STUDY ON SOUND ABSORPTION OF NEEDLE-PUNCHED NONWOVENS

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Certificate

This is to certify that the thesis entitled "**Study on sound absorption of needle-punched nonwovens**" being submitted by **Mr. Ramamoorthy M**, to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy** in the Department of Textile Technology is a record of bonafide research work carried out by him. Mr. Ramamoorthy M has worked under my guidance and supervision and fulfilled the requirements for the submission of the thesis.

The results contained in the thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Abstract

The purpose of this research work is to study the acoustic performance of needle-punched nonwoven fabrics in order to better understand their acoustic behavior in relation to fibre and process parameters, web laying techniques, design of multi-layered composite nonwovens and incorporation of aerogels within them. This also aids in predicting the sound absorption coefficient (SAC) of nonwovens by different modeling approaches using appropriate parameters. The effect of fibre denier and its cross-sectional shape on the sound absorption of polyester needle-punched nonwovens has been investigated. Ideally, the nonwovens produced from 6-denier 4DG fibres should have shown higher SAC due to larger fibre surface area than the other fibres used in this study. But, interestingly, it has been observed that nonwoven produced from 2-denier trilobal fibres exhibited highest SAC followed by those produced from 2-denier round fibre, 6-denier fibres having 4DG, hollow and round cross-sections. Nonwovens produced from finer fibres have higher SAC. Finer fibres offer higher airflow resistance due to more number of fibres get aligned in z-direction of nonwoven fabric, thus forming tortuous channels for the encountering sound waves, consequently greater amount of sound waves get dampened in the fabric structure.

The interactive effects of depth of needle penetration and punch density employed during needling and areal density of nonwovens on properties of nonwovens such as thickness, bulk density, mean flow pore size and specific airflow resistance are reported. Then, the effect of these properties on sound absorption has also been analyzed. The depth of needle penetration predominantly affects the thickness and bulk density of nonwovens compared to punch density. Mean flow pore size in fabric considerably reduces while increasing the areal density of the web. The areal density further significantly affects the specific airflow resistance. It is found that there is a statistically good agreement between

the specific airflow resistance and average SAC (sound absorption coefficients) in terms of high coefficient of determination.

The importance of fibre orientation and its distribution in needle-punched nonwovens on acoustical performance has been investigated. This study has been carried out by varying the web laying techniques such as carded (parallel-laid and cross-laid) and air-laid (random-laid) webs. The type of webs affect pore size distribution and SAC of needle-punched nonwovens. Nonwoven produced from random-laid web exhibits highest SAC followed by the cross-laid and parallel-laid. The results further indicate that orientation of fibres in the nonwoven fabric is an important structural characteristic affecting sound absorption.

In the case of multi-layered nonwovens, the effects of denier and cross-sectional shape of the fibres, and layering sequence on sound absorption have been investigated using polyester fibres of different linear densities and cross-sectional shapes. The fibre webs were produced on a carding machine, each with 330 g/m^2 as a single layer and then three layered webs (1000 g/m^2) were needled. Among the multi-layered single-fibre nonwoven fabrics studied, nonwoven produced with 0.9-denier-solid (S/S/S) fibres exhibits highest average SAC followed by those produced from 2-denier-trilobal (T/T/T) fibres and 6-denier-hollow (H/H/H) fibres. The effect of layering sequence on SAC is analyzed. In order to achieve high SAC with multi-layered nonwovens, it is preferable to place the nonwovens such that its face layer having finer fibres must be closer to the sound source.

A study on sound absorption behavior of aerogel/PET fibre nonwoven composites having different amount of silica is reported. The silica content were varied during in-situ synthesis of silica aerogels in the nonwovens by changing their methanol (MeOH)/tetraethylorthosilicate (TEOS) molar ratio. The silica aerogel/PET nonwoven composites exhibit higher sound absorption compared to untreated PET nonwoven fabric for the entire 1/3rd octave frequency range of 50 to 6300 Hz. Moreover, it is found that silica content in the structure influences the sound absorption of composites i.e., higher the silica content, higher the sound absorption. Increasing the silica content in fabric reduces the mean flow pore size and increases the specific airflow resistance of materials; causing efficient damping of sound waves in the structure. The aerogel incorporated nonwoven composites achieved about 37% higher acoustic absorption than that of the untreated nonwovens. Hydrophilicity and hydrophobicity of aerogel nonwovens have also been investigated to explore their durability.

A comparative analysis of New Delany-Bazley (NDB) model, artificial neural network (ANN) model and regression model has been carried out to predict the SAC of nonwovens at 1/3rd octave intervals for the frequency range, 50 to 6300 Hz. The NDB model is derived from the well-known Delany-Bazley power law equations. The degree of prediction accuracy of SAC in terms of correlation coefficient, mean absolute percentage error and mean square error are observed to be the highest for ANN model, followed by NDB model and regression model. Sound frequency is found to be the foremost parameter affecting the SAC, followed by airflow resistivity of nonwoven fabric.

