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Air permeability properties of thermal bonded nonwoven fabrics

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ABSTRACT

Nonwovens are materials that are permeable and are manufactured using methods different from the traditional methods of fabric manufacture. Nonwovens are characterised by high porosity and randomly laid fibres. They are also of low strength and there is need to impart strength to the fabrics by needle punching, thermal bonding and chemical bonding. During this thermal bonding or chemical bonding the fabrics may undergo structural changes and this may result in pore size and characteristics changing. In this research Nonwoven samples were made by carding polyester, polyvinyl alcohol and polypropylene fibres, to form a web of fibres before needle punching after which the fabrics underwent thermal bonding at temperatures of 150 R°C and 160 R°C. The time at which the samples were exposed to thermal energy (dwell time) was varied between 1 minute and 6 minutes. To analyse the effects of heat and time, air permeability and average pore size diagrams were used. Results showed a decrease in the air permeability with time as well as a decrease in the pore, after thermal bonding. Results also showed that the fabrics with the higher density generally had lower air permeability than those with lower density before and after thermal bonding.

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KEYWORDS

Pore size;
Air permeability;
Nonwoven;
Thermal bonding;
Needle punching;
Polyester fibres;
Polypropylene fibres;
Polyvinyl alcohol fibres.

INTRODUCTION

Nonwovens have been used in various applications be it industrial, home or medical fields, nonwovens have proved to be universal^[1,2]. Nonwovens are permeable fabrics that are characterised by randomly laid fibres that are bound together by various methods^[3]. The manufacturing methods of nonwovens means that the resultant structure is difficult to predict and is random unlike the other structures that are produced using the conventional methods, namely knitted and woven structures^[4-6].

The nonwoven structures will, at times depend-

ing on the end use, require methods of increasing their strength as the strength yield from combining fibres in to a fabric is usually low. To increase the strength of the nonwovens different methods are used and these may result in the alteration of the structure of the nonwoven fabric. The methods used to increase strength include needle punching, thermal bonding and chemical bonding^[7,8]. These methods increase strength by increasing the bonding between the fibres in the nonwoven fabric, be it mechanically or chemically. In this paper the structural change of the nonwoven fabric is investigated by analysing the air permeability and the pore sizes before and after ther-

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mal bonding the samples at different temperatures for varying periods of time. Furthermore the changes caused by these processes may affect the fibres' morphology and other properties of the fabric^[9-11]. Jubera R, Ridruejo A, González C and Llorca J^[11] note that the properties of a nonwoven fabric will be affected by the nature of bonds formed within the fabric. These changes could include porosity, fibre structure and the fabric structure. Chand S, Bhat GS, Spruiell JE and Malkan S^[8] reported a change in the fibre morphology during thermal bonding of fabrics made of polypropylene fibres.

The porosity of nonwovens becomes an important factor, when applications such as air, liquid or engine filtration polishing, medical, separation, resin impregnation, wetting and wicking and hygiene are considered^[4,12-17]. Patanaik^[18], reports that the porosity of materials will affect water permeability. A highly porous material will allow more liquid to go through as the material will have a number of channels through which the liquid can move, while a less porous material restricts the amount of liquid that can flow through the material. S. Lukic and Jovanić P^[19] found that the water permeability is related to the porosity of the samples. He states that the number of free pores in the samples should be sufficiently high for a sample to have high water permeability. Permeability of a material is determined by the fabric morphology where the fibre shape, dimensions, orientation and fibre distribution^[19,20]. Depending on the final shape of the fibres the pores may be constricted and this may lead to smaller sizes in the pore sizes. Densely distributed fibres will generally result in smaller pore sizes as there are more fibres per cross section, while low density fabrics will generally have larger pore sizes. Fibre distribution refers to the manner in which the fibres are laid out and if the fibres are randomly distributed it becomes difficult to predict the size of the pores. Hou X, Acar M and Silberschmidt VV^[21] in his study of thermally bonded nonwovens notes that, where fibres are randomly oriented, as in nonwovens, it is difficult to predict the properties and structures of nonwoven fabrics. In terms of fibre orientation, randomly oriented fibres will lead to unpredictable pore sizes, while well oriented fibres lead to predictable pore sizes. Generally where the fibres are well oriented, where the majority of fibres are in the same

direction, the fibres may be well packed and this in turn reduces the size of the pores.

