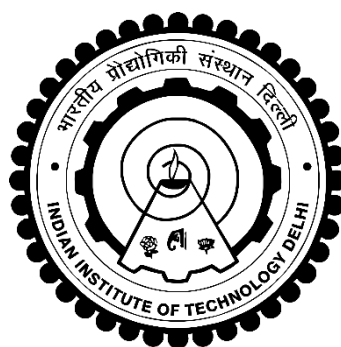


**STUDIES ON MECHANICAL AND ACOUSTIC
BEHAVIOUR OF COIR AND BANANA FIBRE
BASED HYBRID BIOCOMPOSITES**

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**DEPARTMENT OF TEXTILE AND FIBRE ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
MARCH 2020**

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by

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Department of Textile and Fibre Engineering

Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

MARCH 2020

.....dedicated to my beloved parents.

For their endless love, support and encouragement.

CERTIFICATE

This is to certify that the thesis titled “**Studies on mechanical and acoustic properties of coir and banana fibre based hybrid composite structures**”, being submitted by **Mr. Vikas Kumar Singh** to Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of bonafide research work carried out by the candidate in the Department of Textile and Fibre Engineering, IIT Delhi. He has worked under my guidance and supervision and fulfilled the requirements for the submission of thesis, which has attained the standard required for a PhD degree of this institute.

The research work carried out to complete the thesis has not been submitted for award of degree or diploma in any institute in part or full.

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Place: New Delhi

Date:

Acknowledgements

I can feel a sense of fulfilment and significance while writing the acknowledgement for my PhD tenure. It is the time when all the memories of my personal and research journey have come alive, something I was missing for past few months during thesis writing. I feel myself fortunate enough to come across people with high morals and integrity of character. I would like to express my gratitude to everyone who directly or indirectly helped me to evolve into a better researcher, and perhaps a better human being during the past few years.

First of all I would like to express my sincere gratitude to Dr. Samrat Mukhopadhyay, my mentor and supervisor since my master's degree. It is he who introduced me to the field of natural fibres and biocomposites. He has always motivated his students (including me) to make sincere efforts and work on relevant scientific problems, and I hope I haven't disappointed him. I am grateful for his constant motivation, discussions and support during the low phases of research journey. In person, he is a very compassionate human being and there is still a lot to learn from him in this regard.

I would like to thank SRC (Student research committee) members Prof. B. K. Behera (chairman), Prof. R. Alagirusamy and Prof. J. Jacob for critically analysing the research work presented in this thesis. Prof. Behera, also served as Head of department and deserves applause for equipping our department with various testing and characterization facilities for composite materials. I am very grateful to Dr. Kirti soni and Dr. Mahavir Singh from CSIR-National Physical Laboratory, New Delhi, who kindly granted access to their laboratory and acoustic testing facility, which contributed to a major portion of my research work. I would like to thank Mr. Nishant, senior research fellow and PhD scholar in the same lab, for helping me out and streamlining various activities during experimental work at CSIR-NPL.

I am very grateful to all faculty members of my department for providing all possible academic help, at various stages of my research work. I would extend my thanks to departmental staff for their cooperation. My friends Sajan Singh, Mohit Gupta, Vijay

Gaud, Vikas Khatkar, Bapan Adak and Rahul Gadkari from different laboratories across the department and institute, contributed to my research work in various ways. I express gratitude to IIT Delhi for providing infrastructure, Ministry of human resource development for financial assistance and people of my country for subsidised education, throughout my academic career.

It would be incomplete if I do not mention my friends. I am blessed to have a very cheerful friend circle that kept me away from isolation and overthinking. Even during the busiest schedules I could hang out with them and recharge myself for the battle ☺. It is not possible to mention all, but the moments shared with Chandra Jeet Singh, Dr. Taruna Bansala, Mukesh Kumar, Sandeep Tiwari, Durvijay Singh, Ashraf Nawaz, Ankur Shukla, Nagendra Jangra, Priyanka Gupta, Sanjay Panda, Prasun Mathur, Dr. Navdeep, Subha Sharma, Dr. N. Srikrishna, Sumit Tripathi, Neeraj Asthana, Dr. Anu Mishra, Labeesh, Sahil Saini, Utkarsh Solanki and many friends from AIIMS and SCIS, JNU are an integral part of my memories. I have been in touch with various doctoral candidates, research scholars and masters students, and tried to learn something from almost everyone. I would like to thank my labmates for helping me in formatting and editing the thesis.

