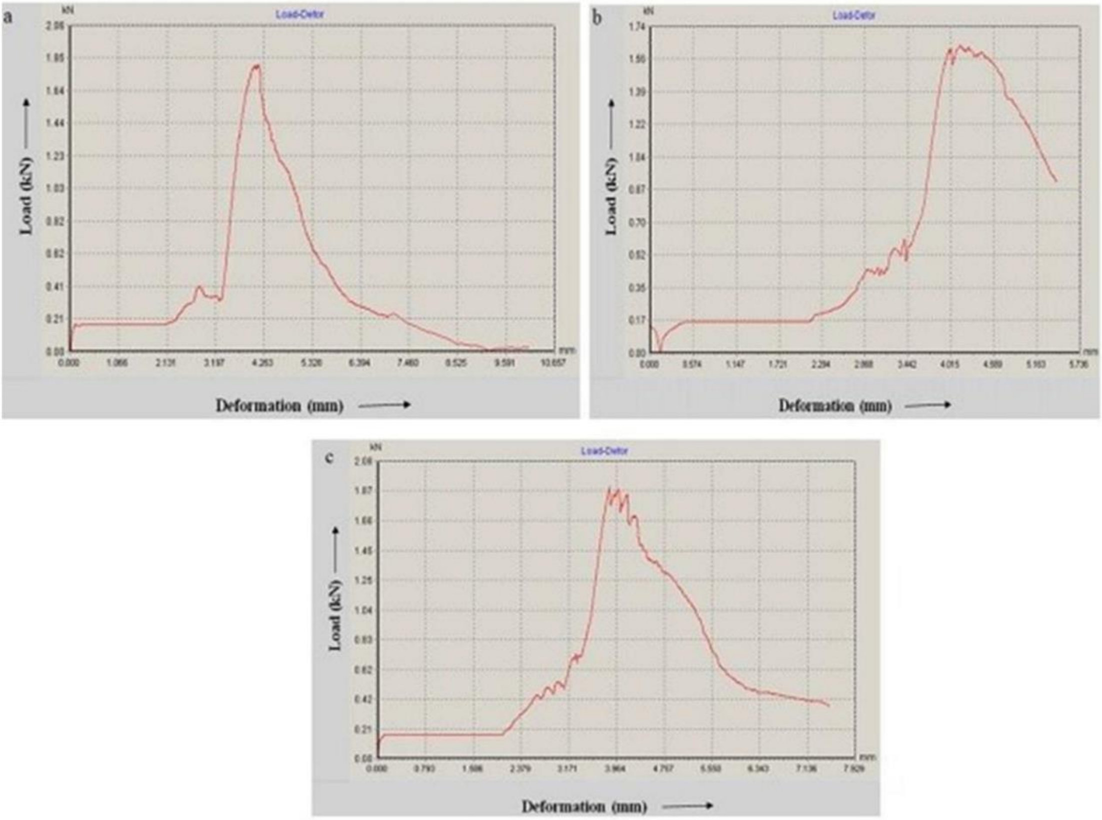

Fig. 3. (a), (b) & (c) Tensile behavior of BFFB configuration sample.

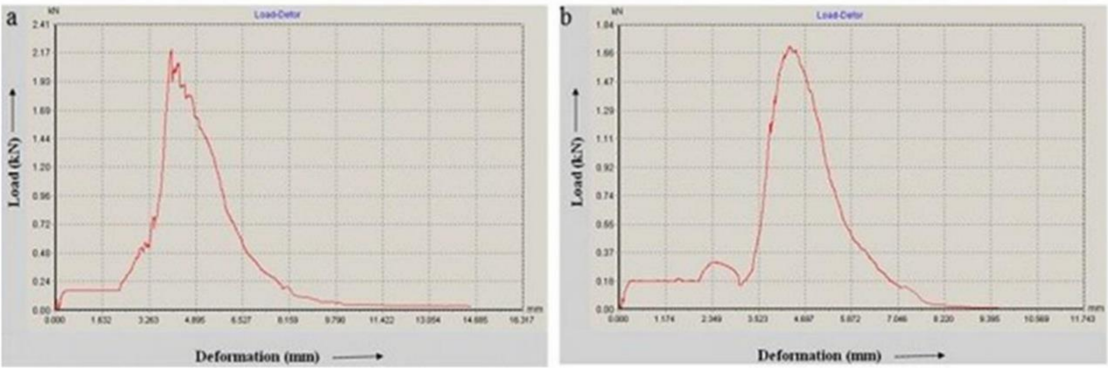

Fig. 4. (a) & (b) Tensile behavior of FBBF configuration sample.

formation while preparing the sample. Fig. 1 demonstrate the VARTM setup showing the resin flow from one side to another side. This method requires a low viscosity mixture of epoxy and hardener for infusion. The upper mold of the VARTM setup provides the uniform thickness of the matrix layer over the composite surfaces. For the uniform flow of resin over the entire carpet surface, the spiral wrap was placed at the inlet side of resin impregnation. The waste carpets were cut into a size of 30 mm × 30 mm and then their backings were combined to obtain the FBBF configuration and fiber to fiber to obtain BFFB configuration. The release agent was

Fig. 5. (a) Demonstrating the 3 Point bending test; (b) BFFB fractured samples; (c) FBBF fractured samples.

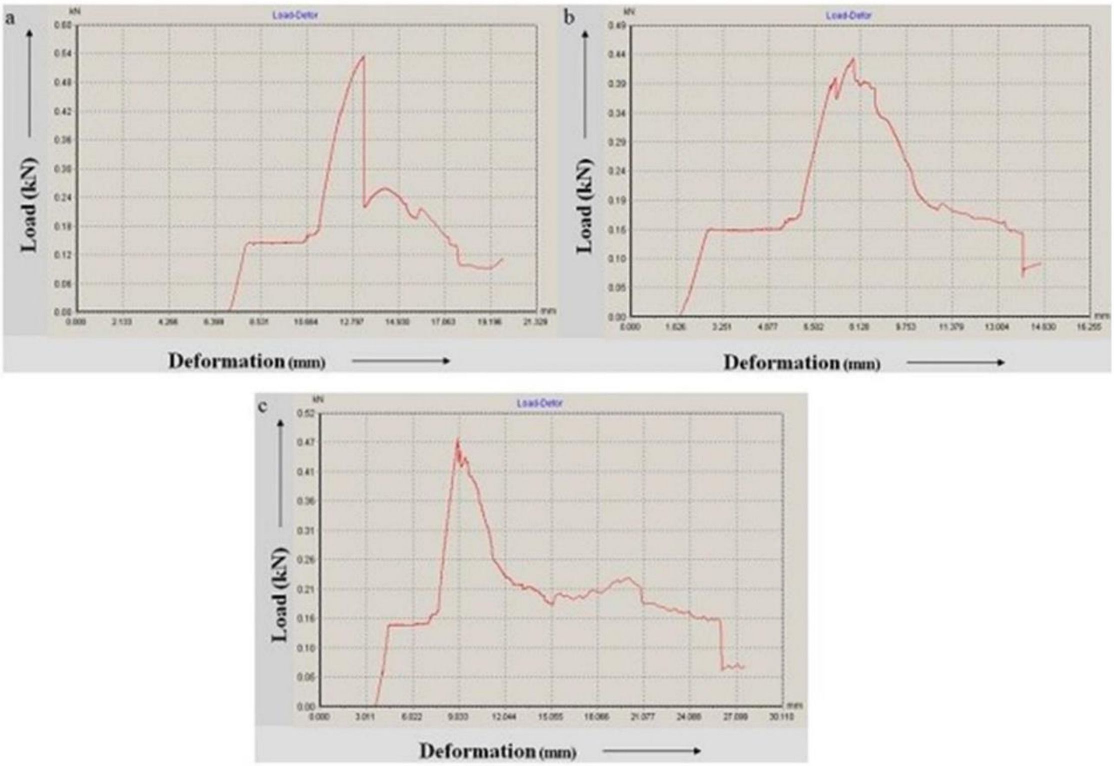

Fig. 6. (a), (b) & (c) Flexure behavior of BFFB configuration sample.

used as Silica gel and sprayed before so that the prepared sample can be detached easily from the bottom surface. The combined layers of carpet were then laid down inside the vacuum bag on the release agent's surface on the glass table. The airtight mold was prepared with the help of the polythene sheet and tacky tape. The inlet and outlet were provided in the mold setup.

Initially, the air inside the mold was expelled out using a vacuum pump to make the mold airtight. The resin entered to impregnate the prepared perform at a uniform rate. The driving and compressive force are offered by applying 1 atm pressure created by a vacuum pump for the proper inflow of resin into the mold. In this method, for the preparation of composite peel ply, a transfer media was used for appropriate and uniform resin infusion. After covering the whole surface by resin infusion, both ends inlet, as well as an outlet of the tube, were clamped and left undisturbed for 24 h for proper curing. For preparing the 30 mm × 30 mm size composite, a mixture of 400 ml epoxy with 40 ml hardener was taken and appropriately mixed using a manual stirrer. The polymerization time of the mixture is about 10 min and after that, it becomes extremely viscous.

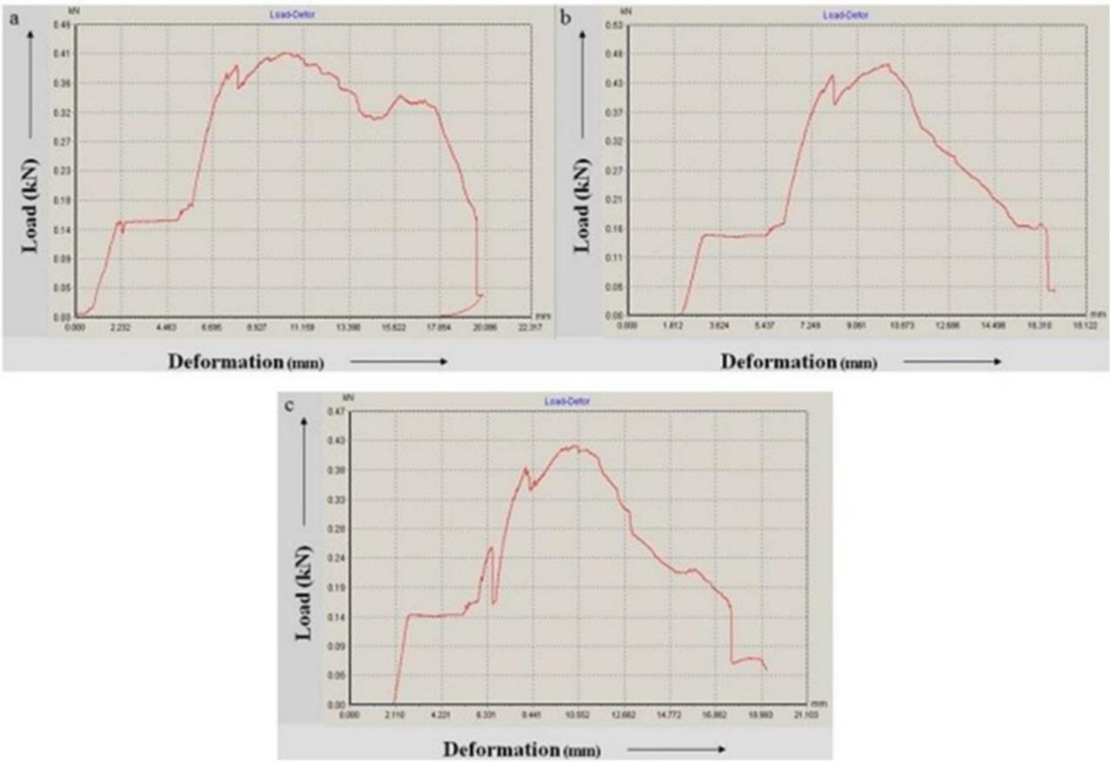

Fig. 7. (a), (b) & (c) Flexure behavior of FBBF configuration sample.

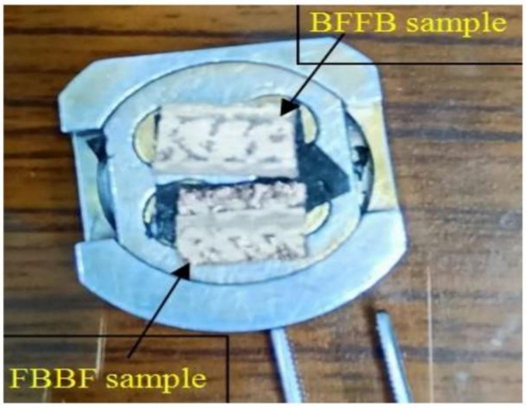

Fig. 8. The gold-coated sample placed on the sample holder.