SAMPLE PREPARATION

Polyvinylalcohol, polyester and polypropylene fibres were used to produce samples with different percentages of each type of fibre. In total, three different samples were manufactured each with different percentages of polypropylene and polyvinyl alcohol fibres. Three types of samples were used to make three different types of samples and furthermore the weight of the samples differed with one set of samples having a density of 500 g/m² and the other 300 g/m². To produce the actual samples, a carding machine was used to produce a web which was consolidated to form a thicker web before passing the sample through a pre-needling process for handling purposes. The resultant web was then superimposed until the required density was reached. After superimposing the nonwoven layers were then passed through the needle punching machine for the final needle punching stage. Each side was needle punched twice to further strengthen the samples. For the heat treatment stage samples were heated using a heat setting machine where the samples were heated for a period of between 1-6 minutes. One set of the samples was heated at a temperature of 150 R°C and the other heated at a temperature of 160 R°C.

MEASUREMENT OF AIR PERMEABILITY

If there are to be any pores that increase in size then there should be a concomitant increase in the air passing through the samples while closed pores would result in reduced air permeability. The air permeability was carried out according to the standard ASTM D 737 using the YG461/IE. The test was carried out to investigate the change in porosity of the fabric after the material had been thermally bonded. It was expected that the PP fibres will melt and form new bonds and possibly take up whole new dimensions, changing from a fibrous structure to a large mass material. The results obtained were given in cubic centimetres per second per unit area (cm³/s/cm²), while the pressure used was 125 Pa.

