(REFEREED RESEARCH)

NONDESTRUCTIVE PREDICTION OF AREAL WEIGHT, GRAB TENSILE STRENGTH AND ELONGATION AT BREAK OF POLYPROPYLENE (PP) SPUNBOND NONWOVEN FABRICS USING DIGITAL IMAGE ANALYSIS

POLİPROPİLEN (PP) SPUNBOND DOKUNMAMIŞ KUMAŞLARIN ALANSAL AĞIRLIK, ÇEKME MUKAVEMETİ VE KOPMA UZAMASI ÖZELLİKLERİNİN GÖRÜNTÜ İŞLEME YÖNTEMİ KULLANILARAK HASARSIZ TESPİTİ

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ABSTRACT

Digital image analysis is widely used in textile applications including fabric pilling behavior of nonwovens and defect detections in woven and knitted fabrics to predict some properties and online control of the quality of nonwoven materials. The estimation of fabric weight using digital image analysis is well established in the literature. But little information could be found about the estimation of grab tensile strength and elongation at break using digital image analysis. This paper investigates the estimation of weight, tensile strength and elongation at break values of polypropylene (PP) spunbond nonwoven fabrics at various weights (12g/m2, 20g/m2, 25g/m2, 30g/m2, 50g/m2) using digital image analysis. The relationships between the experimentally measured material properties and statistical parameters computed using digital image analysis is introduced. With the help of the correlations provided in this article, PP spunbond fabric production companies, which do not have tensile testing device, could roughly estimate the grab tensile strength and elongation at break values of the PP fabrics.

Keywords: Industrial textiles; Industrial fabrics; Technical nonwoven fabrics; spunbonding; Strength; Testing; Image Processing

ÖZET

Görüntü İşleme Yöntemi, dokunmamış kumaşların boncuklaşma eğilimi ve dokuma ve örme kumaşlarda hasar tespiti gibi tekstil uygulamalarında yaygın olarak kullanılmaktadır. Görüntü işleme yöntemi ile kumaş ağırlığının tahmin edilmesi ile ilgili literatürde birçok çalışma bulunmaktadır. Fakat görüntü işleme yöntemi kullanılarak çekme mukavemeti ve kopma uzamasının kumaşlarda tahmini konusu çok az sayıda makalede işlenmiştir. Bu makalede, farklı ağırlıktaki polipropilen spunbond dokunmamış kumaşların (12g/m2, 20g/m2, 25g/m2, 30g/m2, 50g/m2) ağırlık, çekme mukavemeti ve kopma uzaması özelliklerinin görüntü işleme yöntemi ile tahmin edilmesi incelenmektedir. Deneysel sonuçlar ile makalede önerilen istatistiksel yöntemle tahmin edilen kumaş özellikleri karşılaştırılacaktır. Bu makalede incelenen bağıntılar yardımıyla, çekme mukavemeti cihazına sahip olmayan polipropilen spunbond dokunmamış kumaş üretim fabrikaları üretim sırasında kumaşların çekme mukavemetlerini ve kopma uzamalarını tahmin edebileceklerdir.

Anahtar Kelimeler: Endüstriyel tekstiller, endüstriyel kumaşlar, teknik dokunmamış kumaşlar, mukavemet, spunbond üretim yöntemi, test metodları; görüntü işleme

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1. INTRODUCTION

Importance of polypropylene (PP) nonwoven fabrics in textile industry has increased in recent years. The technical developments in polymers and fiber technology have led to improvements in physical, mechanical, thermal and sound properties of nonwoven fabrics [1, 2]. Nonwovens are used in different industrial applications ranging from baby diapers to packaging, furniture, household, automobile, and airplane accessories. Spunbonding process is one of the most important and widely used processes in PP nonwoven sheet production since it provides considerable cost advantage for mass production. Determination of the properties of nonwoven fabrics plays a critical role in widespread use of PP spunbond nonwoven fabrics in new applications. Recently, digital image analysis for evaluation of the fabric properties of nonwoven fabrics has become more popular in research since the fabric is not destructed during the testing of the fabric.

Digital image analysis is widely used in textile applications including fabric pilling behavior [3-5], defect detections and intra yarn porosity in woven and knitted fabrics [6-7]. Turan et al. [8] predicted the intra-yarn porosity of the woven fabrics by using image analysis method. Jeong et al. [9] established a system that can find the woven fabric defects by image analysis and Fuzzy Rule Generation. Moreover, weight, pore and fiber orientation characteristics of nonwoven fabrics have been investigated by using digital image analysis. Zhang et al. [10] measured the diameter of fibers of melt-blown nonwoven fabrics by using the image analysis technique. Likewise fiber diameter, fiber orientation is also an important parameter for spunbond nonwoven fabric since it affects the isotropy of the fabric and digital image analysis was used for the estimation of fiber orientation [11-13]. Porosity and weight estimation of the nonwoven fabrics using digital image analysis are also studied [14, 15]. Lien and Liu [16] calculated the spunbond fabric weight during the production by combining the exponential law of absorption and image processing technique.

