

INFLUENCE OF FIBRE ORIENTATION ON NEEDLE PUNCHED NONWOVEN PROPERTIES

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by

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Submitted

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



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Dedicated
to
My Parents & Sister

CERTIFICATE

This is to certify that the thesis entitled '**Influence of Fibre Orientation on Needle Punched Nonwoven Properties**', being submitted by **Mr. Rupayan Roy** to the 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 him. He has worked under my guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute. The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

The properties of nonwovens are primarily dependent on the constituent fibre characteristics and the structure of nonwovens which is manifested in a unique way by the manufacturing technology and their process parameters. Most of the researchers have focused their attention on the influences of needle penetration depth and punch density in needle punching process. Whereas, due attention was not given to carding process parameters and their influence on the properties of nonwoven fabric. However, it is a well-known fact that the mechanical and functional properties of nonwoven fabrics are highly influenced by the orientation of fibres before and after punching processes.

The present work deals with the influence of fibre orientation on needle punched nonwoven fabric. Modified tracer fibre technique was used to study the orientation of fibre in X, Y and Z direction of nonwoven layered structure. The tracer fibre technique and Lindsley's techniques were used to study the orientation of fibre in X and Y planes of the fabric. The tracer fibre path was tracked by placing a marked template having windows of defined area. The images of tracer fibres were captured and stitched using Nikon SMZ2500 microscope with NIS Elements software. Lindsley's cutting and combing method was used to measure the orientation of carded fibrous web (before punching). To analyze the vertical orientation (Z direction) of fibre in needled punched nonwoven fabric, the batts of different colours were produced separately. The batts placed in a specific order in layered structure were needle punched. The colour summarization technique was used to measure the percentage of fibre transfer of specific colour to bottom most grey layer due to punching process. Accordingly, new structural indices were proposed to measure the 3-dimensional orientation of fibre in nonwoven fabric before and after punching. The influence of carding and punching process parameters on structure and properties of nonwoven fabric was carried out. In order to understand the influence of carding and punching parameters on structure and properties of nonwoven fabric, optimisation of carding and punching parameters was carried out in three sets of experiments. In first set of experiments, the carding parameters i.e. feeder speed, cylinder speed and doffer speed were optimized at constant punching parameters. In second set of experiments, the punching parameters i.e. punch density, needle penetration depth and stroke frequency were optimized by using the optimized carding parameters of first set of experiments. In third set of experiments, carding parameters i.e. feeder speed, cylinder speed and doffer speed

and punching parameters i.e. punch density and needle penetration depth were simultaneously optimized. Box & Behnken's three factors three levels design was used for sample preparation of first two sets of experiments. But for third set of experiments, five factors three levels Box & Behnken experimental design was used for sample preparation. The physical, mechanical and functional properties of nonwoven fabrics like fabric thickness, tensile strength, air permeability, mean pore size, filtration efficiency and pressure drop were measured by using ASTM and BS standard. But in all three sets of experiments, structural studies were limited to X and Y direction of the fabrics. Further, an attempt has been made to evaluate the fibre orientation in Z direction influenced by punching parameters using multi-coloured batts in layered nonwoven structure. Three-factor three-level Box-Benkhen experimental design is used to conduct the study and punch density, needle penetration depth and stroke frequency are taken as variables. Lastly, an attempt has been made to take the benefit of the knowledge generated about the orientation of fibres in nonwoven fabric during this work. Accordingly, the three batts of different orientation of fibres obtained through optimisation of carding parameters were placed in different combination in layered structure and were punched using optimised punching parameters. Finally, influence of fibre orientation in layered structure on physical, mechanical and functional of nonwoven fabric was carried out.

The results confirmed that the proposed structural indices played a decisive role in studying the fibre orientation of nonwoven material in X and Y direction, before and after punching. A very strong correlation was observed between measured structural indices and respective properties. The proposed structural indices were highly influenced by considered carding parameters. The increase of all three carding parameters noticed an improvement in fibre orientation and depicted an increase in filtration efficiency and pressure drop, but inferred a reduction in bursting strength. But the results confirmed the disorientation of fibres in X and Y planes of the fabric, after needle punching operations. The improved carded web characteristics influenced by carding parameters significantly helped to minimise the structural changes, in nonwoven, after optimisation of punching parameters only. The retained fibre orientation, after punching, contributed towards reduced mean flow pore size and air permeability of nonwoven. Evidently, the filtration efficiency depicted an increase for all particle sizes, but with higher value of pressure drop. The results of simultaneous optimisation of carding and punching parameters have though revealed deterioration

in fibre orientation, however, reduction in filtration efficiency was noticed to be comparatively lower but significantly lower reduction in pressure drop was observed.