2.3. Sample preparation for conducting test

For conducting the SEM, first the sample was coated with gold in a sputter coating machine. This paper utilized the rectangular-shaped specimen. For characterization, the fabricated composite was cut by using the cutter according to respective ASTM standards. The ASTM standards and dimensions of the sample as indicated in Table 1. The composite prepared was in rectangular sheet form and so the prepared samples were rectangular flat shaped.

3. Results and discussion

3.1. Tensile test

The tensile strength of a material denotes the ability to sustain the pulling forces applied in the opposite direction, as depicted in Fig. 2. The tensile test was conducted on a WDW-5 computerized electronic universal tensile machine as per the ASTM standard mentioned in Table 1 at a 2 mm/min crosshead speed.

In the BFFB configuration, the matrix deforms after 200 N, and after that load is sustained by the fiber reinforcement. From the above graphs Fig. 3 and Fig. 4 showing load versus deformation curve, it is clear that the deformation was going to increase irrespective of the load rise. The differences in the peak load were observed due to the matrix bonding with the fibers and PVC backing material. For all the samples, the load-deformation responses change from linear to non-uniform fluctuations after deformations of 2.1 mm.

3.2. Flexural test

The flexural test is conducted to determine the flexural stiffness and bending strength of the specimen by a 3-point bending test and 4-point bending test. In this study 3-point bending test has been conducted by using a sharp-edged tool as display in Fig. 5. The sample was prepared as per the standard of ASTM D790 given in Table 1. First of all, the sample was placed as an overhanging beam and deflected under the constant crosshead displacement

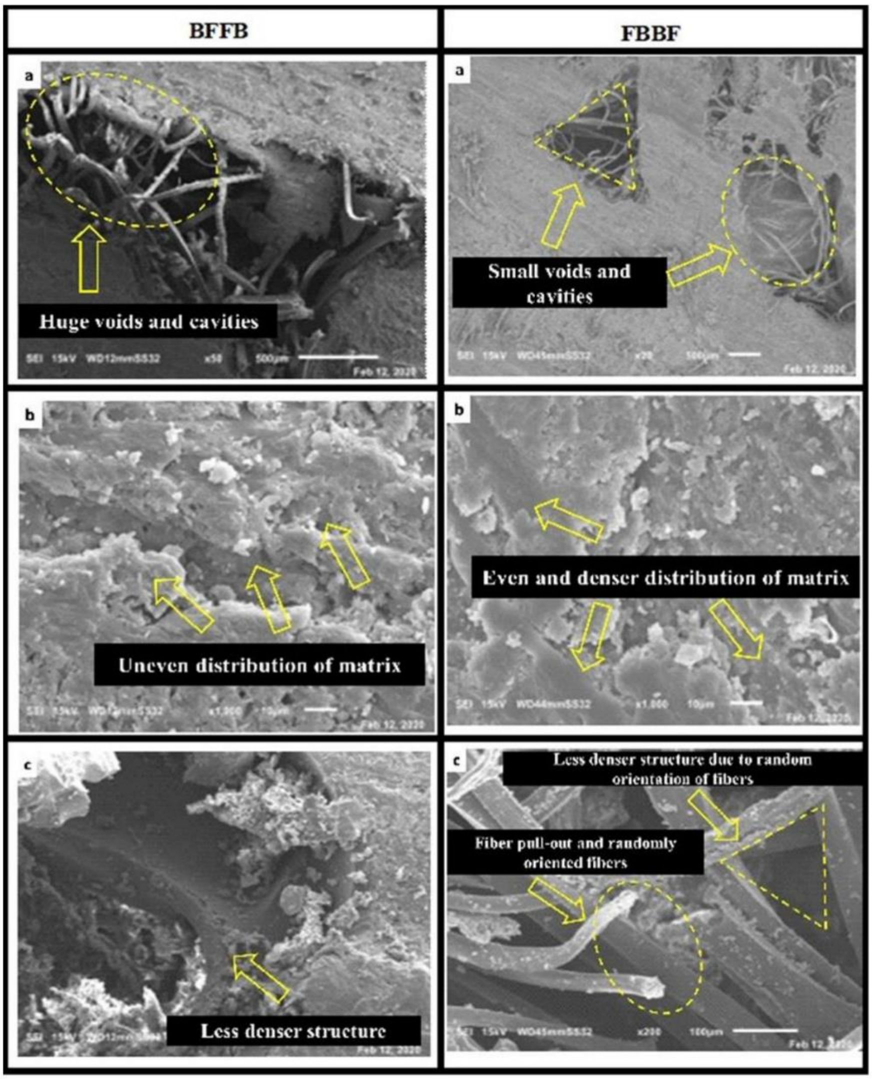

Fig. 9. SEM images demonstrating the fibers and epoxy distribution.

rate of 2 mm/min. The overhang was taken as 10% of the span length (40 mm) on both sides and the load was applied centrally on the sample. The deflection that occurred due to the load used was recorded until the failure of the matrix and bottom fibers occur. The depth penetration of a sharp-edged tool was also recorded.

Mehndiratta et.al [14] in their research work on FRC (glass and carbon) analyzed the span-length taken for conducting flexural tests and found that flexural modulus increased with the span length up to a certain limit and after that, it decreased. In this study, flexural strength has been analyzed, which generally varied with depth, span length and temperature also [15], but here thickness of the sample and span length remains constant. In the BFFB configuration, the sharp peak demonstrates that fiber fractured quickly after the rupturing of epoxy. The BFFB samples during rupture showed a sharp peak while the FBBF samples exhibit non-uniform zigzag peaks. From Fig. 6 and Fig. 7, it is noticed that the maximum load sustained by FBBF sample is 2951 N before fracture, whereas for BFFB configuration, it is 2567 N. The possible reason of this difference in peak load could be resisting the deformation by PVC backing in BFFB configuration samples and piles of fibers in FBBF samples.

3.3. Scanning electron microscopy

SEM studies were performed on JSM-6010LA (JEOL, USA) for both BFFB and FBBF test pieces of polymer samples to analyze the morphology, affinity of fibers with matrix and distribution of epoxy matrix as depicted in Fig. 8. A sample was cut from the specimen to analyze its interfacial structure and bonding. As the sample was non-conductive, it was first gold coated in sputter coating machine JEC 3000 (JEOL, USA) to reduce the surface charge; otherwise, it would contaminate the SEM device the backscattered electrons raised from the sample.

The following SEM figures indicate that at certain places, fibers combined with matrix properly and at some place fibers are found in groups. Fig. 9 (a) reveals the strand of fabric's surface at 15 kV and at 100 X. This demonstrates the FBBF samples have a greater quantity of disturbing fibers compared to BFFB samples. Fig. 9 (b) of FBBF and BFFB shows that laminates' interfacial arrangement exhibits more voids and cavities in BFFB than the FBBF sample. Fig. 9 (c) shows the distribution of epoxy resin and its bridging with fibers and backing material. In BFFB, it shows a lesser density as compared to FBBF samples.

Fig. 9 (a) reveals the surface of the strand of fabric at 15 kV and at 100 X. This demonstrates the FBBF samples have a greater quantity of disturbing fibers compared to BFFB samples. Fig. 9 (b) of FBBF and BFFB shows that laminates' interfacial arrangement exhibits more voids and cavities in BFFB than the FBBF sample. Fig. 9 (c) shows the distribution of epoxy resin and its bridging with fibers and backing material. In BFFB, it shows a lesser density as compared to FBBF samples. It also reflects the excellent interaction between the matrix and the fibers. This interaction supposed to provide good strength to composite samples. Some of the above SEM images, such as in Fig. 9 FBBF (a) and (d), reveal the pull-out and randomly oriented fibers, demonstrating that the sample has a lesser dense structure at the upper surface. Therefore, it can be said that sharp-edged tools during flexural tests easily penetrate the surface of the FBBF sample and load was resist by backing material only. So FBBF sample has better flexural strength than the BFFB samples.

4. Conclusion

The tensile and flexural properties of waste carpet composites reinforced with epoxy matrix have been studied, analyzed, and discussed in this study. These results and outputs can be drawn from physical and mechanical characterization.

- In tensile and flexural tests, it was observed that after rupturing of epoxy matrix load was resist by waste carpet material only.
- The tensile strength was maximum in FBBF samples than the BFFB samples as backing material provided sufficient longitudinal strength to composite samples.
- The flexural strength for the BFFB samples was higher than the FBBF samples by 14.66% because the face fibers of FBBF samples cannot resist the vertical applied load of sharp-edged tools.
- The SEM images exhibit the higher density of FBBF samples as the PVC backing was smooth and plain, so the epoxy in the middle of backings was appropriately filled. This becomes possible due to the presence of spiral wrap at the middle interface of backings. While in the case of BFFB samples, there was some gap among the fibers because of resin's non-uniform flow.

The present work demonstrated the applicability of the waste carpets for the fabrication of structural material. The VARTM method efficiently developed feasible composites with desired mechanical properties. The feasibility of developed composites can be investigated in other applications like wall tiles, sound, and heat insulators, etc. to replace the costly polymers such as glass/carbon/aramid-reinforced polymer composites.

Funding

This research work is financially supported by O/o DC (Handicrafts), Ministry of Textiles, Govt. of INDIA, Under Project ID: K-1 2012/4/19/2020-21/R&D/ST.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to acknowledge the kind support of o/O DC (Handicrafts), Ministry of Textiles, Govt. of India, New Delhi, INDIA for extending all possible help in carrying out this research work directly or indirectly.

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Editorial Program

MI 2 / 2021

Publication date:	**May 28, 2021**
Ad closing date:	**May 5, 2021**

Fibers/Yarns	New fiber developments Intelligent fibers – When damaged ropes change color (C. Zogg, Empa, Dübendorf/Switzerland) Taro fiber extraction and comparison of its specific properties to jute (P.A. Bobade, Jawaharlal Darda Inst. of Eng. & Technology, Yavatmal/India)
Spinning	Impact of fiber blend over yarn strength (K. Patel, Birla Cellulose, Grasim Industries Ltd., Gujarat/India)
Weaving	Study effect of single shot chemical o sizing parameters and its performance (S. Sarwale, SVKM's NMIMS, CTF, MPSTME, Shirpur/India)
Knitting	Knitting roads (S. Zeller, Empa, Dübendorf/Switzerland) Behavior of knitted fabrics exposed to natural aging (I.S. Cubric, University of Zagreb/Croatia) Influence of fiber cross-section and finishing treatment on PET/CO weft knitted fabrics (M. Munjal, MLV Textile & Eng. College, Bhilwara/India)
Textile Finishing	Long-lasting antimicrobial textile finishing reduces infections and environmental impact (Sonovia Technology Ltd., Ramat Gan/Israel; Brückner Textile Technologies GmbH, Leonberg/Germany; Weber Ultrasonics AG, Karlsbad/Germany) Spray technology and antimicrobial prove sustainable powerhouse finishing combo (Baldwin Technology Company, Inc., St. Louis, MO/USA; Sciessent, Beverly, MA/USA) Coating textiles sustainably with chitosan (A. Weber, Fraunhofer IGB, Stuttgart/Germany)
Textile Industry	ITMA Asia + CITME 2021 in the context of the corona crisis (E. Maurer, Cematex, Zurich/Switzerland) ITMA Asia + CITME 2021 in Shanghai/China: preview Application of PA carpet waste for the development of polymer composites: investigations on compression behavior (B. Jaiswal, Madan Mohan Malviya Univ. of Technology, Gorakhpur/India) Fiber ropes in a mining environment (A. Felber, Chemnitz University of Technology, Chemnitz/Germany; H. Mischo, TU Bergakademie Freiberg/Germany et al.) Net-works made in France since 1860 (Filt 1860, Mondville/France) New technology producing cellulosic nonwovens based on botanic wood pulp (K. Gregorich, Lenzing AG, Lenzing/Austria) Airborne fiber fly – a significant contribution to environmental microplastic (M. Stark, Freiburg/Germany)

Application of PA carpet waste for the development of polymer composites: investigations on compression behavior

This article highlights the compression analysis of the polymer composites fabricated from polyamide (PA) carpet waste. The composite was developed using the modified Vacuum-Assisted Resin Transfer Molding (VARTM) method. The proposed composite samples of PA carpet waste demonstrate that the specimen bears a compression load of approx. 2,900 N, which shows the feasibility and application potential in structural applications. This works aims to minimize the hazards and harmful environmental effects caused by the traditional method for carpet waste management, such as landfilling, incineration, decomposition, etc.