In addition to studies regarding the fabric weight, fiber orientation and porosity properties, studies on the tensile properties and failure mechanism of spunbond nonwoven fabrics are also found extensively in literature. Wang et al. [17] investigated the failure mechanisms of the PP/PE core/sheath bicomponent and PP spunbond fabrics under uniaxial loading conditions by using the micro images taken during the tensile test. Rawal et al. [18] studied tensile strength of thermal bonded nonwoven fabrics at 5 different fabric directions. Kim et al. [19] emphasized the importance of affect of melted points of the spunbond nonwovens on the tensile behavior and studied the failure mechanism of point-bonded nonwoven fabrics. Liao and Adanur [20] estimated the fabric failure of spunbond nonwoven fabrics based on the fiber failure.

None of the above mentioned studies directly used digital image analysis for tensile strength prediction of the PP spunbond nonwoven fabrics. This paper investigates the estimation of grab tensile strength and elongation at break values using digital image processing by introducing relationships between experimentally measured macro properties of PP spunbond nonwoven fabric with statistical parameters obtained using the image analysis. The weight of the PP spunbond nonwoven fabric could be estimated using image analysis so several research studies could be found in the literature. On the other hand, studying the strength and the elongation properties of these fabrics is more complex because many structural parameters affect these properties. These structural parameters could be divided into two main categories; fiber properties and fabric properties. In terms of fiber properties, spunbonding process is used to produce PP fibers for all the samples that are investigated in this research. The diameter and the shape of the fiber are taken as same for all samples used in this study because in spunbonding, round fibers are spun using same size holes in spinnerets. In terms of bonding properties, the same cylinders and the same production parameters in calendaring are used for all the samples. All the samples have ellipse-bonding shape. Fiber orientation is also very similar.

2. MATERIALS & METHODS

2.1 Materials

Different weights of 100% PP spunbond fabric samples ($12g/m^2$, $20g/m^2$, $25g/m^2$, $30g/m^2$, and $50g/m^2$) are used in this study. Samples having weights higher than $50g/m^2$ are not studied in this article because in spunbonding technology, fibers are pushed through the spinneret holes and then are drawn and fall on the conveyor belt randomly. If the conveyor belt speed is low, more fibers fall on the conveyor belt. This results in a thicker nonwoven web with high weight. When the speed of conveyor belt is increased, the weight of the spunbond fabric decreases. As more fibers fall on the conveyor belt, there is more possibility to fill the weak regions of the fabric with fibers. Therefore when the weight increases, the weaker points in the fabric disappear and therefore fabric becomes more uniform. In addition, the weak points and nonuniformities in nonwovens having weights more than $50g/m^2$ do not play a critical role in industrial applications. All PP spunbond fabrics were provided by Bayteks Textile Company in Gaziantep, Turkey.

2.2 Experimental Strength and Elongation at Break Measurements

The grab tensile strength and elongation at break properties of PP spunbond nonwoven fabrics are measured in the machine direction according to the ASTM D-5034 standard using the INSTRON 5944 tester located at Fiber Production Center, Zirve University at laboratory conditions (i.e. 20 ± 2˚C and 50% humidity). Ten samples from each type of fabric are tested and the averages are taken. The specimen size is taken as 15cmx10cm and the grip size is taken as 5cm on both sides of the test area.

2.3 Digital Image Processing

The physical and mechanical properties of the nonwovens are directly related to the unevenness of nonwoven fabrics. In this article, the unevenness of the nonwoven fabrics is computed using software-based digital image analysis. For digital image analysis, first of all, spunbond nonwoven specimens with dimensions of 15cm x 10cm are cut out from the nonwoven rolls, which have the various areal weights ($12g/m^2$, $20g/m^2$, $25g/m^2$, $30g/m^2$, $50g/m^2$). Then the specimens are scanned with HP Office Jet 4500 scanner at 2400x2400 dpi perpendicular to the specimen surface at laboratory conditions (i.e. 20 ± 2˚C and 50% humidity). For taking images by a scanner, all the pictures are taken under same scanner light conditions. The nonwoven fabrics that are used in this research are produced from polypropylene, which has zero percent moisture intake. Therefore, these nonwovens fabrics will not be affected by any environmental conditions unless the temperature is more than 70 ˚C.