It was concluded that physical, mechanical and functional properties of nonwoven are very much dependent on proposed structural indices to study the vertical integration of fibres due to punching operation. The percentage of fibre transfer in Z direction is found to be maximum from first layer followed by 2nd and 3rd layers. Further, it was noticed that the mean flow pore size and air permeability followed an initial decrease then increase with the increase of punching parameters. However filtration efficiency and pressure drop confirmed an initial increase and then decrease with the increase of punching parameters. Further, mathematical models were developed, to predict the specific properties of nonwoven fabric considering measured structural indices, using nonlinear regression technique. The results confirmed that orientation of fibres in batts and their placement in layered structure played very crucial role in deciding the properties of nonwoven fabric. The fabric with inverse gradient structure having batts in increasing order of fibre orientation in layered structure provided very high (close to the highest) filter efficiency and very low (close to lowest) pressure drop instead of having higher (close to highest) mean flow pore size and air permeability. Finally, mechanics of needle punched nonwoven fabric structure was developed by utilising the information of present work.

सार

नॉनवॉवन के गुण मुख्य रूप से घटक फाइबर विशेषताओं और नॉनवॉवन की संरचना पर निर्भर करते हैं जो निर्माण तकनीक और उनकी प्रक्रिया मापदंडों द्वारा एक अद्वितीय तरीके से प्रकट होती है। सुई छिद्रण प्रक्रिया में सुई प्रवेश गहराई और पंच घनत्व के प्रभावों पर अधिकांश शोधकर्ताओं ने अपना ध्यान केंद्रित किया है। जबकि, गैर-बुने कपड़े के गुणों पर कार्डिंग प्रक्रिया के मापदंडों और उनके प्रभाव पर ध्यान नहीं दिया गया। हालांकि, यह एक सर्वविदित तथ्य है कि गैर-बुने वस्त्रों के यांत्रिक और कार्यात्मक गुण छिद्रण प्रक्रियाओं से पहले और बाद में फाइबर के उन्मुखीकरण से अत्यधिक प्रभावित होते हैं।