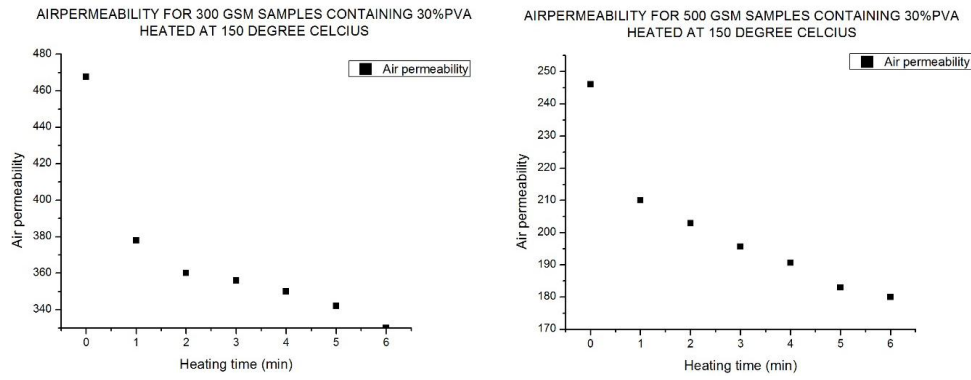


Figure 1 : Air permeability of fabrics containing 30% PVA heated at 150 °C

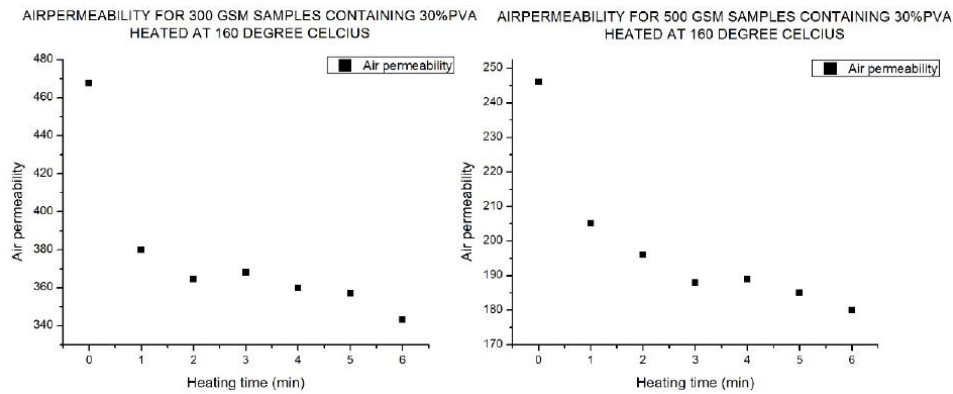


Figure 2 : Air permeability of fabrics containing 30% PVA heated at 160 °C

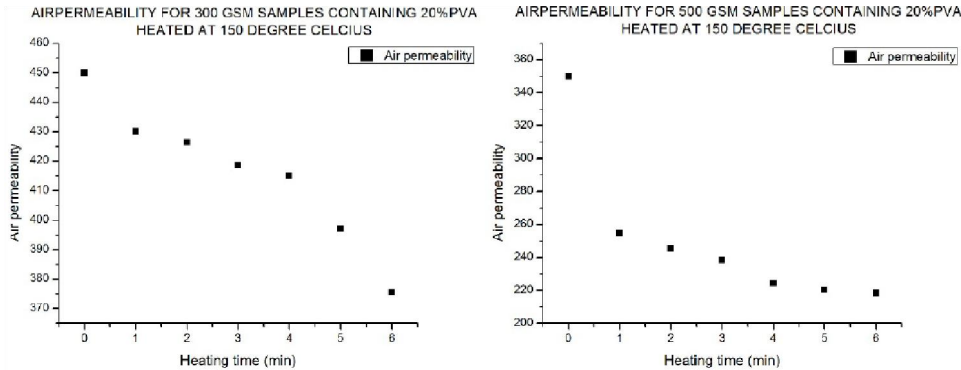


Figure 3 : Air permeability for fabrics containing 20% PVA heated at 150 °C

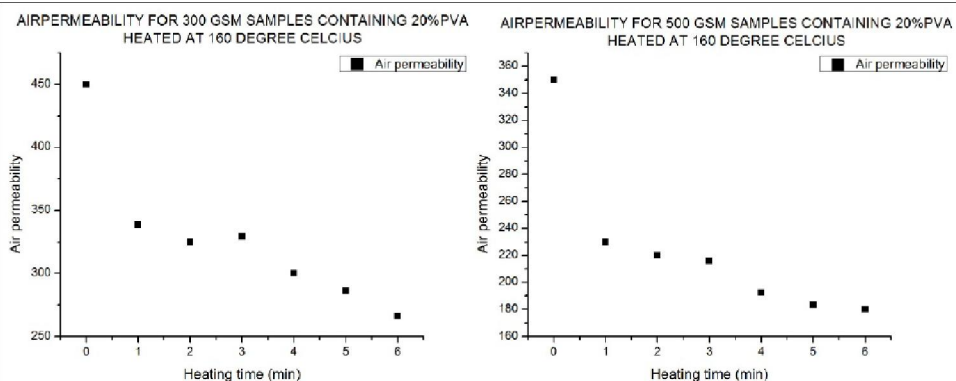


Figure 4 : Air permeability for fabrics containing 20% PVA heated at 160 °C

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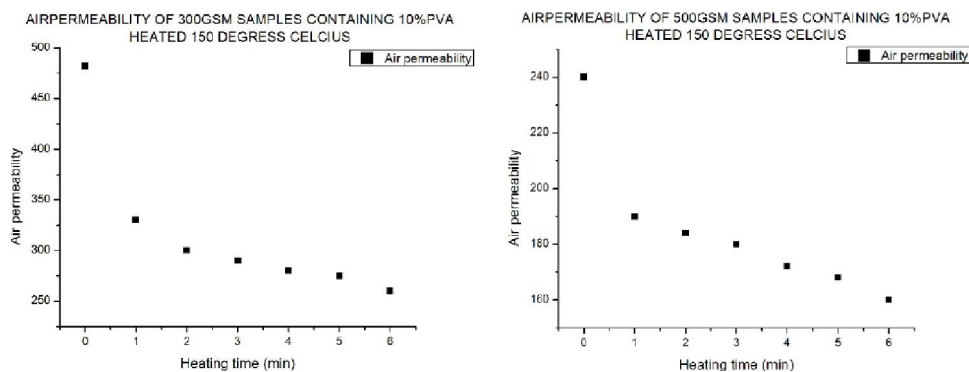