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The carpet architecture usually comprises stacking of synthetic fibers knot into the backing material. Carpet is generally used to sustain the compressive and shear load, and after a specific period, the fiber of the carpet begins to tear and distorted. The distorted and torn carpet becomes a colossal waste source. According to the United States survey report of 2008, carpet waste holds 1-2 % of total municipal solid waste and is significantly increasing every year [1]. As the carpet's full degradation time is around 5-8 years, it contributes much to the waste accumulation of solid waste after consumption sent to waste disposal sites [2, 3]. The non-biodegradable behavior of carpet waste makes it more harmful to the environment and ecology.

Based on the source of origin, waste can be collected as follows: first pre-consumer and post-consumer waste (Fig. 1). Various studies show that carpet waste can be used in the development of composites materials. In this series, the composite to use post-consumer tapestry waste was prepared [4]. Polymers were fabricated from light density polyethylene carpet (LDPE) with low maleic (MAh), and outcomes reveal improved tensile properties [5]. Wool face fabric, synthetic facial fibers, and facial polypropylene fibers were produced to develop composites [6]. It can be used as a substitute for wood, PVC material, etc.

The comprehensive literature has remarked that carpet waste is a severe concern for the environment and is a health hazard. Very limited studies are available on the development of lightweight structural applications using the VARTM method. The compression analysis of the proposed samples is proposed to assess the dynamic load aspect.

Materials and methods

In this work, the VARTM method was employed to fabricate the composite samples, as illustrated in Fig. 2. The epoxy was used as an infusion material into the waste carpet samples cut into rectangular shapes.

Materials selection

The PA waste carpet was used to develop composite materials. Initially, it was manually cleaned on the washing platform. Afterwards, the drying of the washed carpet was done to remove the moisture content. The carpet waste's PVC backing and fibers are composed of cut-pile PA fibers attached to polyvinyl chloride (PVC) backing material. The epoxy resin bisphenol a diglycidyl ether with tri-ethylene-tetra-amine (TETA) hardener, was used as matrix material. The epoxy material and hardener were mixed in 10:1 by weight. The epoxy and hardener materials were purchased from M/s. Bakshi Brothers, Kanpur/India. This study focused on the fabrication of back fiber-fiber back (BFFB), and the second one is fiber back-back fiber (FBBF) configuration.

Testing methods

The compression test sample (155 × 25 × 10 mm) was taken in form of a rectangular shape intermediate column straight beam with a slenderness ratio between 32 and 120 [5, 6]. The load applied to the test samples was recorded by the computerized UTM data acquisition system and follows the ASTM standard (D3410) (Fig. 3).

Results and discussion

The compression testing was performed over 3 different FBBF and BFFB configuration samples. Fig. 4 illustrates that FBBF based specimens (samples a-c) show the highest results

Fig. 1
Trimmed waste of pre-consumer carpet waste [2] and post-consumer carpet waste [3]

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Fig. 2
VARTM method for carpet waste/composites

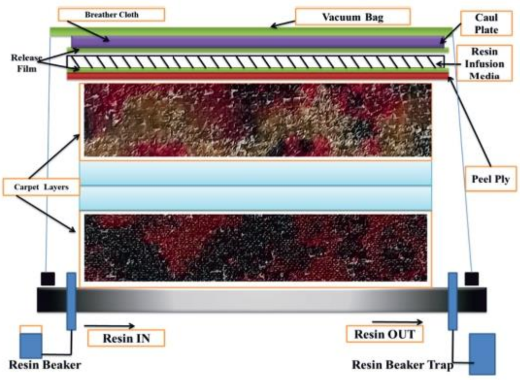

Fig. 4
Load-displacement graph for compression test

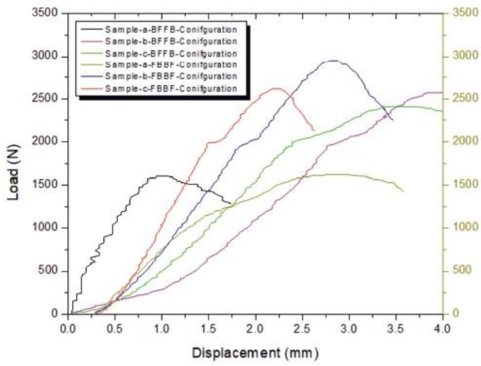

Fig. 3
Compression test setup with testing sample

Compression properties of carpet waste composites

Sr. No.	Configu-ration	Average compressive modulus [MPa]	Average compressive strength [MPa]
1	BFFB	2185	26.03
2	FBBF	2391	32.77

of forces with different values of linear deviation than the load V/s displacement graph of the BFFB specimens (samples a-c). The sharp rising of the curve could be observed while the constant increase in the compression load. Initially, as the load increased, the thermosetting matrix material began to crack with chatter sound. The sample started to buckle after weakening the matrix material showing its backing material's ductile behavior. For FBBF, the maximum value of the compressive load of the 3 sample specimens, viz; a b, c is 1618.48, 2953.86, 2613.13 N, whereas, for BFFB, the maximum value of the compressive load of its specimens were 1605.99, 2574.39, 2409.77 N, respectively. These results for FBBF configuration is due to higher epoxy-PVC backing bonding strength. It causes strong resistance to the compression phenomenon. However, in BFFB configuration, the composite becomes comparatively fragile because of lower bonding strength of epoxy-face fiber causes a decrease in failure resistance strength.

Furthermore, the table briefly illustrates the compressive modulus and compressive strength. The 2 composite configurations during the compression tests displayed two distinctive failure phenomena. Firstly, the samples failed at a particular load, and the samples were plastically deformed due to polymer PVC backing material. 2 configurations show that the fabricated composite materials demonstrate a linear stress-deformation relation within a specified plastic-stress domain [6].

Conclusion

Compression properties of PA carpet waste based epoxy composites have been analyzed in this study. It has been found that the proposed sample shows satisfactory compressive performance due to the better epoxy-PVC backing bonding. It is well suited for lightweight structural functions such as wall tiles, sound insulating materials, thermal insulators, toys, showpiece objectives, etc.

Acknowledgements

This research work is financially supported by o/O DC (Handicrafts), Ministry of Textiles, Govt. of India, New Delhi/India, under Project ID: K-12012/4/19/2020-21/R&D/ST.

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Polymer composite developed from discarded carpet for light weight structural applications:Development and Mechanical analysis

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Abstract: Carpets are the three-dimensional product used as a floor covering in homes, offices, commercial centers, decorative purposes, etc. The average life span of the carpet is four to seven years and after that, it becomes solid waste. The discarded carpets are causing a significant hazardous effect on the environment, climate, soil, and various health issues. To overcome the increasing carpet waste, the re-utilization of carpet is essentially desired. This article focuses on the development of polymer composites developed from discarded nylon carpets for lightweight applications. A modified technique of Vacuum-assisted resin transfer molding (VARTM) was used to fabricate epoxy composites. The tensile and flexural tests evaluated the mechanical performance of the proposed composite. The modified composite is manufactured in two different configurations, namely, face- back-to-back-face (FBBF) and back- face to face- back (BFFB) with the help of the VARTM setup. The result demonstrated that the fabricated BFFB composite has a higher strength. The high-resolution microscopy test of the developed samples shows the feasibility of the composites produced from discarded carpet for lightweight functions. An attempt has been made to resue the waste for the fabrication of cost-effective products.

1 Introduction

Nowadays, carpet waste is a huge concern for the environment and the economy due to high disposal costs and environmental hazards. Only a small fraction of waste carpets gets recycled every year compared to produced carpet waste worldwide [1,2]. It is widely used as a floor covering, in homes, shopping complexes, offices, etc. [3]. A survey has been remarked that approximately 40,000 tons of carpet are discarded as landfills in the United Kingdom (UK) itself. This solid waste becomes a global concern for the environment and economy. [4]. The recycling of any material consists of multiple processing stages and needs heavy expenses. Carpets are non-biodegradable in nature, and it becomes hazardous for soil efficiency, causing environmental problems. The burning of carpets causes air pollution due to plastic content and fibers, which release toxic fumes. [5]. Based on the above issues, the present work highlights the fabrication and characterization of polymer composites develop from carpet waste. In the field of waste carpet re-utilization, many research works have been conducted for waste management. Various types of carpet waste are available in the garbage piles, which are quite difficult to recycle [6]. Various pioneers have performed experiments using carpet waste directly or indirectly in many forms. Onal et al. [7] explored the characterization of the polymeric composites from jute fibers of carpets. The mechanical and physical properties of carpet jute yarn composites were examined. It has been found that that treating the yarn with a 25% NaOH solution improved the fiber-matrix interface. Mishra et al. [8] fabricated structural composites from the post-consumer carpet using the VARTM process. This effort was made to convert such waste into an application form. The findings revealed that such composites are used as structures part like noise barriers. For a range of frequencies, it was found that the noise absorbed by fiber composite was better than conventional for a range of frequencies. Ucar et al. [1] fabricated a cementitious composite reinforced by carpet fibers. This work enhances the toughness of composites. As the fiber content in composite increases, the density of carpet decreases. The mechanical characteristics such as flexural, impact, and toughness of developed composites was examined to determine the feasibility. The results conclude that lightweight composite showed ductile behavior when three-point bending tests were performed, while in flexural strength, it increased with an increase in density. Islam et al. [9]developed insulation materials made from recycled textiles for acoustic and thermal applications. They stated that recycled textile composites are environmentally beneficial and have played an essential role in energy savings and pollution

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reduction. Muzzy et al. [10] used economic techniques to recycle post carpet composites without separating backing fibers with face fibers. They investigated and found that post carpet composites were used with matrix, which was potentially inexpensive with several applications. They also revealed that Nylon post carpet composites were better than polypropylene (PP) post carpet composites in terms of their properties. A large variety of applications of Post carpet composites in many forms helped reduce the activities of landfills. Pan et al. [11] fabricated composites from the discarded nylon 6/nylon 6,6 carpets and studied the mechanical properties, acoustics testing, and water stability. They stated that compression-molded composites had a greater elastic modulus, impact resistance, flexural strength, and sound absorption by 124 %, 32 %, 59 %, and 40 %, respectively as compared to the Jute/PP composites. The researcher stated that Styrene-Butadiene Rubber (SBR) greatly improved the impact resistance & sound absorption by maintaining the sound and flexural properties of fabricated composites. There are lots of researchers have shown their interests towards utilization of carpet and another form of wastes which could be utilized in any form. Basically, they have tried to use wastes because of its ease in availability and tried to convert it into some useful form by various methods. Some have mixed fibres of the carpet with other things, some other have done fabrication and characterization of composites which somehow helps in the utilization of waste. From aforesaid studies, it has been noticed that very limited work exist on the fabrication of composites from waste Nylon carpet.

In this paper waste, Nylon carpet waste was used to manufacture polymer composites using the VARTM technique. The flexural and tensile test was performed to evaluate the application potential of the proposed composites for structural applications. The scanning electron microscopy (SEM) tests were performed on the manufactured composite with the orientation of fiber back fiber (FBBF) and back fiber back (BFFB). This work target to utilize the massive carpet waste generated from domestic and industries applications.

2 Materials and Methods

The fabrication of composite materials was done from the Nylon waste carpet by infusion thermosetting epoxy resin. The carpet waste used for fabrication consists of Nylon carpets as waste fibers. The Epoxy with hardener was obtained from M/s. Universal Enterprises (Polymer Division) 78/44 Latouche Road Kanpur-208001 India. The VARTM setup was utilized to develop the composite samples.

2.1 Fabrication of composite materials

The Epoxy modified carpet waste Nylon layer was used in the Vacuum-assisted resin transfer molding (VARTM) technique [12]. The waste material was used as a reinforcing material in the Epoxy, which improved the interfacial adhesive characteristics of the developed composites between fiber and matrix material. For the strengthening of composite materials, the hardener is added at a ratio of 10:1 in mixed Epoxy. The VARTM method has the advantage of allowing a uniform flow of resin with minimum porosity and bubble formation in the preparation of the sample. Different items, machines, and devices that have been shown in Fig. 1 are resin trap, compressor, vices/clamps, tubes, etc. After preparing the mold, the setup was left undisturbed for 24 hours to solidify in ambient conditions.

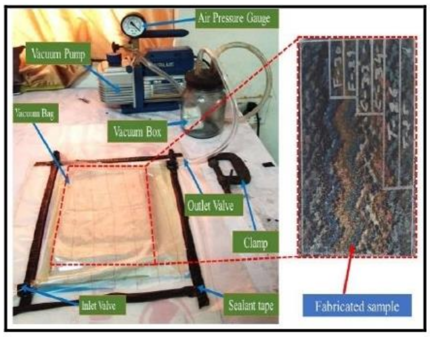

Fig. 1. Fabrication process using VARTM setup.