In literature, images from microscopes were used for the image processing [21-23]. The main reason why scanning was preferred in this study is that, the dimensions of the images taken by microscopes are not large enough (maybe maximum 5mm x 5mm) to make a relationship between the image processing parameters and the macroscale properties of the overall spunbond nonwoven fabrics. Moreover, since the total area, which is loaded during tensile test has to be statistically analyzed completely using the digital image analysis; the nonwoven fabric images were obtained by scanning at high resolution. Attention was paid to eliminate the wrinkling of the nonwoven during the image processing.

During the scanning, a thin black paperboard is placed at the back of the nonwoven fabric. Therefore, black regions of the digital image represent the voids between the fibers and white regions represent the existence of fibers. As a result, as the color reaches to white, more fibers exist at the corresponding position. From each type of sample, ten specimens were used for image processing and mechanical testing. Fig. 1 shows the scanned and investigated images of a spunbond nonwoven fabric.

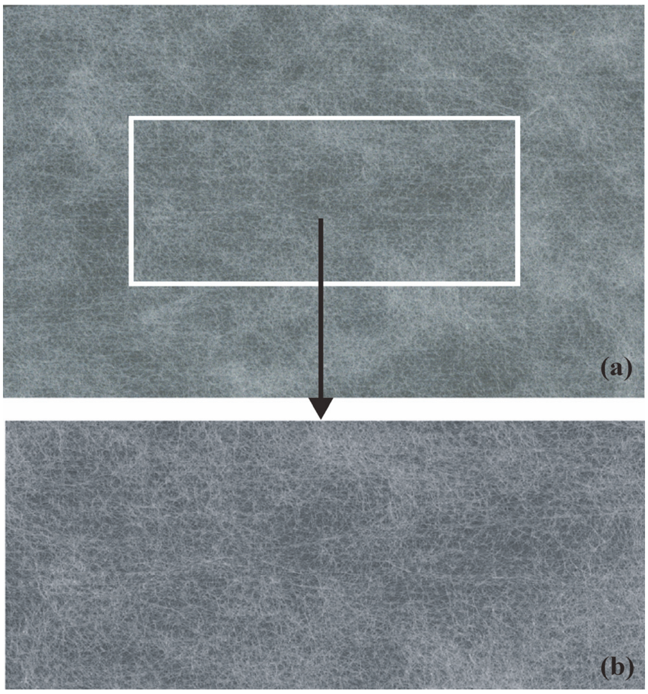

Figure 1: (a) Scanned image of a 12g/m^2 nonwoven specimen (b) Investigated area; magnified image of the area bounded by rectangle in (a)

According to ASTM D-5034 standard, the specimen size is chosen as 15cmx10cm and the area in the middle of the scanned image with dimensions of 4cm x 9cm is analyzed using digital image analysis. In Fig. 1(b), the investigated area of the specimen is given. The investigated region of the image has 1288x586 pixels. New code was written for digital image processing using MATLAB. As the code recognizes the image, the true color image is converted to grayscale intensity image by eliminating the hue and saturation information while retaining the luminance. Then Gaussian low pas filter is used. After these processes, each pixel takes a value between 0 and 1 where, 0 (zero) means black color and 1 (one) means white color. The surface irregularity is measured by using so-called quadrat method [22]**,** where the image is divided into square net of cells named quadrat. In this study, 8x8 quadrats are used and the value of the quadrat represents the mean grey level of the corresponding 8x8 pixels. In Fig. 2, the pixel/quadrat numbers are given before and after applying the quadrat method.

After the quadrat method is applied, an array q_{ij}, which contains mean grey levels, is obtained with the dimensions of 161x71. In the image, Machine Direction (MD) is the *x*-direction and Transverse Direction (TD) is the *y*-direction. There are N quadrats in MD and M quadrats in TD (see Fig. 3).

Using the q_{ij} array, statistical parameters such as mean ($\overline{q}$), variance ($Var(q)$) and coefficient of variation (C_v) are calculated by using the following formulations.