My research journey couldn't have been that smooth had my family not encouraged me. Words are not enough to express my gratitude towards my **parents**, Mrs. Hemlata and Retd. Capt. Soran Singh, for their constant support and blessings. My elder brother and mentor since childhood, Dr. Vinod Kumar Singh, always used to discuss various philosophical and academic aspects of my academic and research work. My sister-in-law, Dr. Kavita Parihar was always there whenever I needed to discuss various topics during my PhD journey. I am grateful to all the members of my family for believing in my dreams and providing constant rock-steady support. Last but not the least, I am grateful to the almighty for blessing me and making me stronger with time.

New Delhi, India
March 2020

Vikas Kumar Singh

ABSTRACT

The quest for lighter and stronger materials led to introduction of fibre reinforced polymer composite materials in the field of material science. Polymer composites produced from synthetic materials do not degrade on disposal and pose a threat to environment in the longer run. Moreover, most synthetic polymers based composites are produced from petroleum which is depleting and will finish in future. Biocomposites have been explored by researchers to partially or fully replace synthetic fibre based polymer composites in various applications. Natural fibres are used instead of glass or other synthetic fibres in as reinforcement in composites due to several advantages like low density, low cost, availability, biodegradability, non-toxicity, high specific strength, non-abrasive nature, ease of processability, etc. Biocomposites have some inherent drawbacks such as poor interface with matrix, moisture sensitivity, etc., which limits their use in various applications. In order to overcome the inherent drawbacks of biocomposites, various physical and chemical treatments, and modifications in matrix or fibre surface have been proposed by researchers, which primarily improve interface between reinforcement and matrix. However, it is still a challenge to improve mechanical properties of biocomposites despite various efforts to improve interfacial adhesion. Another emerging approach to improve mechanical properties of biocomposites is hybridisation. Originally, hybridisation was introduced to synthetic fibre based polymer composites to reduce cost and introduce ductility, which helped in avoiding abrupt failures. Hybridisation in natural fibre based composites started lately. In recent years, studies on hybridisation in biocomposites have gained thrust and hybrid effect is utilised to achieve the desired enhancement in mechanical properties.

In the current study, hybridisation in biocomposites was studied by using coir and banana fibres as reinforcement in polypropylene matrix, and its effect on mechanical and acoustic properties was investigated. A series of hybrid and non-hybrid composites were produced from randomly oriented chopped coir and banana fibres in polypropylene matrix using compression moulding technique. Composites were fabricated at 5%, 10%, 15%, 20% and 25% fibre loading at banana to coir ratio of 1:0, 3:1, 1:1, 1:3 and 0:1. Tensile, impact, and flexural testing of samples was carried out according to ASTM D638, ASTM D256 and ASTM D790 standard test methods, respectively.

Further, hybrid effect in tensile strength, tensile modulus, flexural strength, flexural modulus, and impact energy of the composite samples was studied in detail. Experimental results for tensile properties were compared with predicted values from rule of hybrid mixture, series model, Hirsch model, and modified Halpin-Tsai model. The effect of hybridisation on pseudoductility was also investigated. Hybrid composites at different fibre ratios were compared with non-hybrid composites and the effect of fibre volume fraction, ratio of fibres and fibre dispersion was subsequently discussed. This study also found that positive or negative deviation in hybrid effect is a function of the total fibre loading as well as ratio of two fibres within composite samples.