3 Experimentation and characterization

This paper deals with the fabrication and characterization of Epoxy incorporated carper waste Nylon for structural composites. The orientation of the fabricated carpet composite was of FBBF and BFFB was taken. After fabrication, characterization of the fabricated composite was done by flexural and tensile test. As shown in Fig. 2, the Tensile and Flexural tests have been performed on Universal Testing Machine (INSTRON- 3382, Max. Load 100 KN). The Tensile test specimens were prepared under ASTM D3039 with size (165×20×10) mm [13]. The flexural testing has been performed according to ASTM D790 (60×20×10) mm [14]. The scanning electron microscopy (SEM) was performed to examine the structural integrity and failure mechanisms.Try to ensure that lines are no thinner than

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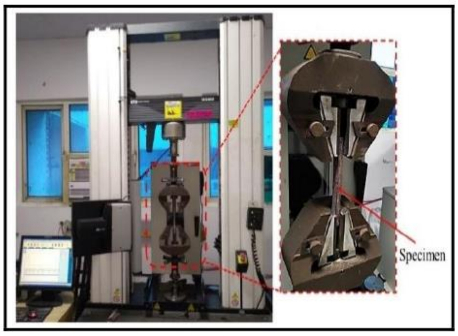

Fig. 2.UTM setup (INSTRON- 3382).

3.1 Tensile Test

The tensile test is one of the most common testing techniques to determine tensile strength and tensile modulus. The tensile tests were performed on two different test pieces of the same dimensions and material, and accordingly, two readings were found. According to the ASTM standard, the tensile test has been performed on fabricated composite. Fig. 3 shows the damaged test specimen nylon waste carpet composite. The load against the deformation curve is noticed in Fig. 4. On both samples, the load-deformation result varies from linear to non-uniform after 2.1 mm deformations. The failure at peak load for both composites is absorbed due to their ductile nature. Moreover, Fig 4 also shows that BFFB samples can bear a higher load after the initial failure in a full load. Furthermore, variations in the peak load of FBBF and BFFB configuration have been observed due to the disparity in composite thickness. The failure of FBBF samples at a lower load indicates the presence of brittleness in the composite. The multivariate configuration and variations in the strength of face fibers lead to the deviation in the properties of carpets. Table 1 presents the tensile properties of the fabricated composites for both configurations. The average elongation of the BFFB specimen is higher than the FBBF specimen because the fibers positioned away from the neutral axis filled with resin have higher specific strength. The tensile strength of the fabricated composite of FBBF is 7.3 MPa, and BFFB is 11.37. It can be observed that the high tensile strength of the BFFB is obtained as compared to the FBBF composite.

Table 1. Tensile properties of fabricated sample.

Sample code	Maximum load (N)	Tensile strength (MPa)	Elongation (%)
FBBF	919.5	7.3	1.59
BFFB	2841.5	11.37	2.03

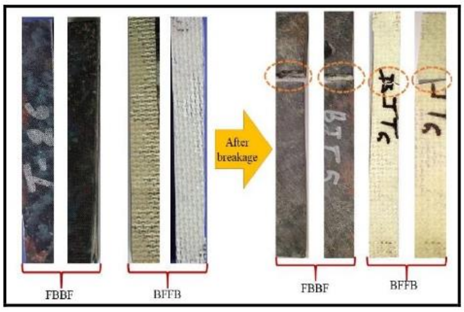

Fig. 3. Failure module of FBBF and BFFB sample.

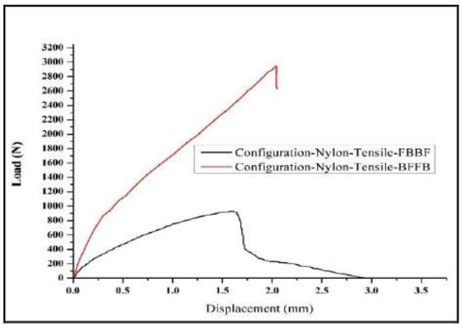

Fig. 4. Typical tensile load vs displacement curve.

3.2 Flexural Test

The most common purpose of a flexural bending test is to determine flexural strength and flexural modulus. The machine was directly linked to the computer in this test, so any deflection in the stress or strain during testing was sensed and shown through a graph in each sample. In this study, the flexural tests have been performed on two different test pieces of the same dimension and material, and accordingly. In order to perform the flexural test, the required dimension for testing of the composite was made to cut by ASTM D790 standard. The dimension was 60x20x10 mm^3, and its cross-sectional area was 60x20 $mm^{2.}$ Fig. 5 shows the samples after the flexural testing was performed. Table 2 presents the flexural properties of the fabricated composites for both configurations.

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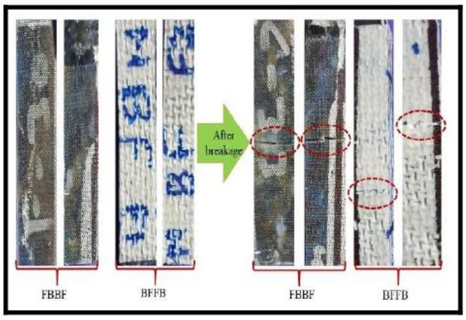

Fig. 5. Flexural module of FBBF and BFFB sample.

Table 2. Flexural properties of fabricated sample.

Sample code	Maximum Flexural load (N)	Flexural strength (MPa)	Maximum Displacement
FBBF	2020	33.19	2.54
BFFB	968	25.47	7.39

The flexural strength of the prepared specimen was investigated at the constant thickness and span length. As shown in Fig. 6, the sharp peak in the BFFB configuration indicates that the fiber gets fractured promptly after splitting Epoxy. Fig. 6 demonstrated the load vs displacement curve and its shows that non-uniform zigzag peaks are generated by samples of FBBF, with a maximum load of 2020 N before fracturing. By comparison, a maximum load of 968 N will hold the BFFB configuration. The probable reason is due to the nylon carpet backrest tolerance to deformations of the peak load gap. The actual cause for the variations in flexural module between the FBBF and the BFFB configuration is the dispersion of Epoxy due to the difference in reaction between the Nylon backing and the fiber-infused resin.

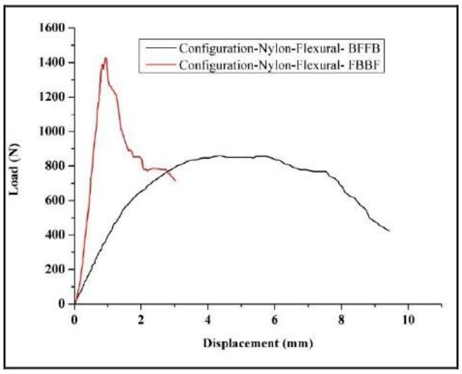

Fig. 6. Typical Flexural module load v/s displacement curve.

3.3 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is used to analyze the high-resolution image of the surface of the breakage sample up to micro and nano-level [15]. As shown in Fig. 7, the SEM analysis has been examined of fracture point after the tensile testing. The images produced by SEM show the extensive fiber breakage and good surface bonding. The images collected through SEM have different magnifications and resolutions up to different microns in different regions. It can easily visualize the fibers, surface textures, homogeneity between carpet fibers and Epoxy, and porosity of the sample from these images.

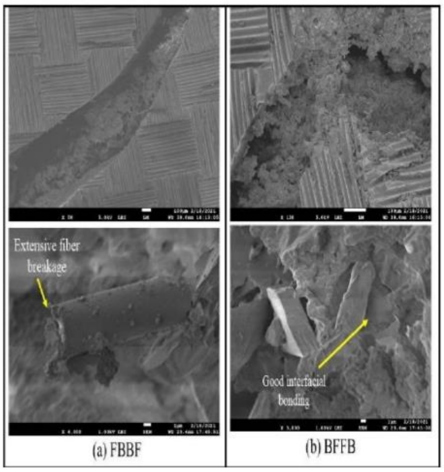

Fig. 7. SEM analysis of failure mode of fiber breakage in the composite after tensile test.

4 Conclusion

This paper focuses on the recycling of nylon carpet waste for the manufacturing of polymer composite. In two different configurations of FBBF and BFFB, the samples were prepared through the VARTM technique. The fabricated waste carpet composite samples of FBBF and BFFB configuration were characterized through flexural and tensile tests. Based on the findings, the following conclusion can be drawn:

- A tensile and flexural test noted that after rupturing of the epoxy matrix, the load was resisted by reinforcing material only. The results obtained by flexural and tensile tests in terms of forces required for the failure of the samples were used to find the strengths of the two carpet samples tested in each case.
- The fabricated BFFB composite has a higher strength than FBB. The result demonstrated that it could be economically used for structural application.
- From the images of SEM, it can be concluded that the higher porosity in the composite, the lower the strength and vice versa. The higher

the homogeneity of mixture between carpet fiber and Epoxy in the composite, the higher will be the strength.

- By seeing the results obtained through different characterization, it can be concluded that the applications of such composites could be sound barriers, light containers, infrastructure composites, decorative purposes, selves to keep lightweight objects, etc.

The proposed work investigates the tensile and flexural properties of the composite manufacture from nylon carpet waste. Based on the result obtained, it has been noted that the proposed material can be used for lightweight applications such as sound barriers, heat insulation, wall tiles, etc. In future, the other investigations such as compression tests and advanced characterization are highly desired to understand the composite behavior in fatigue and creep conditions. The addition of some other carpet waste such as polypropylene, wool, polyester etc. and different hardener material can be used for composite development.

Acknowledgment

The authors would like to thank o/O DC (Handicrafts), Ministry of Textiles, Government of India, New Delhi, India.

Declaration of conflicting interests

The authors declared no potential conflicts of interest.

Funding

This research work is financially sponsored by o/O DC (Handicrafts), New Delhi, India, under R&D Project ID: K-12012/4/19/2020-21/R&D/ST.

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FEST 2021 notification for paper 21

1 message

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Water absorption study and characterization of polymer composites developed from discarded nylon carpet

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Abstract

The scientific objective of this research work is to reuse the polymer materials generated from carpet waste. The nylon obtained from the discarded carpet was used as reinforcement material into the epoxy matrix phase. A modified approach of Vacuum-assisted resin transfer molding (VARTM) was used to infuse the mixture of epoxy and hardener into the nylon carpet polymer composites. The work's primary focus is to investigate the polymer composite's water absorption behavior developed from carpet waste. In water, the sample of composite material was used to test water absorption behavior. It will justify the application of proposed composites for lightweight structural applications in a moisture environment. The nylon fiber-based-epoxy composite was dipped in water as per ASTM standard for a period of four different duration, namely, 24, 48, 72, 144 hours. The findings demonstrate that it can effectively withstand in moisture environment and a maximum 4.5% weight of samples is increased in this test among all the samples for a different duration. Also, the composite developed shown a lower water diffusion co-efficient than the nail head structure and linden wood. After this, the carpet waste composite samples were investigated for thermal degradation and chemical behavior using X-Ray diffraction (XRD) and Fourier transform infrared (FTIR) spectroscopy, respectively. The finding shows that the proposed composite is well suited for lightweight components such as dashboard panels, sound absorbers, panel sheets, wall tiles, etc.

Keywords: Discarded, Carpet, Nylon, Polymer, Composite, Vaccum

1. Introduction

Nowadays, waste management and recycling are widely recognized as major issues to balance environmental concerns. A large amount of plastic is generated from various resources involving industries, domestic, medical, etc. The waste generated from the carpet and textile sector consists of a substantial amount of preconsumer and post-consumer materials. There is an extreme need for the recycling of waste generated from such types of industries. It helps to optimize energy consumption and maximize the profit in the sectors. The textile industry is essential in the lives of every human being because it is attributed to basic needs for living. Carpets are a vital part of the textile sector manufactured by hand or by automation [1]. Generally, carpet has 4 to 6 years; after this duration, it is converted into waste. Then the waste was disposed of in landfills [2], energy production through incineration. Carpet waste could be effectively used to fabricate composite for applications such as furniture, subflooring, roof panels, exterior support, interior panels of the vehicle, etc. Among all of the nylon are the most significant produced synthetic textiles [3]. Therefore, a considerable quantity of nylon fibers is available. Various pioneer scholars resued the carpet waste and converted it into some useful form. In this series, Venkateshwaran et al. [4] reported that the water permeability depends on the absorption of water by the jute hybrid composite. Jain et al. [5] developed a composite material from the discarded carpet of nylon and olefin material in a different configuration such as BFFB and FBBF through the VARTM method. Furthermore, they applied a tensile test on both the composite material and obtained nylon with better tensile strength. Mishra et al. [6] fabricate a carpet composite material from the VARTM method. Later, they tested the hardness and compressive test of the composite materials. Karmaker [7] studied the moisture effect on jute/polypropylene composite. They conclude that water absorption was linearly proportional to the fiber content in the composite. Gassan and Bledzki [8] perform mechanical testing with the moisture effect on the silanized jute/ epoxy composite. They conclude that the moisture content degrades the mechanical properties of the composite. Karaudman et al. [9] investigated the behavior of water absorption of polymer composite, which was comprised of carpet-based jute yarn and thermoset matrices. The flexural and impact properties of the composite were investigated by aging in distilled water. The water absorption behavior of composites was investigated by treating jute yarn with NaOH. It was found that when alkali-treated jute yarn composite reduces, the water absorption of the composite resulted in interface improvement. Mohanty et al. [10] modified hessian cloth and carpet backing cloths, which were the two varieties of jute fibers, and done involvement of alkali treatment and cyanoethylation. The characterization of the fabrics treated chemically was done by X-ray diffraction analysis (XRD) and thermogravimetric analysis (TGA). Mechanical properties were found to be increased in comparison with the parent material.