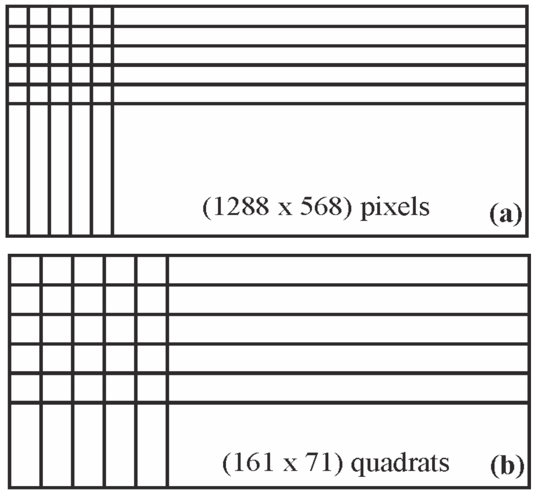

Figure 2. The pixel/quadrat numbers (a) before (b) after application of quadrat method on the image

$$\overline{q} = \frac{\sum_{1}^{N}\sum_{1}^{M} q_{ij}}{M\,N}$$

$$Var(q) = \frac{\sum_{1}^{N}\sum_{1}^{M} \left(q_{ij} - \overline{q}\right)^2}{M\,N} \qquad (1)$$

$$C_v = \frac{\sqrt{Var(q)}}{\overline{q}}$$

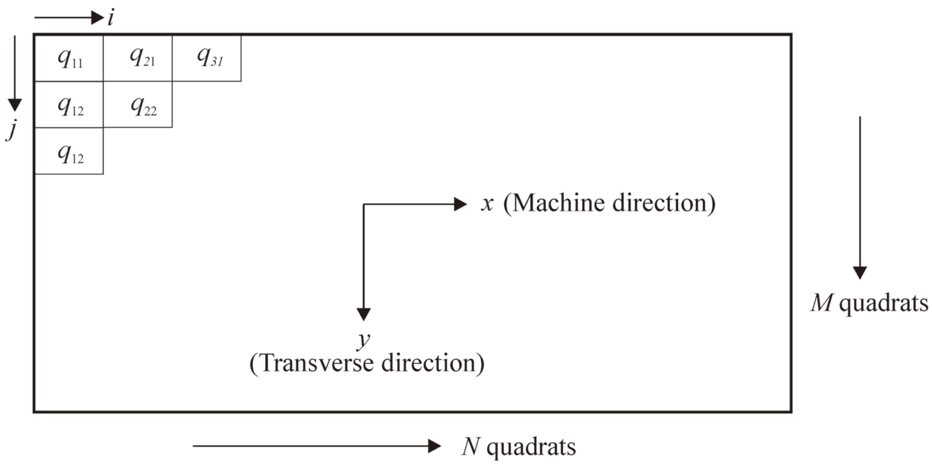

Figure 3. Mean grey level array of the image after applying quadrat method

The uniformity of the PP spunbond nonwoven fabric can be represented by the coefficient of variation (C_v). C_v is defined as the ratio of the standard deviation to the mean value and its main advantage is that it does not have a unit.

In this research, the mean value of the grey scale gives information about the weight of the spunbond fabric. As the mean value reaches to 1 (white), it means that the weight of the fabric is increasing. The coefficient of variation represents the extent of variability of grey level of quadrats in relation to the mean grey level and therefore describes the surface uniformity and unevenness [21].

Another parameter that can be used for understanding the uniformity of the mass distribution of spunbond fabric is the index of dispersion (I_d) or variance-to-mean ratio (VMR) [30-32]. Index of dispersion (I_d) is by using the following equation:

$$I_d = \frac{Var(q)}{\bar{q}} \quad (2)$$

A decrease in the index of dispersion shows that the image becomes more uniform. In other words, a higher index of dispersion for the same mean represents that the variation is higher and therefore uniformity is lower. Here some parameters (fiber diameter, fiber orientation, web density etc.), which may affect the fabric properties, are not directly taken into account in the image processing. However, these parameters indirectly affect the statistical parameters calculated in the framework of this study by using grey scale level of image. For example, for same amount of fibers, increase of fiber diameter will increase mean grey scale level of the image. The bonding parameter will affect mean grey scale level. In case the fibers have a preferred orientation, this physical parameter will affect the coefficient of variation in the machine direction.

3. RESULTS & DISCUSSION

In this article, PP spunbond nonwoven specimens with the specific weights of 12g/m^2, 20g/m^2, 25g/m^2, 30g/m^2 and 50g/m^2 are used. The specimens are categorized using the terms S12, S20, S25, S30 and S50 respectively according to their weights. The relationships between the experimental measurements (i.e. strength, elongation, weight) and numerically calculated values (i.e. mean, coefficient of variation, and index of dispersion) are reported in the following.

3.1 Areal Weight

The specimens were cut out directly from a roll of manufactured PP spunbond fabric. The manufacturer provided the areal weights of the spunbond fabrics. The average weight of ten specimens and relative error of the average weight from the value provided by the producer of each fabric type are given as shown in Table 1.