As biocomposites have a strong potential in structural applications, the acoustic behavior is an important parameter to be investigated. Sound insulation of hybrid composites composed of banana:coir::1:1 and total fibre loading of 5%, 10%, 15%, 20% and 25% was determined. Impedance tube method (using four microphones) based on DIN EN ISO 717-1 standard test method was used to determine transmission loss through the samples, and results were compared to that of non-hybrid composites. Effect of hybridisation, volume

fraction, fibre dispersion, and various other factors on sound insulation of composite structures was investigated. For sound absorption applications, hybrid and non-hybrid fibrous beds were produced from coir and banana fibres at different areal density of 1500 gsm, 3000 gsm, and 4500 gsm. Two microphone method in impedance tube setup was used for studying sound absorption according to DIN EN ISO 10534 standard test method. The effect of various parameters affecting sound absorption of these fibrous beds were investigated and discussed in detail. Acoustic testing in both cases, was carried out in the frequency range of 150 Hz to 6600 Hz.

It was found that composite samples displayed better sound insulation but poor sound absorption. On the other hand, fibre beds performed well in sound absorption and poorly in sound insulation. Therefore we developed a unique fibrous structures having a gradient in compactness using banana and coir fibres. This structure was intended to fulfill the conflicting requirements of sound insulating materials and sound absorbing materials. A process was designed to create a structure with varying rigidity along the cross-section, i.e., compactness changes on moving from one face to the opposite face. These samples were fabricated at 1500 gsm, 3000 gsm and 4500 gsm and were tested under sound absorption and transmission mode in the impedance tube, as mentioned earlier. It was found that these structures performed notably well in sound absorption as well as sound insulation. The factors affecting acoustic property were also determined and compared to that of fibrous beds. The study also suggests ideal structures for various acoustic applications. It was interesting to see that samples with gradient compactness displayed maximum noise reduction coefficient (NRC) of 0.78 and transmission loss upto 23 dB.

Finally all important findings elucidated in the previous chapters have been summarised and future scope of the research work is suggested. The results presented as a part of this thesis are expected to be used in production of sustainable materials for a wide range of applications. Outcome of this work has a potential to contribute towards studies on other biodegradable fibres or fillers, and can be used for various types of cellulose based agricultural wastes.

सारांश

पदार्थ विज्ञान के क्षेत्र में हल्की व मजबूत पदार्थों की खोज के सन्दर्भ में रेशों द्वारा प्रबलित बहुलक सयुक्त पदार्थ का परिचय हुआ। कृत्रिम पदार्थों से निर्मित कोम्पोजिट का जल्द क्षय नहीं हो पाता। अतः वे दीर्घ काल में पर्यावरण के लिए हानिकारक होते हैं। इसके अलावा अधिकांश मानव निर्मित बहुलक आधारित कोम्पोजिट पेट्रोलियीयम से उत्पन्न होते हैं, जो घट रहे हैं और भविष्य में खत्म हो जाएँगे। शोधकर्ताओं के विभिन्न अनुप्रयोगों में आंशिक रूप से या पूरी तरह से कृत्रिम रेशों पर आधारित बहुलक कोम्पोजिट को बदलने के लिए जैवकोम्पोजिट पदार्थों का पता लगाया गया है। कम घनत्व, कम लागत, उपलब्धता, जैव-उपलब्धता, गैर-विषाक्तता, उच्च विशिष्ट शक्ति, गैर-अपघर्षक प्रकृति, प्रक्रियात्मकता में आसानी आदि जैसे कई लाभों के कारण कोम्पोजिट में सुदृढीकरण के रूप में प्राकृतिक रेशों का उपयोग किया जाता है। जैवकोम्पोजिट पदार्थों में कुछ अंतर्निहित कमियाँ हैं जैसे आव्यूह, नमी संवेदनशीलता, आदि के साथ खराब अंतरफलक, जो विभिन्न अनुप्रयोगों में उनके उपयोग को सीमित करता है। जैव रसायन के अंतर्निहित कमियों को दूर करने के लिए, शोधकर्ताओं द्वारा विभिन्न भौतिक और रासायनिक उपचारों और आव्यूह या रेशों सहित संशोधन प्रस्तावित किए गए हैं, जो मुख्य रूप से सुदृढीकरण और आव्यूह के बीच सामंजस्य में सुधार करते हैं। हालांकि, यह अभी भी एक चुनौती है कि उक्त तलों के बीच आसंजन को बेहतर बनाने के विभिन्न प्रयासों के बावजूद जैवकोम्पोजिट्स के यांत्रिक गुणों में सुधार हो। जैवकोम्पोजिट के यांत्रिक गुणों में सुधार के लिए एक और उभरता हुआ दृष्टिकोण है संकरण। मूल रूप से, कृत्रिम रेशों पर आधारित बहुलक कोम्पोजिट में संकरण को लागत कम करने और लचीलापन लाने के लिए पेश किया गया था, जो पदार्थों के अचानक विफलताओं से बचने में मदद करता था। प्राकृतिक रेशों पर आधारित कोम्पोजिट में संकरण हाल ही में शुरू हुआ। हाल के वर्षों में, जैवकोम्पोजिट में संकरण पर अध्ययन से जोर मिला है और यांत्रिक गुणों में वांछित वृद्धि प्राप्त करने के लिए संकरित प्रभाव का उपयोग किया जाता है।