The present research article contains the recycling method of post carpet (nylon) waste. The moisture absorption of composite has been used to calculate the amount of water consumed under defined conditions. Factors influencing water absorption include the type of plastic, chemicals used, temperature, and exposure time. Evidence highlights the durability of products in damp or moisture conditions. The findings of XRD and TGA demonstrate the feasibility of the proposed composite for lightweight applications. This work aims to reutilize the waste nylon carpet for the development of polymer composites.

2. Materials and methods

2.1 Sample preparation

The waste carpet (nylon) was used as reinforcement and epoxy as a matrix material to fabricate composite samples. Primarily, the nylon-based carpet waste is followed by the open drying and cleaning process. In this process, GY-257, Diglycidyl ether bisphenol-A (DGEBA) based resin was purchased from M/s. Universal enterprises (Polymer Division)-78/44, Latouche Road, Kanpur, India. It was modified with aromatic glycidyl ether hardener (Araldite® HY-951) as a curing agent in the proportion of 10:1. This blend shows properties of low viscous 500 – 700 mPa-s (at 25 °C). The samples were fabricated in two configurations: BFFB and FBBF.

The VARTM technique is used in this study to fabricate the composite material. Fig. 1 represents the schematic of the VARTM Setup. The upper mold and spiral wrap are present in the Setup to ensure a homogeneously flow of resin over the carpet pile.

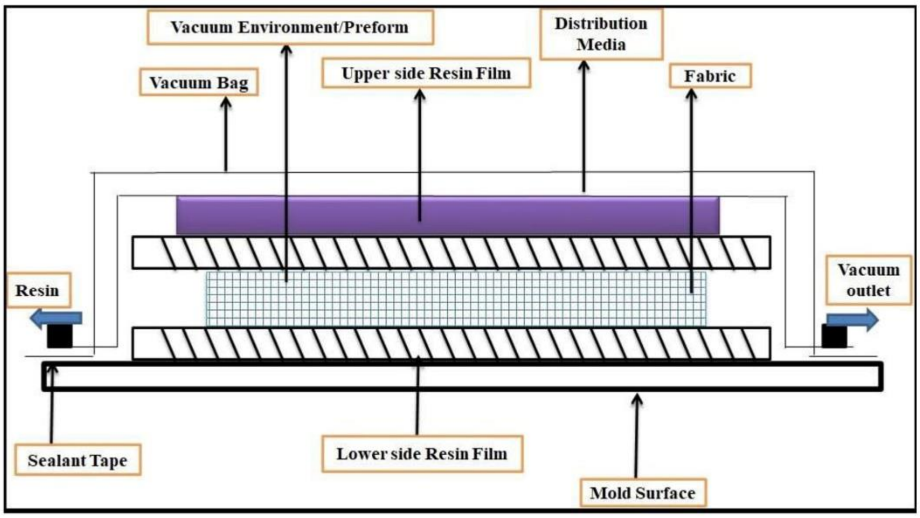

Fig. 1 Setup of VARTM for Nylon carpet waste Composite

The carpets piles were put in the dimension of 250×300 mm^2 in the BFFB and FBBF configuration separately. The polythene sheet and tacky tape created an airtight mold with the inlet and outlet valve. The matrix material flow to infuse the carpet pile through the vacuum pressure applied by the vacuum pump. A peel ply and transfer media are used to infuse matrix material into the carpet ply properly. After the matrix has been wholly infused, the inlet and outlet valves are tightly closed for 30 hours and cured.

2.2. Water absorption behavior of waste carpet composites

The water absorption test was conducted according to an ASTM-D570 (as display in Fig.2). Generally, three concept which regulates the moisture dispersion in the material. The first one is water diffusion into the micro-voids among adjoining polymer chains. The next one is with the help of capillary action arises in the polymer composite, and the last one is diffusion over the micro holes presented in the composite. After absorbing moisture, the interfacial adhesion force between the reinforcement and matrix is reduced [11], [12].

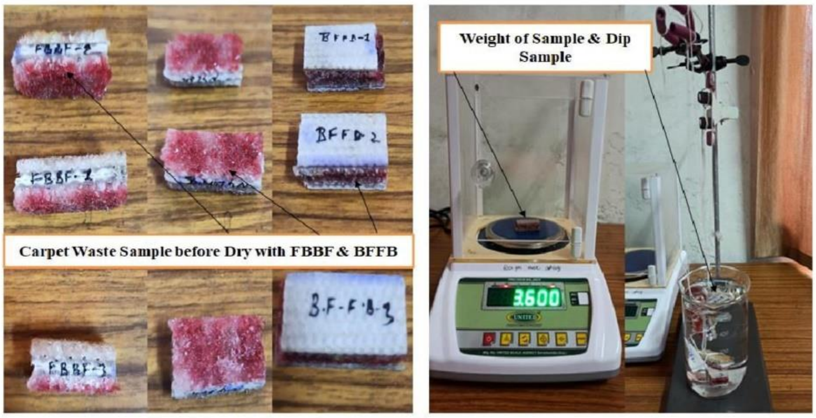

Fig. 2 Water absorption test

The following procedure has opted for the water absorption test

- Firstly, the specimens are entirely dipped in water for several hours.
- Then, the samples are taken out from the water and allowed to drain for one minute.
- The specimens after draining are wiped off and weighed immediately, and the weight of each sample is noted.
- The dry weight of each specimen has been recorded.
- The percentage of water absorption is calculated by the water absorption percentage (M) given by the following formula.

$$M = \frac{Wet\ weight - Dry\ weight}{Dry\ weight} \times 100 \tag{1}$$

2.3. Morphology analysis

X-Ray Diffraction (XRD) tests were used in the present study to analyze the crystallographic structure of the waste carpet composite material. The XRD research is used to classify crystalline phases of a substance utilizing a crystal structure review and expose details on the chemical composition. X-ray diffraction curves of the studied samples are characterized by diffraction peaks of the nylon carpet and epoxy matrix crystalline structures. XRD test was done on the Ultima IV diffractometer. XRD pattern has been obtained with the help of Bragg's equation:

$$n\lambda = 2dsin\theta \tag{2}$$

here, n= Integral number of wavelength

λ= wavelength of the electron

d= Spacing of the crystal

θ= Reflected angle

Thermogravimetric analysis (TGA) of the waste carpet composite (TGA 55) was performed from room temperature to 800 $^{\circ}C$ with a 10 $^{\circ}C/min$ heating rate. In this test, the sample's thermal stability was investigated regarding weight loss as a function of temperature in a nitrogen atmosphere.

3. Result and discussion

3.1. Water absorption test

The water absorbed tests on the nylon-based composite material. The test was performed for 216 hours at the iteration of 24 hrs. The amount of moisture absorbed in the sample is shown in Table 1, and in graphical form, in Fig. 3, the test is carried out on BFFB and FBBF, both configuration and two samples of each configuration. The result shows that composite samples are absorbed a maximum of 4.22% at the 144 hours after that negligible water absorb. Also, similar results are confirmed by the researcher [13], [14].

Table 1 water absorption of different samples

Time	**% water absorbed**			
Hrs	BFFB configuration		FBBF configuration	
	BFFB-1	BFFB-2	FBBF-1	FBBF-2
24	3.04	2.76	3.3	2.59
48	3.63	3.03	3.55	2.99
72	3.76	3.25	3.74	3.16
96	4.06	3.53	4.36	3.3
120	4.1	3.59	4.41	3.52
144	4.14	3.68	4.53	3.56
168	4.22	3.78	4.73	3.67
192	4.22	3.78	4.73	3.67
216	4.22	3.78	4.73	3.67

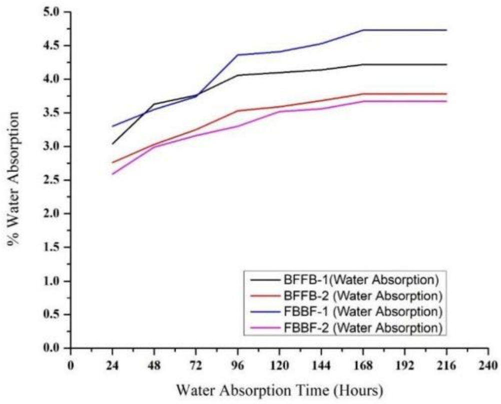

Fig. 3 Graph between %water absorption vs. time

3.2. X-Ray diffraction analysis (XRD)

The results of XRD of the carpet waste Above graph of XRD such that of carpet waste nylon reinforcement with epoxy materials. X-ray diffraction is a non-destructive research tool for studying the crystalline material composition [15], abbreviated as maxima point position peaks at certain angles of incidence theta. XRD two-point atoms more highly count par second 16500 and 14000 of intensity. In epoxy, the XRD characterization method is primarily used to determine the degree of epoxy and nylon reinforcement. The crystalline characteristics of nylon/epoxy composite are visible in the diffractogram at $2\theta = 31°$, shown in Fig. 4. The peaks of epoxy are also exhibiting at 20°.

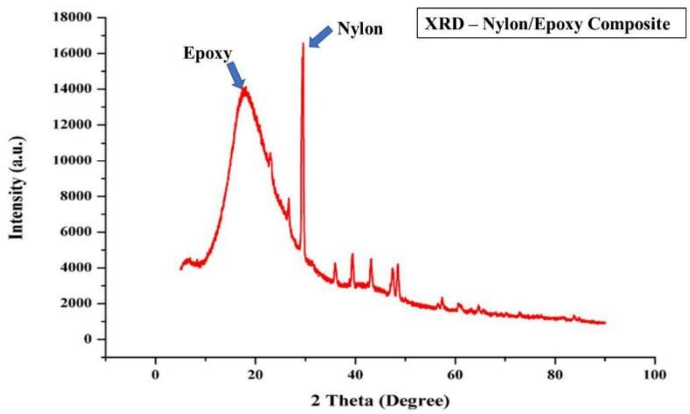

Fig. 4 XRD analysis of Nylon/Epoxy composite

3.3. Thermogravimetric analysis

Fig. 5 shows the TGA of a nylon-based carpet composite. There are three primary reaction stages of degradation. The first stage shown at 240 °C was caused by the decomposition of impurities and volatile components. The loss of weight fraction was around 15.6%. The second degradation step is associated with the polymeric fraction's decomposition. At this point, there was massive thermal degradation related to the deterioration of the polymeric. A temperature rises of about 300 °C is equivalent to the highest weight loss resin was decomposed. Then in the third stage, the nylon is decomposed. The decay of the nylon ended approximately at 680 °C, with a 70 % weight loss. Finally, around 800 °C, it degrades about 75% weight loss of the whole sample.