Table 1. Average weights and deviations from the expected weight values of PP spunbond fabrics

Specimen	Average weight [g/m^2]	Relative Error [%]
S12	12.4	3.3
S20	20.2	1.0
S25	25.5	2.0
S30	30.3	1.0
S50	52.7	1.4

As given in Table 1, the maximum relative error of average weight is observed for S12 as 3.3%. This value is considered small enough to be neglected in further steps. As the number of fibers per unit area of the nonwoven fabric increases, the weight of the fabric also increases. In the corresponding image of the nonwoven specimen, white color density increases with the weight of the nonwoven fabric and the mean of the grey scale q_{ij} array is expected to increase. In Fig. 4, the areal weight, *W,* of the investigated PP spunbond fabric is given as a function of computed mean grey scale array, $\bar{q}$. The coefficient of determination, which indicates how well the points fit the best line, is used for the data. As the coefficient of determination (R^2) approaches to the value 1, the points perfectly fit the best line. With R^2 = 0.976, it can be said that mean grey scale level is linearly proportional to the weight of the PP spunbond nonwoven fabric.

ImageRef4

Figure 4. The relationship between the weight, *W*, of the PP spunbond nonwoven fabric and mean, $\bar{q}$, of the grey scale level

The relationship between coefficient of variation and weight are given in Fig. 5(a). As the weight of the nonwoven fabric increases, the variation of grey scale value of each quadrat from the mean decreases. Therefore, as the nonwoven weight increases, the coefficient of variation decreases (see Fig. 5a) because as the areal weight of the PP spunbond fabric increases, the thickness of the fabric also increases so more fibers in the thickness will be seen and the non-uniformities will be covered by these fibers.

Index of dispersion is used to describe the mass uniformity of the fabrics statistically. An increase in the index of dispersion means that more local regions with large deviations from the mean appear. A small deviation on the local mass density gradient from the average mass density gradient suggests the presence of a uniform mass distribution. As the fabric areal weight increases, the variation of the local regions from the mean decreases and therefore, the index of dispersion also decreases (Fig. 5b). This reveals that the fabric texture becomes more uniform.

ImageRef5

Figure 5. Relationship between the weight of the PP spunbond nonwoven fabrics and (a) Coefficient of variation and (b) Index of dispersion

According to the results given in Fig. 5, the coefficient of variation and the index of dispersion capture the physical meaning of uniformity of the mass distribution. Because when the fabric areal weight increases, more fibers at the cross section of the fabric will be distributed and more uniform fabrics will be produced.

3.2 Grab Tensile Strength

Grab tensile strength values are measured using grab tensile test according to the ASTM D-5034 standard. For more reliable estimation, ten specimens are cut in the machine direction and tested. Then the average breaking load is calculated. It is worth mentioning that tensile breaking loads are measured in the present experimental procedure because of the difficulty in determining the cross-sectional area of the nonwoven specimens accurately so in the literature, the breaking load is accepted as the tensile results. Therefore, in ASTM D-5034 standard, tensile strength is taken as the force to rupture. In Fig. 6, tensile strength values of the PP spunbond nonwoven fabrics with different areal weights are given as a function of the mean grey scale level calculated using digital image analysis. As shown in Fig. 6, the grab tensile strength of the investigated PP spunbond fabric is linearly proportional to the mean grey scale level of the image.

ImageRef6

Figure 6. Tensile strength of the PP spunbond fabrics versus mean

Correlation between tensile strength and the mean gray scale can be approximated as linear with R^2 = 0.930 value. The results shown in Fig. 6 is feasible because as the gray scale increases, image whiteness is getting higher so the PP spunbond fabric will have more fibers especially at the third dimension i.e. thickness direction. So when the fabric is drawn during the strength test, more fibers will be against the force applied and therefore the strength will be higher.

In Fig. 7, the correlations between the tensile strength and the coefficient of variation and index of dispersion are shown. It is shown that the coefficient of variation and the index of dispersion increase, the PP spunbond fabric become less uniform and the average tensile strength value decreases. Higher variation in the regional grey scale of the fabric results in failure at the lower force. In most cases, fabric fails at the region that has the lowest strength and therefore the weakest region of the fabric determines the tensile strength of whole fabric.

Increase in the coefficient of variation and index of dispersion show an increase in the number of weak regions in the PP spunbond fabric. It is known that spunbond fabric fails at the weakest region, so this correlation appears to be feasible.