वर्तमान कार्य सुई छिद्रित गैर बुने कपड़े पर फाइबर अभिविन्यास के प्रभाव से संबंधित है। संशोधित ट्रेसर फाइबर तकनीक का उपयोग गैर-बुना स्तरित संरचना के एक्स, वाई और जेड दिशा में फाइबर के उन्मुखीकरण का अध्ययन करने के लिए किया गया था। ट्रेसर फाइबर तकनीक और लिंडस्ले तकनीक का उपयोग कपड़े के एक्स और वाई विमानों में फाइबर के उन्मुखीकरण का अध्ययन करने के लिए किया गया था। ट्रेसर फाइबर पथ को परिभाषित क्षेत्र की खिड़कियों वाले एक चिह्नित टेम्पलेट को रखकर उसका धावन पथ देखा गया था। ट्रेसर फाइबर की छवियों को एनआईएस एलिमेंट्स सॉफ्टवेयर के साथ निकॉन एसएमजेड २५०० माइक्रोस्कोप का उपयोग करके लिया गया और सिला गया। लिंडस्ले की कटिंग और कंधी करने की विधि का उपयोग कार्डेड रेशेदार वेब (छिद्रण से पहले) के उन्मुखीकरण को मापने के लिए किया गया था। सुइयों के छिद्रित गैर बुने कपड़े में फाइबर के ऊर्ध्वाधर अभिविन्यास (जेड दिशा) का विश्लेषण करने के लिए, अलग-अलग रंगों के बैट अलग-अलग उत्पादित किए गए थे। स्तरित संरचना में एक विशिष्ट क्रम में रखे गए बैट को सुई छिद्रित किया गया था। पंचिंग प्रक्रिया के कारण अधिकांश ग्रे लेयर के नीचे विशिष्ट रंग के फाइबर स्थानांतरण के प्रतिशत को मापने के लिए रंग संक्षेप तकनीक का उपयोग किया गया था। तदनुसार, नए संरचनात्मक सूचक को पंचिंग से पहले और बाद में नॉनवॉवन कपड़े में फाइबर के ३ -डाइमेंशनल ओरिएंटेशन को मापने का प्रस्ताव दिया गया था। नॉनवॉवन कपड़े की संरचना और गुणों पर कार्डिंग और पंचिंग प्रक्रिया के मापदंडों का प्रभाव था। गैर-बुने कपड़े की संरचना और गुणों पर कार्डिंग और पंचिंग मापदंडों के प्रभाव को समझने के लिए, प्रयोगों के तीन सेटों में कार्डिंग और पंचिंग मापदंडों का अनुकूलन किया गया था। प्रयोगों के पहले सेट में, कार्डिंग पैरामीटर यानी फीडर की गति, सिलेंडर की गति और डाफर की गति को लगातार छिद्रण मापदंडों पर अनुकूलित किया गया था। प्रयोगों के दूसरे सेट में, पंचिंग मापदंडों यानी पंच घनत्व, सुई प्रवेश गहराई और स्ट्रोक आवृत्ति को प्रयोगों के पहले सेट के अनुकूलित कार्डिंग मापदंडों का उपयोग करके अनुकूलित किया गया था। प्रयोगों के तीसरे सेट में, कार्डिंग पैरामीटर यानी फीडर गति, सिलेंडर गति और डाफर गति और पंचिंग पैरामीटर यानी पंच घनत्व और सुई प्रवेश गहराई को एक साथ अनुकूलित किया गया था। प्रयोग के पहले दो सेटों का नमूना तैयार करने के लिए बॉक्स और बेकन के तीन कारकों के तीन स्तर डिजाइन का उपयोग किया गया था। लेकिन प्रयोगों के तीसरे सेट के लिए, नमूना तैयार करने के लिए पांच कारकों तीन स्तरों बॉक्स और बेकन प्रयोगात्मक डिजाइन का उपयोग किया गया था। एएसटीएम और बीएस मानक का उपयोग करके कपड़े की मोटाई, तन्य शक्ति, वायु पारगम्यता, ताकना आकार, निस्पंदन दक्षता और दबाव गिरावट जैसे गैर-बुने वस्त्रों के भौतिक, यांत्रिक और कार्यात्मक गुणों को मापा गया। लेकिन प्रयोगों के सभी तीन सेटों में संरचनात्मक अध्ययन कपड़ों की एक्स और वाई दिशा तक सीमित थे। इसके अलावा, स्तरित नॉनवॉवन संरचना में बहु-रंग के

बैट्स का उपयोग करते हुए पंचिंग मापदंडों से प्रभावित जेड दिशा में फाइबर अभिविन्यास का मूल्यांकन करने का प्रयास किया गया है। तीन-कारक तीन-स्तरीय बॉक्स-बेनखेन प्रयोगात्मक डिजाइन का उपयोग अध्ययन और पंच घनत्व का संचालन करने के लिए किया जाता है, सुई प्रवेश गहराई और स्ट्रोक आवृत्ति को चर के रूप में लिया जाता है। अंत में, इस काम के दौरान गैर बुना हुआ कपड़े में फाइबर के उन्मुखीकरण के बारे में उत्पन्न ज्ञान का लाभ लेने का प्रयास किया गया है। तदनुसार, कार्डिंग मापदंडों के अनुकूलन के माध्यम से प्राप्त फाइबर के विभिन्न अभिविन्यास के तीन बैट्स को स्तरित संरचना में अलग-अलग संयोजन में रखा गया था और अनुकूलित छिद्रण मापदंडों का उपयोग करके छिद्रित किया गया था। अंत में, नॉनवॉवन कपड़े के भौतिक, यांत्रिक और कार्यात्मक पर स्तरित संरचना में फाइबर अभिविन्यास का प्रभाव बाहर किया गया था।