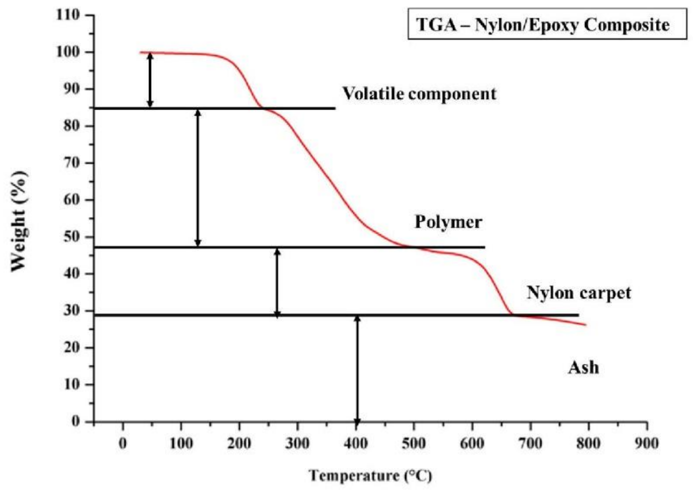

Fig. 5 TGA analysis of Nylon/Epoxy composite

4. Conclusion

The discarded carpet was successfully converted into a structural composite material with the help of epoxy matrix polymer. The fabricated sample was tested for water absorption for 210 hours. Form the experimental analysis conclusion can be summarized as followings point:

- The composite was developed from a modified vacuum environment to transfer epoxy resin into the carpet pile structure. The vacuum environment is remarked as a useful method for developing composites with uniform dispersion and infusion.
- The results show that composite materials absorb less than 4.8% of their weight, then after, the sample absorbs negligible moisture. It demonstrates the higher feasibility of the proposed composite in the moisture area.
- An XRD pattern confirms the crystalline structure of a nylon-based composite produced at 31^{o}. This structure is highly desired for structural composite materials.
- The thermogravimetry analysis results demonstrate that the produced composite has good thermal stability. The graph indicates that since the temperature rises to 700°C, the material degrades by over 75%.

The finding shows that the proposed composite could be transformed for lightweight components such as dashboard panels, sound absorbers, panel sheets, wall tiles, etc. In the future, other types of carpet waste such as polyester, polypropylene, wool can be used to manufacture polymer composites. This approach could be efficiently used for solid waste management of the carpet and textile sector. Further, mechanical and advanced characterization is highly desired to estimate the potential of the proposed composites.

Acknowledgment

The authors would like to acknowledge the kind support of o/O DC (Handicrafts), Ministry of Textiles, Govt. of India, New Delhi, India, to directly extend all possible help in this research work.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest.

Funding

This research is being funded in part by o/O DC (Handicrafts), Ministry of Textiles, Govt. of India, Under Project ID: K-12012/4/19/2020-21/R&D/ST.

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Journal of Textile and Apparel, Technology and Management

Volume 12, Issue 2, 2021

Investigation on Impact and Flexural Behavior of Polymer Composite Developed from Discarded Carpet

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ABSTRACT

In the 21st century, waste becomes the primary concern for the manufacturing sector and industries. The carpet and textile industry products are increasing in view of customer varying needs. This article highlights the development of polymer composites from waste carpets (Nylon). The Vacuum-assisted resin transfer molding method (VARTM) is used to infuse epoxy and hardener into the waste nylon carpet. The mixture is properly fused into the fibrous material without any blow holes and entrapping of air in a vacuum environment. It enhances the mechanical strength of the developed composites. The impact and flexural performance of the proposed polymer composites is investigated in this work. The outcomes of the developed carpet waste composites show the feasibility of lightweight structural applications. It can exhibit better shock load resistance and flexural than some conventional synthetic fiber polymer composites. This technique utilizes the carpet fiber sheets waste to manufacture composites with improved mechanical properties (Impact and flexural), ensuring recycling the waste carpet to overcome the environmental hazards.

Keywords: carpet, VARTM, composite, shock load, flexural strength

1. Introduction

Nowadays, waste becomes a severe issue for manufacturing industries. The carpet sector is proliferating due to varying requirements of comfort conditions and applications. The average life of the carpet is a maximum of five-seven years (Miraftab, Horrocks, & Woods, 1999; Singh & Dwivedi, 2020). After that, it converts into massive solid waste. A new method is required to develop for carpet recycling to reduce the problems generated through conventional techniques. Therefore, various studies and approaches toward recycling carpet waste were conducted, which is quite different. Numerous studies focus on composite fabrication by utilizing the waste carpet, which can be used in low structural applications. Besides, the different carpet waste processing options are explored, including waste to energy through Incineration, fiber reprocessing, carpet re-use, and plastics reprocessing. In recent studies, the development of composites using fabric waste has been explored for sound and heat applications (Pan, Zhao, Xu, Ma, &

Yang, 2016; Partha, G., Rathinamoorthy, & Ramachandran, 2000). There are various types of carpet waste, such as backing sheets, fibers, available in the garbage piles. Industries and environmental expertise are anxious about the decomposition of such kinds of carpet wastes. Various pioneer scholars are working on recycling carpet waste and its utilization in the development of some products. In this series, Yang et al. (Xuan, Chen, Yang, Dai, & Chen, 2018) analyzed the effect of various parts of carpet waste by adding to the cement mortar. The findings reported that the addition of carpet face fibers was more feasible for improving mortar impact behavior. It was also found that the reinforcing effect of face fibers was more prominent at higher temperature or higher impact pressure. Some parts of the carpet revealed a negative effect on the impact resistance irrespective of the temperature variation. The microstructure and the pore distribution of mortar were significantly improved, which favors a change in residual strength. Wang et al.(Ucar & Wang, 2011) carried out a comparative examination of the impact strength between GFRP and sisal fiber composite. They were analyzed that developed composite can be utilized as an alternate material over the traditional materials. This work suggests that the polymer composites required features could be altered using jute fibers and explored the possibility of using carpet waste jute yarn to enhance the physical and mechanical properties of fiber-reinforced composites. Jute yarn was treated with 25 wt.% NaOH solution to enhance the fiber-matrix interface. Carvalho et al. (Laranjeira, De Carvalho, Silva, & D'Almeida, 2006) examined the compression behavior of wool and acrylic hand-tufted tapestries using varying compressive load. Wool tapestries demonstrate higher compression and recovery than similarly crafted acrylic tapestries. It diminishes the compression and mates with a rise in pile density. Due to the improved compression period, the percentage of the recovery of the tapestries has improved. The efficiency, aesthetics, and durability of the carpet are highly affected by the repeated loads. The efficiency of the cyclic compression load is evaluated in terms of decrease, restoration, and matting. The composition of the stack yarns and the tapestry building parameters significantly influence the carpet quality. Based on the outcomes, the wool carpet is more efficient the acrylic for compression behavior. Mishra et. al.(Mishra & Vaidyanathan, 2019) developed the lightweight components for tooling material from post-consumer carpet waste. A little addition of 5. % by weight of graphene nanoplatelets is used as filler material to improve the strength features. The proposed composite validates consistent hardness and compression results based on the number of cure cycles. The fabrication costs in this method are about the same as those of instruments made from the critical cost estimates of epoxy and polyurethane resins. Sotayo et.al. (Sotayo, Green, & Turvey, 2018)discussed an exhaustive literature survey on the recycling of waste carpets. The study summarized that the re-use of carpets could be the most cost-efficient and environmentally friendly approach. It is related to substantial savings in raw materials and energy consumption; however, it is viable for certain types of carpet waste and necessitates proper processing centers. Mohit et al. (Mohit et al., 2021) explore the several advantages to natural fibers: low density, low cost, ecological, biodegradable, and high mechanical efficiency. The study fabricated the epoxy composites modified by randomly oriented short jute fiber to boost the bending and impact properties. The findings conclude that the flexural and impact characteristics are improved by jute fiber and tensile were remain constant.

The exhaustive literature review demonstrates the feasibility of the carpet waste application to develop composites and other manufacturing products. It has been remarked that the waste generated from the carpet industry is very harmful to the environment and its decomposition is very costly and detrimental for ecology. It can be reutilized or recycle for the development of products. But, a very limited study is available on the fabrication of polymer composites from carpet waste. This work targets the lightweight structural application through carpet waste composites. The impact and flexural performance of the developed composites is estimated in this work. A modified manufacturing method is used in a vacuum environment for the development of samples. (Mohammadhosseini, Abdul Awal, & Mohd Yatim, 2017)The sample was tested using ASTM standards to evaluate the application potential for end-use. An attempt has been used to utilize recycled carpet waste.

2. Materials and Methods

The waste carpet pieces changed into the size of $30\,mm \times 30\,mm$ to use in the VARTM setup. The carpet pieces' backing is combined to obtain the back fiber to fiber back (BFFB) configuration. At the starting step, a release agent (silica gel) is spread over the surface to remove the developed specimen firmly from the bottom surface. This configuration is placed into the vacuum bagging at the silica gel surface of the glass table. A vacuum mold is created with the help of a porous sheet and tacky tape. The inlet at atmospheric pressure and the outlet at the compressor side were offered in the mold setup. First, the air inside the mold was expelled out by running a vacuum pump to make the mold air-free or perfect vacuum. The resin was then allowed to infuse into the preform prepared. The driving force and suction force were formed by 1 atm pressure created by the vacuum pump for proper infusion of resin motion into the mold. After this, the samples inside the bagging are under the mixture flow and completely spread the mixture into the mold. Both ends of the suction and outlet pipe are remained clamped for proper curing in 24 hours. The polymerization time of the mixture for Diglycidyl ether of bisphenol A, Lapox (L-12) resin with Tri-ethylene-tetra-amine, K-6 hardener was used as described in Figs. 1. (a-c). For preparing a $30\,mm \times 30\,mm$ size composite sample, a blend of 400 ml epoxy with a 40 ml hardener is well mixed through the manual stirring process.

Figure 1. (a) Mold release agent, (b) Tacky tape, and (c) VARTM Setup

2.1 Charpy Test for Specimen

The impact performance of developed samples was investigated using the Charpy test. These samples were tested destructively with the Charpy Impact tester, as displayed in Fig. 2 (a). The Charpy test is used to measure the amount of energy that the sample absorbs until fracture—one of the most common tests used in evaluating relative toughness in a fast. Depending upon the sample shape and size, a notch is made to increase the sample's stress concentration. Afterward, the sample is breaks, and the failure mode is presented in Fig. 2 (b). It is generally avoided to make a notch for the pieces having very low strength.

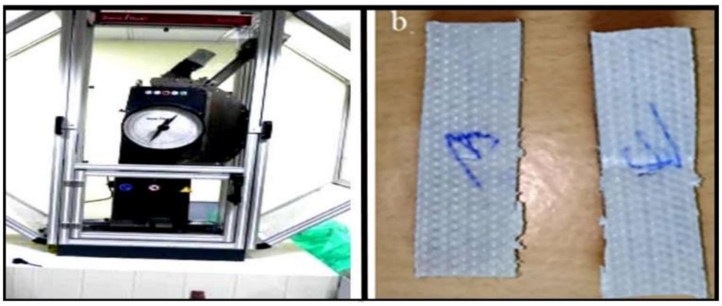

Figure 2. (a) Pendulum Impact Tester and (b) Undeformed Samples for Charpy Test

The dimension 55 mm ×10 mm ×10 mm of the sample was taken according to ASTM D4812 (Navaranjan & Neitzert, 2017). No notch was prepared for these samples, and it is tested in a flat mode in the form of the simply supported beam on the Pendulum impact tester (PSW 750). The hammer strikes the sample at the lateral side facing the BFFB. The swing of the striking hammer shows the amount of energy absorbed by the test piece. The larger the amount of swing by the hammer lesser the energy absorbed by the test piece. The amount of energy released during the sample fracture depends mainly on the difference between the hammer swing's initial and final heights. The collision is triggered by using a pendulum from the maximum height ho against the test sample. When the hammer is released, it swings through an arc, strikes the test sample, and, after fracturing, returns to a height hf. Once the pendulum falls, each impulse were recorded until the trajectory of the pendulum is reversed. The observed change in the initial energy and the retained energy signifies a gauge of the energy needed to fracture the test sample. This quantity is called absorbed energy in the Charpy test, and is represented by E_{total}.

To calculate the total amount of absorbed energy following formula is used:

$$E_{total} = mg(h_o - h_f) \qquad (1)$$

Here,
E_{total} = Total amount of energy absorbed,
m = Mass of the hammer,
g = Acceleration due to gravity,
h_o = Initial height of the hammer,
h_f = Final height achieved after striking the sample.

2.2 Flexural Test for Specimen

Flexural tests were performed on three different test pieces of the same dimension and material, and accordingly, three readings were found. To perform the flexural test, the required dimension for testing of the composite was made to cut by ASTM D790 standard. The dimension was 60x20x10 mm, and its cross-sectional area was 60x20 mm. The machine used in this testing was having a maximum capacity of 10 KN and the strain rate was 2 mm/min. The most common purpose of the flexural bending test is to determine flexural strength and flexural modulus. The flexure test method indicates the nature of the sample or job subjected to simple beam loading. This test is also known as the transverse beam test in the case of some materials. For increments of load, maximum fiber strain and stress are evaluated. The results of this test are plotted on a load versus deformation diagram. Flexural strength is equal to the maximum stress generated in the sample's outermost fiber at the time of the flexural test. It is evaluated at the convex or tension surface of the specimen. The slope of the stress vs. deflection curve gives the flexural modulus of the sample. In the case of the linear curve absence, a secant line can be fitted to the curve to obtain the slope. The 3-point bending test setup and after the test sample is present in Figs. 3 (a-b).