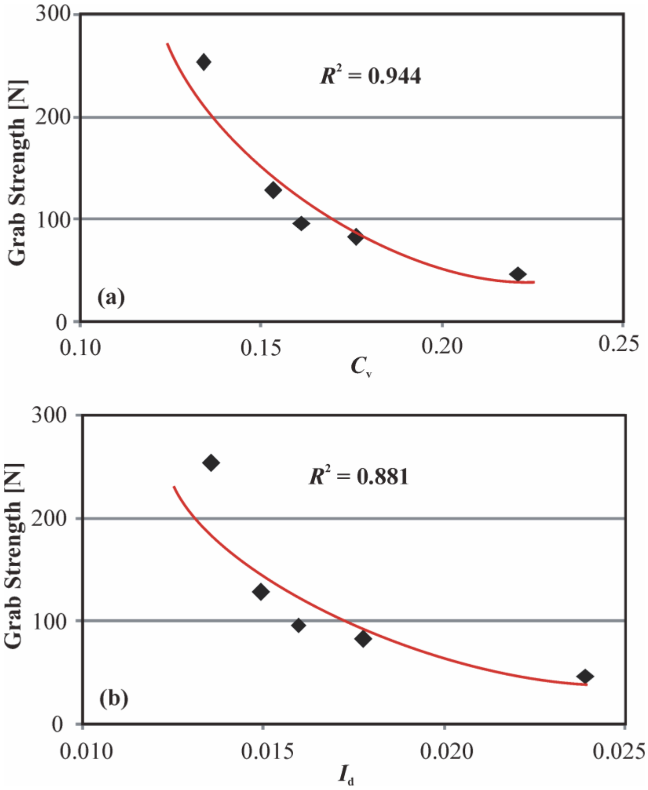

Figure 7. Relationship between the grab tensile strength of the PP spunbond nonwoven fabric and (a) Coefficient of variation, (b) Index of dispersion

In Fig. 6 and Fig. 7, the comparison is not performed between the nonwoven samples with the same weights but the correlation was found with the fabrics at different weights. Since the tensile strength increases at the higher weights (see Fig. 8), the tensile strength should be normalized with the weights of the different PP spunbond fabrics.

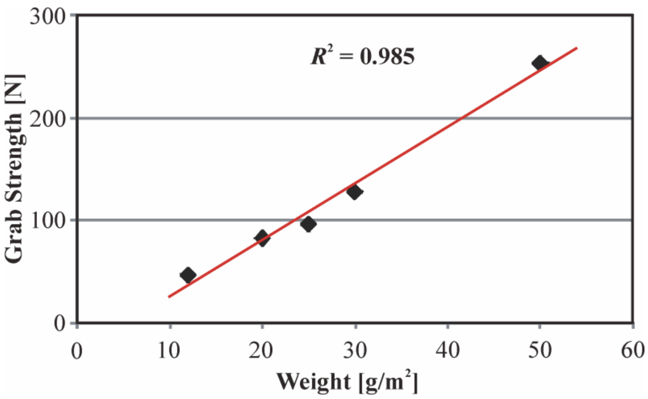

Figure 8. Relationship between the experimental tensile strength and weight

By normalizing, the correlation between the tensile strength and the mean gray scale, the coefficient of variation, and the index of dispersion can be found independent of the weight of the fabric. Here the tensile strength is normalized by dividing the break load by the weight of the loaded area (4cmx9cm) of the specimen and the strength per unit mass (Fig. 9) is calculated.

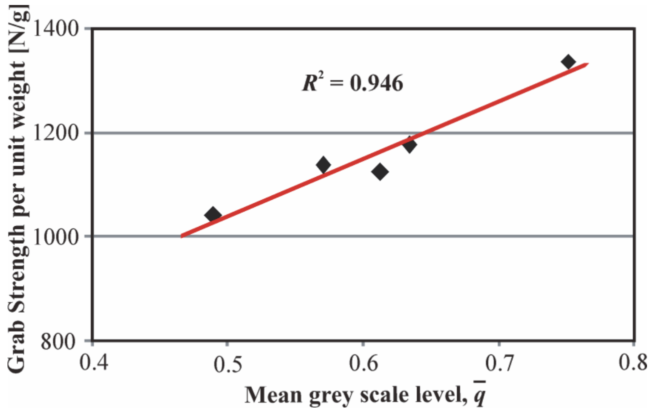

Figure 9. Relationship between tensile strength per unit weight and mean grey scale level

In Fig. 10, the correlations between the normalized grab tensile strength and the coefficient of variation, and index of dispersion are shown. As the coefficient of variation and the index of dispersion increase, the spunbond fabric become less uniform and the average normalized tensile strength decreases.