Figure 5 : Air permeability for samples containing 10% PVA heated at 150 °C

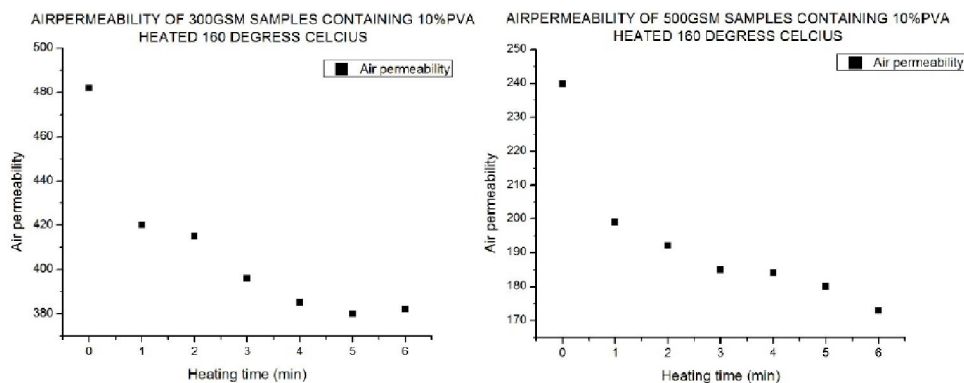


Figure 6 : Air permeability for samples containing 10% PVA heated at 160 °C

MEASUREMENT OF PORE SIZES

The size of the pores was determined using the Quantachrome Porometer 3G. Pore size results were given in μm while the machine gave the pore distribution as well. Similar to air permeability, the pore size tests were carried out to determine any changes in the pore size but unlike air permeability which gave results related to airflow, the pore size tests would give a much more precise analysis of changes within the nonwoven structure.

RESULTS AND DISCUSSION

Air permeability

Figures 1 to 6 show the results for the air permeability tests for the samples having an areal density of 300 g/m^2 and 500 g/m^2 with all the samples containing varying amounts of PVA and PP fibres.

Effect of areal density on the air permeability

From Figures 1 to 6 it can be seen that the air permeability of the 300 gsm samples was higher than

that of the 500 gsm samples. This can be explained by the fact that for the 300 gsm samples there were fewer fibres per unit area. The lower number of fibres per cross section meant that the air flow through the fabric was higher and resulted in higher readings on the machine. For the 500 gsm there were more fibres per unit cross sectional area hence there were lower readings for the air permeability tests.

Effect of temperature on air permeability

For all the samples, the air permeability of the samples was observed to have reduced after thermal bonding of the samples (see Figure 1 to 6). The reduction in the airpermeability was inversely proportional to the time of heating with lower airpermeability values being observed for the samples heated for 6 minutes for the 500 g/m^2 samples. This reduction was regardless of the temperature used for heating the fabrics. This reduction was due to the shrinkage in the structure due to the heating of the samples. During the experiment, samples were heated at $170 \text{ R}^\circ\text{C}$ but showed extreme shrinkage of samples, with some samples shrinking by more than 40 mm resulting in a more compactly

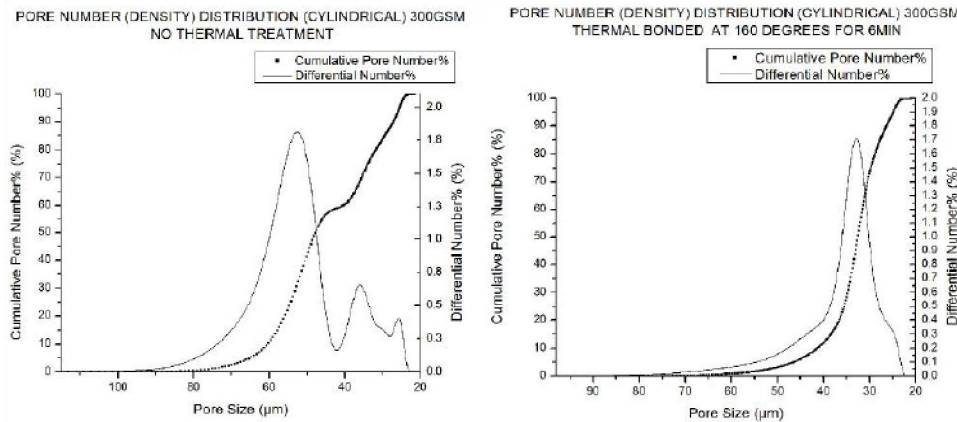


Figure 7 : Porosity for 300 g/m² samples containing 10% PVA thermal bonded at 160 °C