परिणामों की पुष्टि की कि प्रस्तावित संरचनात्मक सूचकांकों ने एक्स और वाई दिशा में नॉनवॉवन सामग्री के फाइबर अभिविन्यास का अध्ययन करने से पहले और छिद्रण के बाद निर्णायक भूमिका निभाई। मापा संरचनात्मक सूचकांकों और संबंधित गुणों के बीच एक बहुत मजबूत संबंध देखा गया। प्रस्तावित संरचनात्मक सूचकांक माना कार्डिंग मापदंडों से अत्यधिक प्रभावित थे। सभी तीन कार्डिंग मापदंडों की वृद्धि ने फाइबर अभिविन्यास में सुधार देखा और निस्पंदन दक्षता और दबाव गिरावट में वृद्धि को दर्शाया, लेकिन फटने की ताकत में कमी का अनुमान लगाया। परिणामों ने सुई छिद्रण संचालन के बाद, कपड़े के एक्स और वाई विमानों में तंतुओं के भटकाव की पुष्टि की। कार्डिंग मापदंडों से प्रभावित उन्नत कार्ड वेब विशेषताओं में केवल छिद्रण मापदंडों के अनुकूलन के बाद, नॉनवॉवन में संरचनात्मक परिवर्तनों को कम करने में काफी मदद मिली। छिद्रण के बाद बनाए रखा फाइबर अभिविन्यास, कम औसत छिद्र प्रवाह आकार और नॉनवॉवन की हवा पारगम्यता की दिशा में योगदान दिया। जाहिर है, निस्पंदन दक्षता ने सभी कण आकारों में वृद्धि का चित्रण किया, लेकिन दबाव गिरावट के उच्च मूल्य के साथ। कार्डिंग और पंचिंग मापदंडों के एक साथ अनुकूलन के परिणाम हालांकि फाइबर अभिविन्यास में गिरावट से पता चला है, हालांकि, निस्पंदन दक्षता में कमी को तुलनात्मक रूप से कम देखा गया था लेकिन दबाव गिरावट में काफी कम कमी देखी गई थी।

यह निष्कर्ष निकाला गया कि नॉनवॉवन के भौतिक, यांत्रिक और कार्यात्मक गुण छिद्रण ऑपरेशन के कारण तंतुओं के ऊर्ध्वाधर एकीकरण का अध्ययन करने के लिए प्रस्तावित संरचनात्मक सूचकांकों पर बहुत अधिक निर्भर हैं। जेड दिशा में फाइबर स्थानांतरण का प्रतिशत पहली परत से अधिकतम पाया जाता है और इसके बाद २ और ३ परतें होती हैं। इसके अलावा, यह देखा गया कि छिद्र प्रवाह का आकार और वायु पारगम्यता एक प्रारंभिक कमी के बाद फिर छिद्रण मापदंडों की वृद्धि के साथ बढ़ गई। हालांकि निस्पंदन दक्षता और दबाव गिरावट ने प्रारंभिक वृद्धि की पुष्टि की और फिर छिद्रण मापदंडों की वृद्धि के साथ कमी आई। इसके अलावा, गणितीय मॉडल विकसित किए गए थे, जो कि गैर-बुनेकपड़े के विशिष्ट गुणों का अनुमान लगाने के लिए, नॉनलाइन रिग्रेशन तकनीक का उपयोग करके मापा संरचनात्मक सूचकांकों पर विचार कर रहे थे। परिणामों ने पुष्टि की कि फाइबर के उन्मुखीकरण और स्तरित संरचना में उनके स्थानन ने नॉनवॉवन कपड़े के गुणों को तय करने में बहुत महत्वपूर्ण भूमिका निभाई। उलटी ढाल संरचना वाले कपड़े की स्तरित संरचना में जिसमें बैट्स फाइबर अभिविन्यास के बढ़ते क्रम में लगे होते हैं उनमें बहुत अधिक (उच्चतम के करीब) फिल्टर दक्षता और बहुत कम (सबसे कम के करीब) दबाव गिरावट पायी जाती है ना की उच्च (उच्चतम के करीब) औसत छिद्र प्रवाह आकार और हवा पारगम्यता। अंत में, गैर-बुने कपड़े की संरचना को वर्तमान कार्य की जानकारी का उपयोग करके विकसित किया गया था।

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