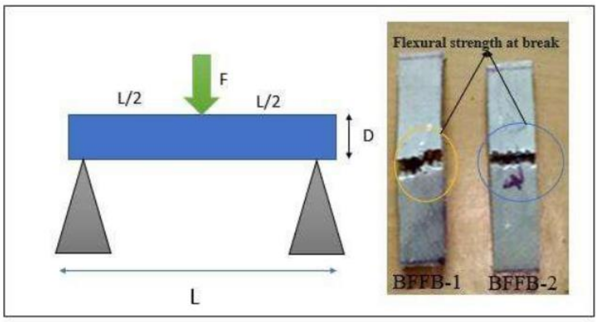

Figure 3. Arrangement for Flexural Test (a) Demonstrating the 3-point Bending Test (b) BFFB Fractured Samples

The 3-point bending test is the most used test for calculating the flexural strength of polymers. The crosshead movement generally measures the deflection of the specimen. This test can easily evaluate flexural strength and flexural modulus. Flexural strength can be obtained from the following formula given in equation 2.

$$\sigma = \mathrm{F} \times \mathrm{L} = \frac{3\mathrm{PL}}{2\mathrm{bd}^2} \quad (2)$$

where:
σ= flexural strength (N/m^2)
F= maximum peak load (N)
L= distance between load points (mm)
b= sample width (mm)
d= sample thickness (mm)

In this analysis, a sharp-edged instrument is used to perform a 3-point bending test and sample was prepared according to the ASTM D790 standard. This method is used to evaluate the flexural properties of reinforced and non-reinforced plastics. According to this standard specimen should be solid and uniformly rectangular. First, the sample was mounted as an overhanging beam and deflected below the constant 2 mm/min crosshead displacement rate. The 10 percent of the span length on both sides was drawn from the overhang and the load was added centrally to the sample. The deflection that occurred during the load application was reported before the matrix and bottom fibers collapsed. The sharp-edged tool depth penetration was also reported.

3. Results and Discussion

3.1 Analysis of Charpy Test (Impact Strength)

In this study, the Charpy test is executed by allowing the hammer to use its nominal initial potential energy up to 85%. The pendulum hammer's size is based on the assumption that loss of speed during sample testing should be kept as minimum as possible (Onal & Karaduman, 2009). During the test, the hammer is pre-loaded to standard height and released. The amount of absorbed energy is registered in the device's database, equivalent to the swingarm's farthest travel. This absorbed energy in joules is equal to the difference between the hammer's initial position and the finishing position. The impact velocity of the hammer was kept at 5.2 m/s with a hammer weight of 10.95 kg. Both the test samples were partially broken after Charpy test. The average values of absorbed energy recorded in Charpy test for BFFB-1, BFFB-2 was 0.7521J and 0.8883 J, respectively tabulated in Table 1.

Table 1. Calculation of Impact Strength and Impact Modulus

Sample No.	Actual energy absorbed (E_{total}) Joules	Impact strength (I_S) I_S=E/a (kJ/m^2)	Impact modulus (I_m) = Impact Energy/ Volume of sample
BFFB-1	0.7521	7.5212	0.0001367
BFFB-2	0.8883	8.8830	0.0001615

Figs. 4 (a-b) illustrates the graph of Work versus Standard travel (mm) for BFFB-1, BFFB-2, respectively. The graphs of samples 1 and 2 demonstrate that while the hammer travels 3.45 mm the work is 0.397 Joules. But at the travel arc length of 10.25 mm, the work done by the hammer is 0.53 Joules for sample 1 and 0.708 Joules for sample 2. The main difference that can be visualized from the above graph is that the maximum standard travel for sample 2 is larger than the standard travel for sample 1. The approximate linear line between 0 and 5 mm indicates the jerk produced at the time of hammer strike. The average values recorded of both the samples were: E_{total} = 0.8202 J and *Impact strength* (I_S) = 8.2021 kJ/m2 in the Charpy test. These observations demonstrates that within short travel of hammer, the work done is large. The linear straight line indicates the hammer's return to its initial position having no obstacles or resistance in its way. The above results demonstrate that energy absorbed and impact strength for composite sample 2 have a larger value than sample 1. In this configuration of composite, it strikes the PVC backing of the sample. Furthermore, the carpet has been designed to sustain the compressive load and shear load, so it quickly falls in impact load testing.

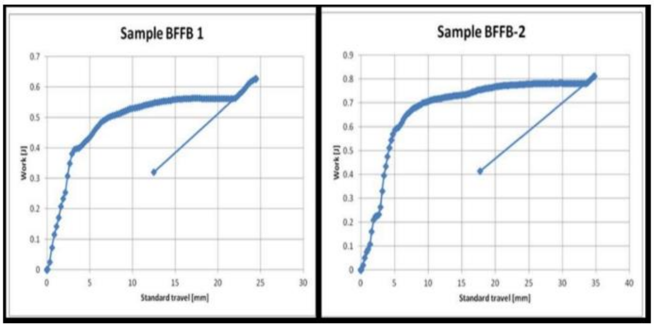

Figure 4. (a-b) Charpy Test: Amount of Energy Absorbed in Joule with their Standard Travel in mm

3.2 Analysis of 3-point Bending Test (Flexural Strength)

The three-point bending test characterizes the behavior of a rectangular-shaped sample subjected to the perpendicular load applied to the longitudinal axis of the sample. In this test, flexural stress is generated in the convex side of the sample and strain-stress in the concave side. (Pan, Zhao, Xu, Hou, & Yang, 2016) This stress, in this way, creates an area of shear stress along the midline. Shear stress must be minimized while ensuring the primary failures evaluate from flexural stress. This can be possible by considering the span to depth ratio in a proper manner. Under 3-point loading conditions, this measure tests the force needed to bend a beam. In this test, two parallel supports are mounted on rectangular or flat-crossed specimens that allow free rotation around an axis parallel to the pin axis and the specimen axis. In this analysis, flexural strength was evaluated, which also differed commonly with width, span length, and temperature, but here the sample thickness remains constant and span length also remains constant. Form Fig. 5, the initial test run shows a sharp rise in the load with a minimum crosshead and soon after, this converts to a large crosshead distance with no increase in the load applied. This happens because of a weak backing surface, which allows the sharp-edged tool to penetrate its surface easily. In this, every sample has a sharp peak demonstrate that fiber fractured quickly after rupturing of epoxy. It showed the approximate sharp peak for the first sample and zigzag peak for the last samples during the rupture. From Fig. 5. We found that maximum load was sustained by sample 2 (Sotayo, Green, & Turvey, 2015). The possible reason for this difference in peak load could be the non-uniform penetration of epoxy inside the sample and bonding of the fibers. In Fig. 5. Sample-1 has an exception of wavy peak show difference of peak load within short deformation. It is because of the yielding of the material when its reinforcing fibers fracture in random order and in a non-uniform way. In the first sample, there is no wave neither yielding phenomenon occurs, but it just broken in a brittle manner, demonstrated the strong bonding and affinity among the fibers with the matrix material. After rupture of the lower or tensile surface of the specimen backing, the remaining load is resisted by the upper surface and its fibers. Both the test samples were partially broken after the bending test. The average values of flexural strength calculated in the test for BFFB-1, BFFB-2 were 28.245 and 22.570 MPa, respectively (Table 2). The average values of flexural modulus calculated in the test for BFFB-1, BFFB-2 were 0.051 and 0.057 GPa.

Table 2. Calculation of 3-point Bending Strength and Flexural Modulus

Sample No.	Flexural strength (MPa)	Flexural modulus (GPa)
BFFB-1	22.570	0.057
BFFB-2	28.245	0.051

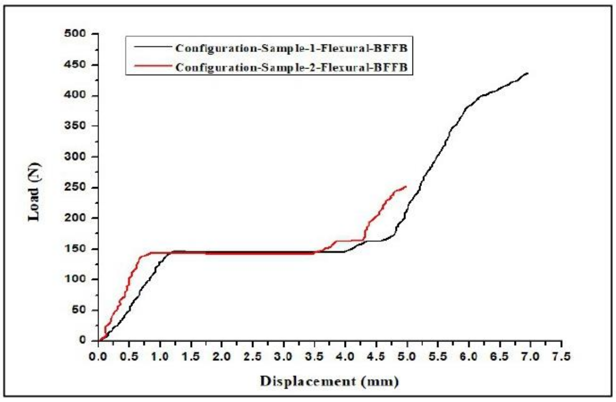

Figure 5. Flexural Test Result

4. Conclusion

This paper focuses on the development of polymer composites from waste nylon carpets. The epoxy and hardener mixture is infused into the waste carpets samples through a modified and effective method (VARTM). Based on obtained results, the following conclusion can be drawn:

- In a vacuum environment, the dispersion of the mixture is uniform without any blowholes and other failures. The impact and flexural performance of the proposed polymer composites samples is examined through the Charpy test and 3-point bending test, respectively. The improper infusion of epoxy at the time of fabrication made the composite weaker and explained low strength composite.
- In the Charpy test case, BFFB configuration samples were tested to find the impact strength from absorbed impact energy values. The values of the absorbed energy in Joule for F1, F2 were 1.6912 J and 1.8319 J, respectively. The samples' impact strength is noticed as 16.9128 KJ/m2 and 18.3198 KJ/m2, respectively.
- The backing got damage at certain places, so it also contributes to the composite lesser strength. The improper infusion of epoxy at the time of fabrication made the composite weaker, maybe explaining low strength composite. The waste carpet and torn fibers at various places cannot give the uniform strength in all the directions of the composite. The outcomes of the impact and flexural test show the feasibility of proposed composites in light structural applications.

The outcomes suggest that the achieved strength and impact behavior can be used for lightweight structural components. There is much work left to be done in the field of management of waste products. The proposed samples can be endorsed for light structural functions, decor items, wall tiles, etc. The addition of other types of hardener and filler materials can improve the proposed carpet waste composite impact and flexural performance

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest.

Funding

This research work is financially supported by o/O DC (Handicrafts), Ministry of Textiles, Govt. of INDIA, Under Project ID: K-12012/4/19/2020-21/R&D/ST.

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Certificate No: 112020450

CERTIFICATION OF PARTICIPATION

This Certifies that

Dr.Rajesh Kumar Verma

Madan Mohan Malaviya University of Technology

for Participating and Presenting a paper title **Study on polymer (epoxy) composite using carpet waste for lightweight structural applications: A new approach for waste management** in 11th Conference on Materials Processing and Characterization -2020(ICMPC 2020) organized by Department of Mechanical Engineering & Metallurgy Engineering and Material Science, Indian Institute of Technology Indore (IIT Indore) during 15-17 Dec 2020.

Convenor	Convenor	Convenor
Prof. Anand Parey	Asst.Prof. K. Eswara Prasad	Prof. Swadesh Kumar Singh
IIT Indore	IIT Indore	GRIET HYDERABAD

E-48

CERTIFICATE OF PARTICIPATION

This certificate is awarded to Prof./Dr./Mr./Ms. Kaushlendra Kumar

for participating and presenting a paper titled Polymer Composite Developed From Discarded Carpet for Light Weight Structural Applications: Development And Mechanical Analysis

in 12th International Conference on Material Processing and Characterisation (ICMPC-2021) conducted by the Department of Mechanical Engineering, National Institute of Technical Teachers Training and Research NITTTR Chandigarh, India during 06-09 October 2021

Convener	Convener	Convener
Prof. Sukhdeep Singh Dhami	Prof. Rupinder Singh Khalasa	Prof. Swadesh Kumar Singh
NITTTR, Chandigarh	NITTTR, Chandigarh	GRIET, Hyderabad

- **Media Coverage of Project Work**

Dr. Rajesh Kumar Verma (Project PI), Balram Jaiswal (Senior research expert), Rahul Vishwakarma (Senior research expert), Kuldeep Kumar (Junior research fellow), Kaushlendra Kumar (Junior research fellow)

Project work coverage from the National media (DD News) Dated 20/08/2021, 08:46 AM

9:30 AM | 0.9KB/s

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मौजूदा हालात में जटिल हो रहीं राष्ट्रीय सुरक्षा चुनौतियां >>3

जागरण विशेष

अव कालीन के अपशिष्ट से वनाई जा सकेंगी टाइल्स

गोरखपुर: एमएमएमयूटी के एसोसिएट प्रोफेसर डा. आरके वर्मा ने कालीन के अपशिष्ट से ध्वनिरोधी शीट्स और दीवार पर लगाने वाली टाइल्स बनाने का तरीका ईजाद किया है। (पेज-10)