वर्तमान अध्ययन में, पॉलीप्रोपाइलीन आव्यूह में सुदृढीकरण के लिए नारियल और केले के रेशों का उपयोग करके जैव रसायन में संकरण का अध्ययन किया गया था तथा यांत्रिक और ध्वनिक गुणों पर इसके प्रभाव की जांच की गई थी। संकरित और गैर-संकरित कोम्पोजिट की एक श्रृंखला को संपीड़न ढलाई तकनीक का उपयोग करके पॉलीप्रोपाइलीन आव्यूह

में बेतरतीब ढंग से उन्मुख कटा हुआ नारियल और केले के रेशो से उत्पादित किया गया था। इसे ५: १०%, १५%, २०% और २५% रेशों युक्त में १:०, ३:१, १:१, १:३ और ०:१ के अनुपात में तैयार किया गया। नमूनों की तन्यता, प्रभाव और वक्र सम्बन्धी परीक्षण क्रमशः ए.एस.टी.एम. डी ६३८, ए.एस.टी.एम. डी २५६ और ए.एस.टी.एम. डी ७९० मानक परीक्षण विधियों के अनुसार किए गए।

इसके अलावा, तन्य शक्ति, तन्य मापांक, लचीलापन शक्ति, लचीलापन मापांक, और समग्र नमूनों की प्रभाव ऊर्जा में संकर प्रभाव का विस्तार से अध्ययन किया गया। तन्य गुणों के लिए प्रायोगिक परिणामों की तुलना संकरित मिश्रण, श्रृंखला प्रतिरूप, हिर्श प्रतिरूप और संशोधित हलपीन-त्साई प्रतिरूप के नियम से अनुमानित मूल्यों के साथ की गई थी। छद्मता पर संकरण के प्रभाव की भी जांच की गई। रेशों के विभिन्न अनुपातों पर संकरित कोम्पोजिट की तुलना गैर- संकरित कोम्पोजिट के साथ की गई और रेशों के आयतन अंश के प्रभाव, रेशों और रेशों के फैलाव के अनुपात पर बाद में चर्चा की गई। इस अध्ययन में यह भी पाया गया है कि संकरित प्रभाव में सकारात्मक या नकारात्मक विचलन कुल रेशों के साथ-साथ समग्र नमूनों के भीतर दो रेशों के अनुपात का एक कार्य है। चूंकि जैवकोम्पोजिट्स में संरचनात्मक अनुप्रयोगों में एक मजबूत क्षमता है, इसलिए ध्वनिक व्यवहार की जांच करने के लिए एक महत्वपूर्ण मापांक है। केले से बना संकरित कोम्पोजिट का ध्वनि रोधन: नारियल ::१:१ और कुल रेशों युक्त ५%, १०%, १५%, २०% और २५% निर्धारित किया गया था। डीआईएन एन आईएसओ ७१७-१ मानक परीक्षण विधि पर आधारित प्रतिबाधा नलिका विधि (चार ध्वनिग्राही का उपयोग) का उपयोग नमूनों के माध्यम से संचरण हानि का निर्धारण करने के लिए किया गया था और परिणाम गैर-संकरित कोम्पोजिट की तुलना में थे। संकरित कोम्पोजिट के ध्वनि रोधन पर संकरण, आयतन अंश, रेशों के फैलाव और विभिन्न अन्य कारकों के प्रभाव की जांच की गई। ध्वनि अवशोषण अनुप्रयोगों के लिए, १५०० जीएसएम, ३००० जीएसएम और ४५०० जीएसएम के विभिन्न क्षेत्र घनत्व पर नारियल और केले के रेशों से संकरित और गैर- संकरित रेशोदार बेड का उत्पादन किया गया। प्रतिबाधा नलिका व्यवस्था में दो ध्वनिग्राही का उपयोग डी आई एन ई एन आई एस ओ १०५३४ मानक परीक्षण विधि के अनुसार ध्वनि अवशोषण के अध्ययन के लिए किया गया था। इन रेशोदार बेड के ध्वनि अवशोषण को प्रभावित करने वाले विभिन्न मापदंडों