सारांश

इस शोध का उद्देश्य नीडल पंचेड़ नॉनवोवन कपडे का ध्वनिक प्रदर्शन पड़ना है। उसके अनुसार उनके ध्वनिक व्यवहार को बेहतर ढंग से समझने के लिए फाइबर और प्रक्रिया पैरामीटर, वेब बिछाने की तकनीक, बहु-स्तरित संमिश्र के डिजाइन नॉनवॉवेंस और उनके भीतर एरोजेलस का समावेश, यह उपयुक्त मापदंडों का उपयोग करते हुए विभिन्न मॉडलिंग दृष्टिकोणों द्वारा गैर-ध्वनियों के ध्वनि अवशोषण गुणांक (एसएसी) की भविष्यवाणी में भी सहायता करता है। पॉलिस्टर नॉनवॉवेन्स के ध्वनि अवशोषण पर फाइबर निषेध का प्रभाव और इसके पार-अनुभागीय आकार की जांच की गई है। आदर्श रूप से, इस अध्ययन में इस्तेमाल किए जाने वाले अन्य फाइबर की तुलना में, बड़े फाइबर सतह क्षेत्र की वजह से 6-डेनियर 4 डी.जी फाइबर से बने नॉनवॉवोन्स को उच्च एस.ए.सी. दिखाया जाना चाहिए। लेकिन दिलचस्प बात यह है कि, यह देखा गया है कि 2-डेनिअर ट्रिलोबल फाइबर से बने नॉनवोवन का उच्चतम एसएसी का प्रदर्शन किया गया है, जो 2-डेनिअर राउंड फाइबर, 4 डीजी, खोखले और गोल क्रॉस-सेक्शन वाले 6- डेनिअर फाइबर का उत्पादन करते हैं। पतले फाइबर से बने हुए नॉनवोवन का सएसी ज़्यादा है। पतले फाइबर उच्च वायुरोधी प्रतिरोध की पेशकश करते हैं क्योंकि अधिक संख्या में फाइबर को नॉनवोवन कपड़े में z-दिशा में गठबंधन मिलता है। इस तरह, ध्वनि लहरें एक धोखाधड़ी चैनल बनाने के लिए, परिणामस्वरूप, कपड़े की संरचना में अधिकतम ध्वनि की लहर घट जाती है।

नीडल पेनिट्रेशन की गहराई और पंच घनत्व कार्यरत नीडलिंग के दौरान और नॉनवॉवन्स का अवास्तविक घनत्व जैसे नॉनवॉवन्स के गुणधर्मोपर जैसे कि मोटाई, थोक घनत्व, माध्य पोर आकार और विशिष्ट एयरफ्लो प्रतिरोध की इंटरैक्टिव प्रभावसूचना दी जाती है। फिर, ध्वनि अवशोषण पर इन गुणों का प्रभाव का भी विश्लेषण किया गया है। पंच डेंसिटी की तुलनामे नीडल डेप्थ पेनिट्रेशन मुख्य रूप से नोवोवेन के मोटाई और थोक घनत्व को प्रभावित करती है। वेब के अनाल घनत्व में वृद्धि करते समय कपड़े में मीन प्रवाह का आकार कम हो जाता है। अखाड़ा घनत्व अधिक विशिष्ट वायुरोधी प्रतिरोध को प्रभावित करता है। यह पाया गया है कि विशिष्ट एयरफ्लो प्रतिरोध और औसत एसएसी के बीच एक सांख्यिकीय अच्छा समझौता है दृढ़ संकल्प के उच्च गुणांक के संदर्भ में।