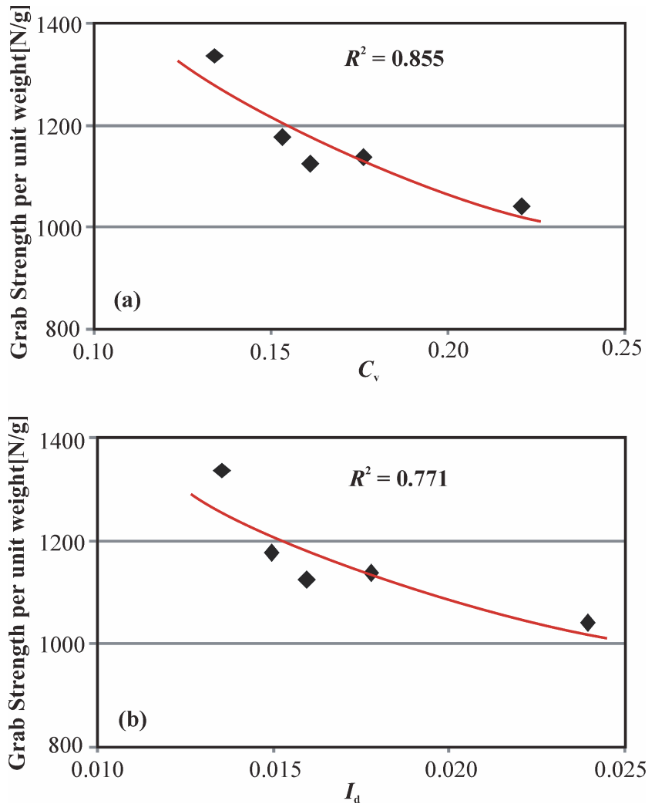

Figure 10. Relationship between the tensile strength per unit weight versus (a) Coefficient of variation, (b) Index of dispersion

3.3 Elongation at Break

The percent of elongation values of PP spunbond fabrics are measured at the point of break. In Fig. 11, elongations at break values are given as a function of mean grey scale level. As the mean grey scale level increases, the elongation of nonwoven increases linearly. When the number of fibers in the fabric increases, the grey scale level of the PP spunbond fabric increases. Higher number of fibers therefore provides more resistance against the applied force. So, more fibers will be extended. Since each fiber in the fabric is going to be pulled at their different locations, a higher elongation until failure will occur.

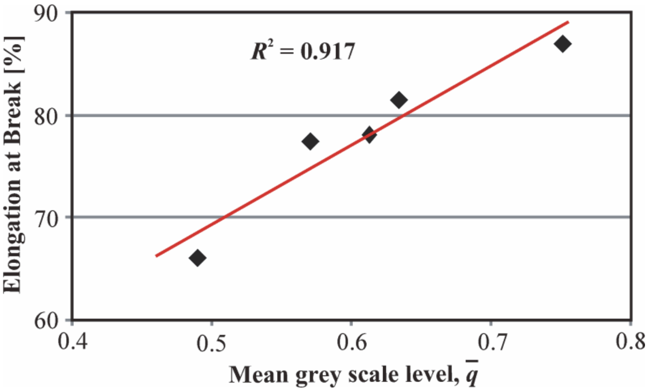

Figure 11. Relationship between elongation at break and mean gray scale level

Fig. 12 shows the relationship between the elongation at break values of the fabric and coefficient of variation and index of dispersion. When the C_v of spunbond fabric increases, more variation in the number of fibers per cross section of fabric will be observed. Since the fabric fails at its weakest region, less force will be needed and faster failure of the fabric will occur. Therefore, the elongation at the failure for the lower force results in lower elongation.