न्यूज गैलरी

राज-नीति ▸ पृष्ठ 3

स्कूलों में नल से जल पहुंचाने वाला पहला राज्य वना जम्मू-कश्मीर

श्रीनगर: जम्मू-कश्मीर में हर सरकारी

एक हजार लो

एक्शन ▸ एलजी की ओर से गठित

जागरण ब्यूरो, नई दिल्ली

दिल्ली में एक हजार लो फ्लोर बस खरीद मामले की जांच सीबीआइ करेगी। उपराज्यपाल अनिल बैजल की ओर से गठित समिति की रिपोर्ट के आधार पर गृह मंत्रालय ने सीबीआइ को इस मामले की प्रारंभिक जांच शुरू करने को कहा है। सीबीआइ अगले एक-दो दिन में मामला दर्ज करेगी।

दिल्ली में एक हजार लो फ्लोर बसों की खरीद के तहत एनुअल मेंटेनेंस कांट्रैक्ट (एएमसी) की आड़ में बड़े पैमाने पर घोटाले का आरोप है। उपराज्यपाल ने तीन सदस्यीय समिति को मामले की जांच सौंपी थी। समिति की रिपोर्ट के आधार पर सोमवार को गृह मंत्रालय के अपर

स्वतंत्रता दि

कालीन के अपशिष्ट से कंपोजिट मैटीरियल बनाया जाना उपलब्धि

यह भी पढ़ें

Lockdown India: शहरों से पलायन कर गांवों को लौटे लाखों लोगों को शरण नहीं दे रहे खुद अपने

डा. वर्मा द्वारा कालीन के अपशिष्ट से कंपोजिट मैटीरियल बनाया जाना उनकी ही नहीं बल्कि विश्वविद्यालय की बड़ी उपलब्धि है। मैं उन्हें इस सफलता के लिए बधाई देता हूं और शोध प्रक्रिया को आगे भी बढ़ाते रहने की शुभकामना देता हूं।

-प्रो. जेपी पांडेय, कुलपति, एमएमएमयूटी

पालीमर कंपोजिट बनाने के लिए अपनाई यह विधि

कालीन के अपशिष्ट से पालीमर कंपोजिट बनाने के लिए डा. वर्मा ने वैक्यूम असिस्टेड ट्रांसफर मोल्डिंग सेटअप का इस्तेमाल किया है। इस सेटअप में मौजूद एक डाई में वह कालीन का अपशिष्ट पूरी तरह सुखाकर डालते हैं और फिर वैक्यूम की स्थिति में पाइप के माध्यम से इपाक्सी रेजीन (एक तरह का लिक्विड पालीमर) और ट्रेटामाइन हार्डनर (पालीमर को मजबूती देने वाला केमिकल) का प्रवाह सुनिश्चित करते हैं। इससे कालीन का अपशिष्ट पालीमर कंपोजिट मैटीरियल में बदल जाता है। अपने शोध में उन्होंने नायलान, पालिस्टर, पालीप्रिपलीन और ऊन के इस्तेमाल से तैयार कालीन के अपशिष्ट से पालीमर कंपोजिट में बनाने में सफलता पाई है।

प्रदूषण की समस्या का भी रखा ध्यान

डा. वर्मा ने बताया कि गोरखपुर, वाराणसी और मिर्जापुर मंडल में कालीन उद्योग के अपशिष्ट निस्तारण में आ रही समस्या और उससे हो रहे पर्यावरण प्रदूषण ने उन्हें इस विषय पर शोध के लिए प्रेरित किया। इसके अलावा उनका ध्यान कालीन के इस्तेमाल की अवधि समाप्त हो जाने के बाद उसके निस्तारण में आ रही समस्या पर भी गया। खराब हो चुकी कालीन या तो जला दी जाती है या जल में प्रवाहित कर दी जाती है। निस्तारण के दोनों ही तरीके पर्यावरण के लिए नुकसानदायक है। कालीन जलाने से उसमें इस्तेमाल नायलान या पालिस्टर भी जलता है, जिससे वायु प्रदूषण होता है। जल में प्रवाहित करने से उसमें इस्तेमाल होने वाले केमिकल उसे प्रदूषित कर देते हैं। समस्या के निदान के लिए उन्होंने जैसे ही भारत सरकार के वस्त्र मंत्रालय के हस्तशिल्प विभाग को शोध प्रस्ताव भेजा, उसे तत्काल मंजूर कर लिया गया और धनराशि भी आवंटित कर दी गई। उस

अंतरराष्ट्रीय जर्नल में भी प्रकाशन

सेंट्रल इंस्टीट्यूट आफ प्लास्टिक इंजीनियरिंग एंड टेक्नालाजी लखनऊ और भारतीय प्रौद्योगिकी संस्थान (आइआइटी) रुड़की ने भी परीक्षण के बाद इस शोध पर मुहर लगा दी है। नीदरलैंड के रिसर्च जर्नल 'एल्सवीयर' के साथ ही चीन के रिसर्च जर्नल में भी इसके प्रकाशन से शोध को अंतरराष्ट्रीय मान्यता भी मिली है।

डा. राकेश राय, गोरखपुर। वह दिन दूर नहीं जब कालीन निर्माताओं को अपशिष्ट निस्तारण के लिए परेशान नहीं होना पड़ेगा। गोरखपुर के मदन मोहन मालवीय प्रौद्योगिकी विश्वविद्यालय के शोधार्थियों ने इसका हल निकाल लिया है। विश्वविद्यालय के मैकेनिकल इंजीनियरिंग विभाग के एसोसिएट प्रोफेसर डा. आरके वर्मा ने अपने शिष्यों के सहयोग से कालीन के अपशिष्ट से हल्के वजन का ऐसा पालीमर कंपोजिट मैटीरियल तैयार किया है, जिससे ताप व ध्वनिरोधी शीट्स और दीवारों पर लगाई जाने वाली टाइल्स बनाई जा सकती हैं।

जागरण विशेष

डा. राकेश राय • गोरखपुर

अब कालीन के अपशिष्ट से बनाई जा सकेंगी टाइल्स

एमएमएमयूटी, गोरखपुर के डा. आरके वर्मा के शोध पर आइआइटी रुड़की की मुहर, वायु व जल प्रदूषण में भी आएगी कमी

वह दिन दूर नहीं जब कालीन के अपशिष्ट के निस्तारण की समस्या समाप्त हो जाएगी। गोरखपुर के मदन मोहन मालवीय प्रौद्योगिकी विश्वविद्यालय के शोधार्थियों ने इसका हल निकाल लिया है। विश्वविद्यालय के मैकेनिकल इंजीनियरिंग विभाग के एसोसिएट प्रोफेसर डा. आरके वर्मा ने अपने शिष्यों के सहयोग से कालीन के अपशिष्ट से हल्के वजन का ऐसा पालीमर कंपोजिट मैटीरियल तैयार किया है, जिससे ताप व ध्वनिरोधी शीट्स और दीवारों पर लगाई जाने वाली टाइल्स बनाई जा सकती हैं।

अंतरराष्ट्रीय जर्नल में भी प्रकाशन: सेंट्रल इंस्टीट्यूट आफ प्लास्टिक इंजीनियरिंग एंड टेक्नोलाजी, लखनऊ और भारतीय प्रौद्योगिकी संस्थान (आइआइटी) रुड़की ने भी परीक्षण के बाद इस शोध पर मुहर लगा दी है। नीदरलैंड के रिसर्च जर्नल 'एल्सवीयर' के साथ ही चीन के रिसर्च जर्नल में भी इसके प्रकाशन से शोध को अंतरराष्ट्रीय मान्यता भी मिली है।

अपशिष्ट निस्तारण में आती समस्या: डा. वर्मा ने बताया कि गोरखपुर, वाराणसी और मिर्जापुर मंडल में कालीन उद्योग के अपशिष्ट निस्तारण में आ रही समस्या और उससे हो रहे प्रदूषण ने उन्हें इस विषय पर शोध के लिए प्रेरित किया। उनका ध्यान कालीन के इस्तेमाल की अवधि समाप्त हो जाने के बाद उसके निस्तारण पर भी गया। खराब हो चुकी कालीन या तो जला दी जाती है या जल में प्रवाहित कर दी जाती है। कालीन जलाने से उसमें इस्तेमाल नायलान या पालिस्टर भी जलता है, जिससे वायु प्रदूषण होता है। प्रवाहित करने से केमिकल जल को प्रदूषित करते हैं। उन्होंने भारत सरकार के वस्त्र मंत्रालय के हस्तशिल्प विभाग को शोध का प्रस्ताव भेजा, जिसे तत्काल मंजूर कर धनराशि आवंटित कर दी गई। धनराशि से वह अन्य शोधार्थियों संग शोध कार्य को एक निर्णायक मुकाम तक पहुंचा चुके हैं। डा. आरके वर्मा शोध के औद्योगिक इस्तेमाल के लिए इसे पेटेंट कराने की प्रक्रिया भी शुरू कर चुके हैं।

« वैक्यूम असिस्टेड ट्रांसफर मोल्डिंग सेटअप का प्रदर्शन करते डा. आरके वर्मा (बीच में) • जागरण

नैनोटेक्नोलाजी के इस्तेमाल से बढ़ाएंगे गुणवत्ता

इस शोध के अगले चरण में डा. वर्मा ने नैनोटेक्नोलाजी का इस्तेमाल कर कालीन के अपशिष्ट से तैयार पालीमर कंपोजिट की गुणवत्ता बढ़ाने की दिशा में कार्य शुरू कर दिया है। इसके लिए उन्होंने कंपोजिट के निर्माण में कार्बन नैनोटेक्नोलाजी, कार्बन नैनोशीट्स और ग्रेफीन आक्साइड के इस्तेमाल की योजना बनाई है।

डा. वर्मा द्वारा कालीन के अपशिष्ट से कंपोजिट मैटीरियल बनाया जाना बड़ी उपलब्धि है। मैं उन्हें बधाई देता हूं और शोध प्रक्रिया को आगे बढ़ाते रहने की शुभकामना देता हूं।

प्रो. जेपी पांडेय, कुलपति, एमएमएमयूटी

अपनाई यह विधि: कालीन के अपशिष्ट से पालीमर कंपोजिट बनाने के लिए डा. वर्मा ने वैक्यूम असिस्टेड ट्रांसफर मोल्डिंग सेटअप का इस्तेमाल किया। इसमें एक डाई में वह कालीन का अपशिष्ट पूरी तरह सुखाकर डालते हैं और फिर वैक्यूम की स्थिति में पाइप के माध्यम से इपाक्सी रेजीन (एक तरह का लिक्विड पालीमर) और टेट्रामाइन हार्डनर (पालीमर को मजबूती देने वाला केमिकल) का प्रवाह सुनिश्चित करते हैं। इससे कालीन का अपशिष्ट पालीमर कंपोजिट मैटीरियल में बदल जाता है।

इस खबर को विस्तार से पढ़ने के लिए स्कैन करें

Project work coverage from the National Hindi newspaper Dainik Jagran New Delhi Edition, Dated 20/08/2021

- **Patent Published from the Project Work**

(12) PATENT APPLICATION PUBLICATION | (21) Application No.202111032430 A

(19) INDIA

(22) Date of filing of Application :19/07/2021 | (43) Publication Date : 20/08/2021

(54) Title of the invention : METHOD OF FABRICATION OF A POLYMER COMPOSITE FROM POLYESTER CARPET

(51) International classification	:B32B0015092000, C08G0059500000, C08J0011060000, C08L0063000000, C08K0003040000
(31) Priority Document No	:NA
(32) Priority Date	:NA
(33) Name of priority country	:NA
(86) International Application No	:NA
Filing Date	:NA
(87) International Publication No	: NA
(61) Patent of Addition to Application Number	:NA
Filing Date	:NA
(62) Divisional to Application Number	:NA
Filing Date	:NA

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(57) Abstract :
The present disclosure relates generally to production of composites employing carpet waste. More specifically, the disclosure is directed to a method of fabrication of a polymer composite from waste polyester carpet and epoxy resin. The disclosure also provides a method of recycling polyester carpet and a polymer composite comprising an epoxy matrix and a polyester carpet. The polymer composite has improved tensile strength, tensile modulus, flexural modulus and flexural strength.

No. of Pages : 30 No. of Claims : 12

The Patent Office Journal No. 34/2021 Dated 20/08/2021 36702

Patent filed on the fabrication of composite material for this project

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Tarun-Khurana

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S.No	Form	Diary No.	Request No	Title	Amount (Rupees)
1	Form-XIV	11506/2021-CO/L	17330	Structural Composite Material Developed from discarded Carpet	500
Amount in Words			Rupees Five Hundreds		500

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