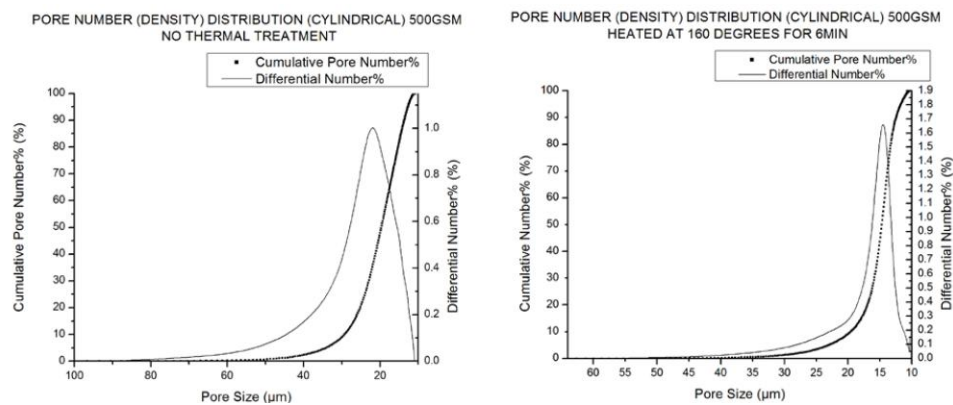


Figure 8 : Porosity for 500 g/m² samples containing 10% PVA thermal bonded at 160 °C

packed samples. The samples were thus excluded from the testing. One other explanation could be that the melting of the PP fibres when heat was applied resulting in a change in the internal structure of the fabric resulting in the change of pore sizes and subsequently the reduction in the air permeability values of the samples. The shrinkage in pore size is supported by the Figures 7 and 8. The 300 g/m² samples had the highest air permeability values compared to the 500 g/m² fabrics. Before any thermal bonding of samples could occur, the inherent increase in the number of fibres in the cross section for the 500 g/m² fabric, led to higher compactness for the 500 g/m² fabrics which led to the reduced air permeability in the 500 g/m² samples leading to reduced air permeability results. Further heating of the samples resulted in the melting of fibres within the samples leading to significant reduction in the air permeability. Apart from the melting of fibres, shrinkage of the polyester and PVA could have been experienced as PVA would have gone through the glass transition temperature at above 100 R°C.

Pore size

Effect of areal density on pore size

In relation to the density of the fabrics, the 300 g/m² fabrics had a larger average pore size compared to the 500 g/m² fabrics. From the graph the average pore size of the 50µm and 60µm, whereas the 500 g/m² samples had an average of between 20µm and 30µm.

Effect of temperature on pore size

Figures 8 and 9 show samples the average porosity of two samples namely the 300 g/m² and the 500 g/m² samples after heating. The results show that the mean pore size for the 300 g/m² (before) thermal bonding was 54.24 µm while for the 500 g/m² samples the mean pore size was 30.77µm. After thermal bonding the samples at 150 and 160 R°C, the mean pore decreased to 35.95µm and 19.3µm for the 300 g/m² and 500 g/m² respectively. The shrinkage of the samples can be explained by the shrinkage of the sample and the partial melting of

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the PP fibres in the fabric in the sample leading to clogging of the pores hence a reduced pore size. At above 140 R°C the melting process of the PP fibres began and the fibres began to lose their cylindrical shape. As the temperature of the fibres then reaches 160 R°C, the fibres are in almost a liquid state and can be shaped into any shape. As the heat is then removed the fibres do not take up the cylindrical shape but the shape acquired during the melting phase. The resulting shape of the fibres impedes the pores in the fabric leading to reduced pore size. Furthermore the shrinkage experienced by the whole fabric structure leads to a further reduction in the pore size. Wang^[22] reports that fibres will shrink during thermal bonding resulting in the shrinkage in the reduction in the size of the fabrics.