ध्वनिक प्रदर्शन पर नीडल पंचेड़ नॉनवॉवंन्स में फाइबर अभिविन्यास और इसके वितरण के महत्व की जांच की गई है। इस अध्ययन को वेब बिछाने की तकनीक जैसे की कार्डिड (पैरेलल लेड और क्रॉस लेड) और एयर लेड (रैंडम लेड) वेब को बदलकर अलग किया गया है। वेब का प्रकार पोर साइज विचलन और नॉनवॉविन्स के एसएसी को प्रभावित करता है। रैंडम लेड से बनाया गया नॉन वोवन उच्चतम एसएसी दिखाते हैं उसके बाद क्रॉस लेड और पैरेलल लेड है। इसके परिणाम से आगे संकेत मिलता है कि नॉनवोवन कपड़े में तंतुओं के उन्मुखीकरण ध्वनि अवशोषण को प्रभावित करने वाली एक महत्वपूर्ण संरचनात्मक विशेषता है। बहु-स्तरित नॉनवॉवेंस के मामले में, फाइबर डेनियर और क्रॉस सेक्शन शेप का परिणाम और लेयरिंग अनुक्रम ध्वनि अवशोषण पर पॉलिएस्टर विभिन्न रैखिक घनत्व और पार अनुभागीय आकृतियों की जांच की गई है । फाइबर वेब कार्डिंग मशीन पर बनाया गया था,प्रत्येक में 330 ग्राम / मी^{2} को एक परत के रूप में और फिर तीन स्तरित वेब (1000 ग्राम /मी^{2}) नीडल किया गया । बहु-स्तरीय एकल-फाइबर नॉनव्यूवन वस्त्रों का अध्ययन में नॉनवॉवन 0.9-डीनिअर-सॉलिड (एस / एस / एस) फाइबर के साथ निर्मित नॉनवॉवन 0.9-डीनिअर-सॉलिड (एस / एस / एस) फाइबर के साथ निर्मित, उच्चतम औसत एसएसी प्रदर्शन करात है। इसके बाद 2-डेनिअर-ट्रिलोबल (टी / टी / टी) फाइबर और 6-डेनिअर-खोखले (एच / एच / एच) फाइबर। एसएसी पर लेयरिंग अनुक्रम का असर विश्लेषण किया गया है। बहु स्तरीय नॉनवॉवंन्स के साथ उच्च एसएसी प्राप्त करने के लिए, यह नॉनवॉवेंस को जगह देने के लिए बेहतर है जैसे कि उसके चेहरे की तरल परत वाले फाइबर को ध्वनि स्रोत के करीब होना चाहिए।

ध्वनि पर एक अध्ययन नॉनवोवन्स में सिलिका ऐरोजल के इन-सिट्री संश्लेषण के दौरान उनके मेथनॉल (मेओएच) / टेट्राथिलोर्लोसिलिसेट (टीओओएस) मूला अनुपात को बदलकर विविधता दी गई थी। सिलिका ऐरोजल / पीईटी नॉनवोवन कंपोजिट, 50 हर्ट्ज से लेकर 6300 हर्ट्ज तक की पूरी 1/3 राक्षसी आवृत्ति रेंज के लिए अनुपचारित पीईटी नॉनव्यूड कपड़े की तुलना में उच्च ध्वनि अवशोषण का प्रदर्शन करते हैं। ऐरोजल / पीईटी फाइबर के अवशोषण व्यवहार को अलग-अलग सिलिका युक्त नॉनवोवन कंपोजिट का पता चला है। इसके अलावा, यह पाया जाता है कि संरचना में सिलिका सामग्री कंपोजिटों के ध्वनि अवशोषण को प्रभावित करती है, अर्थात्, उच्च सिलिका सामग्री, उच्च ध्वनि अवशोषण। कपड़े में सिलिका सामग्री को बढ़ाने से मतलब फ्लो पोरस आकार कम होता है और सामग्री के विशिष्ट वायुरोधी प्रतिरोध को बढ़ाता है;

संरचना में ध्वनि तरंगों के कुशल भिगोना पैदा करने के कारण। ऐरोजल में नॉनवॉवन कम्पोजिट शामिल थे, जो कि अनुपचारित नॉनवॉवेन्स की तुलना में लगभग 37% अधिक ध्वनिक अवशोषण प्राप्त करते थे। ऐरोजल नॉनओवन्स की हाइड्रोफिलिसिटी और हाइड्रोफोबिसिटी भी उनकी स्थायित्व को तलाशने के लिए जांच की गई है।

न्यू डेली-बज़ली (एनडीबी) मॉडल, कृत्रिम तंत्रिका नेटवर्क (एएनएन) मॉडल और प्रतिगमन मॉडल का एक तुलनात्मक विश्लेषण किया गया है, जो आवृत्ति रेंज के लिए 1/3 आक्तेव अंतराल पर गैर-विवेन के एसएसी की भविष्यवाणी करने के लिए किया गया है, 50 से 6300 हर्ट्ज। एनडीबी मॉडल प्रसिद्ध डेली-बजेली बिजली कानून समीकरण से प्राप्त होता है। सहसंबंध गुणांक के संदर्भ में एसएसी की भविष्यवाणी की सटीकता की डिग्री, पूर्ण प्रतिशत त्रुटि और मतलब वर्ग त्रुटि एएनएन मॉडल के लिए सर्वोच्च माना जाता है, इसके बाद एनडीबी मॉडल और प्रतिगमन मॉडल का पालन किया जाता है। ध्वनि आवृत्ति एसएसी को प्रभावित करने वाले अग्रणी पैरामीटर के रूप में पाया जाता है, इसके बाद नॉनवॉवेन फैब्रिक की एयरफ्लो प्रतिरोधकता।

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