के प्रभाव की जांच और विस्तार से चर्चा की गई। दोनों मामलों में ध्वनिक परीक्षण, १५० हर्ट्ज से ६६०० हर्ट्ज तक की आवृत्ति सीमा में किया गया था।

यह पाया गया कि समग्र नमूनों ने बेहतर ध्वनि रोधक दिखाया लेकिन खराब ध्वनि अवशोषण। दूसरी ओर, रेशेदार बेड ने ध्वनि अवशोषण में और खराब ध्वनि रोधन में अच्छा प्रदर्शन किया। इसलिए हमने केले और नारियल के रेशों का उपयोग करके सघनता में एक ढाल के साथ अद्वितीय रेशेदार संरचनाओं का विकास किया। इस संरचना का उद्देश्य ध्वनि रोधक पदार्थ और ध्वनि अवशोषित पदार्थ की परस्पर विरोधी आवश्यकताओं को पूरा करना था। अनुप्रस्थकाट के साथ अलग-अलग कठोरता के साथ एक संरचना बनाने के लिए एक प्रक्रिया तैयार की गई थी, अर्थात्, एक सतह से विपरीत सतह पर जाने पर सघनता में परिवर्तन होता है। इन नमूनों को १५०० जीएसएम, ३००० जीएसएम और ४५०० जीएसएम पर गढ़ा गया था और पहले बताए अनुसार प्रतिबाधा नलिका में ध्वनि अवशोषण और प्रसारण विधा के तहत परीक्षण किया गया था। यह पाया गया कि इन संरचनाओं ने ध्वनि अवशोषण के साथ-साथ ध्वनि रोधन में भी उल्लेखनीय प्रदर्शन किया। ध्वनिक बेड की तुलना में ध्वनिक संपत्ति को प्रभावित करने वाले कारक भी निर्धारित किए गए थे। अध्ययन विभिन्न ध्वनिक अनुप्रयोगों के लिए आदर्श संरचनाओं का भी सुझाव देता है। यह देखना दिलचस्प था कि क्षीण होती सघनता वाले नमूनों ने अधिकतम शोर में कमी ०.७८ (एन.आर.सी) और २३ डेसीबल तक ध्वनि के संचार में गिरावट को प्रदर्शित किया।

अंत में पिछले अध्यायों में वर्णित सभी महत्वपूर्ण निष्कर्षों को संक्षेप में प्रस्तुत किया गया है और भविष्य में शोध कार्य की गुंजाइश का सुझाव दिया गया है। इस शोध के एक भाग के रूप में प्रस्तुत किए गए परिणामों का उपयोग अनुप्रयोगों की एक विस्तृत श्रृंखला के लिए स्थायी पदार्थों के उत्पादन में किया जाता है। इस कार्य के परिणाम में अन्य जैवनिम्नरी रेशों पर अध्ययन की दिशा में योगदान करने की क्षमता है तथा इसका उपयोग विभिन्न प्रकार के कोशिका रश आधारित कृषि अपशिष्टों के लिए किया जा सकता है।

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