REFERENCES

- [1] D.Das; 5 - Composite nonwovens in absorbent hygiene products. In: Composite Non-Woven Materials, Edited by Das D, Pourdeyhimi B: Woodhead Publishing, 74-88 (2014).
- [2] A.Rawal, A.Priyadarshi, S.Lomov, I.Verpoest, J.Vankerrebrouck; Tensile behaviour of thermally bonded nonwoven structures: model description. *J Mater Sci.*, **45(9)**, 2274-2284 (2010).
- [3] A.Rawal, S.Agrahari; Pore size characteristics of nonwoven structures under uniaxial tensile loading, *J Mater Sci.*, **46(13)**, 4487-4493 (2011).
- [4] A.Rawal; Structural analysis of pore size distribution of nonwovens †, *The Journal of The Textile Institute*, **101(4)**, 350-359 (2010).
- [5] N.Mao, S.J.Russell, B.Pourdeyhimi, S.J.Russell; Handbook of nonwovens (2007).
- [6] D.Hussain, F.Loyal, A.Greiner, J.H.Wendorff; Structure property correlations for electrospun nanofiber nonwovens, *Polymer*, **51(17)**, 3989-3997 (2010).
- [7] S.S.Ramkumar, A.S.Umrani, D.C.Shelly, R.W.Tock, S.Parameswaran, M.L.Smith; Study of the effect of sliding velocity on the frictional properties of nonwoven fabric substrates, *Wear*, **256(3-4)**, 221-225 (2004).
- [8] S.Chand, G.S.Bhat, J.E.Spruiell, S.Malkan; Structure and properties of polypropylene fibers during thermal bonding, *Thermochimica Acta*, **367-368(0)**, 155-160 (2001).
- [9] S.Chand, G.S.Bhat; Role of fiber morphology in thermal bonding, *International Nonwoven Journal*, **9** (2002).
- [10] G.S.Gupta, D.K.Smith; Chapter X Nonwovens in absorbent materials. In: *Textile Science and Technology*, Edited by Chatterjee PK, Gupta BS, **13**, Elsevier, 349-388 (2002).
- [11] R.Jubera, A.Ridruejo, C.González, J.Llorca; Mechanical behavior and deformation micromechanisms of polypropylene nonwoven fabrics as a function of temperature and strain rate, *Mechanics of Materials*, **74(0)**, 14-25 (2014).
- [12] James DBN, DE, US), Sanford-crane, Henry (Elkton, MD, US), Dual-pore structure polishing pad, In: *United States: Rohm and Haas Electronic Materials CMP Holdings, Inc. (Newark, DE, US)* (2012).
- [13] JI.ourmals, DN, Steady flow of a viscous fluid through a saturated porous medium of a finite thickness, the bottom of which is impermeable and thermally insulated while the other side is stress free, kept at a constant temperature.
- [14] A.Rawal, H.Saraswat; Stabilisation of soil using hybrid needlepunched nonwoven geotextiles, *Geotextiles and Geomembranes*, **29(2)**, 197-200 (2011).
- [15] X.L.Jin, L.C.Zhang; A statistical model for material removal prediction in polishing, *Wear*, **274-275(0)**, 203-211 (2012).
- [16] C.L.Pai, M.C.Boyce, G.C.Rutledge; On the importance of fiber curvature to the elastic moduli of electrospun nonwoven fiber meshes, *Polymer*, **52(26)**, 6126-6133 (2011).
- [17] A.Mukhopadhyay; 8 - Composite nonwovens in filters: applications, In: *Composite Non-Woven Materials*, Edited by Das D, Pourdeyhimi B: Woodhead Publishing, 164-210 (2014).
- [18] R.D.A.Asis Patanaik; Water Flow Through the Polypropylene-Based Geotextiles, *Journal of Applied Polymer Science*, **(108)**, 3876-3880 (2008).
- [19] S.Lukić, P.Jovanić; Structural analysis of abrasive composite materials with nonwoven textile matrix, *Materials Letters*, **58(3-4)**, 439-443 (2004).
- [20] PB.L.Rahul Vallabh; Abdel-Fattah Seyam New Approach for Determining Tortuosity in Fibrous Porous Media, *Journal of Engineered Fibers and Fabrics*, **5(3)** (2010).
- [21] X.Hou, M.Acar, V.V.Silberschmidt; 2D finite element analysis of thermally bonded nonwoven materials: Continuous and discontinuous models, *Computational Materials Science*, **46(3)**, 700-707 (2009).
- [22] X.Y.Wang, R.H.Gong, Z.Dong, I.Porat; Abrasion resistance of thermally bonded 3D nonwoven fabrics, *Wear*, **262(3-4)**, 424-431 (2007).