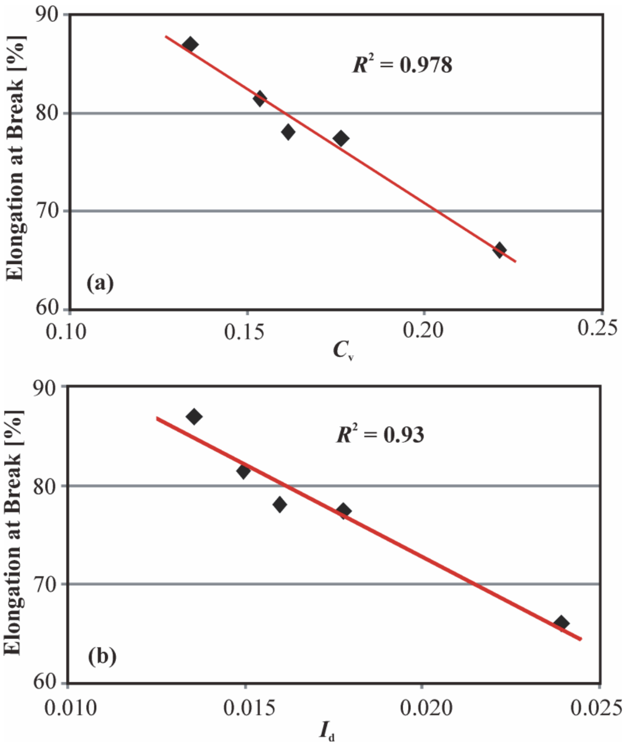

Figure 12: Relationship between the elongation at break and (a) Coefficient of variation, (b) Index of dispersion

3.4 Failure Behavior of PP Spunbond Nonwoven Specimens

In this study, two main types of failure behavior of PP nonwovens were observed; tearing of the fabric starting from the weakest part and rupturing of the fabric at once. In the first type of behavior, the failure starts from the weakest region. In Fig. 13, the digital image of the specimen before testing and the picture of the failed nonwoven fabric are represented. As stated, the failure initiated at the region of the specimen, which is more likely black in its image.

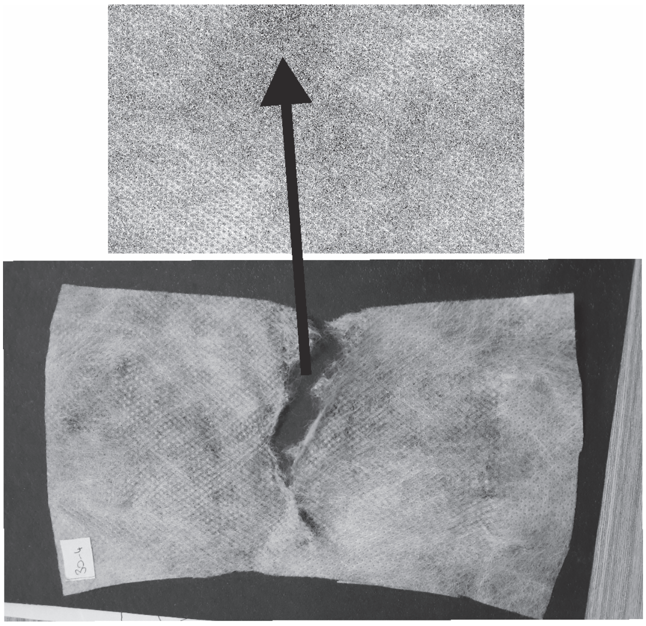

Figure 13. Representation of start of failure at weakest region

In Fig. 14, images of the different steps of tensile test of nonwoven fabric are shown. As the force increases, first the weakest region locally fails and then this failure results in a hole in the fabric. Then this hole gets bigger and finally the fabric starts to tear from this region. This type of failure occurs when the C_v of the fabric is higher because higher C_v means higher variability in the gray scale level. This type of failure could also be called "slow failure" since very dramatic changes in the fabric structure are seen with the time and more than one type of change (first rupture, then tear) is observed.

The second type of failure is the rupture of the fabric suddenly sat once. This type of failure is seen when the fabric is more uniform and when it does not have very weak region compared to the rest of the fabric specimen. Fig. 15 shows the failure with rupturing of the fabric. This type of failure is also called 'fast failure' because there will not be dramatic changes seen before the failure and fabric fails very fast.

Figure 14: Slow failure of nonwoven S30 specimen

Figure 15: Fast failure of nonwoven S30 specimen

4. CONCLUSIONS

The areal weight, grab tensile strength and elongation at break of the investigated PP spunbond nonwoven fabrics are estimated using the digital image analysis with newly developed computer program. Correlations between the experimental material properties and the statistical parameters calculated using digital image analysis are obtained. According to the results, the following conclusions are reported;

- The experimental areal weight of the PP spunbond nonwovens is directly proportional to mean grey scale level and inversely proportional to the coefficient of variation of grey scale level.
- There is a good linear correlation between grab tensile strength of the PP spunbond fabric and the mean grey scale level of its image.
- Increase in the coefficient of variation and the index of dispersion reveals that the density of weaker parts in the PP spunbond fabric increases and so that the grab tensile strength decreases.
- As the mean grey scale level increases, the elongation of nonwoven increases linearly. Increase of C_v and Index of dispersion reveals a decrease in elongation at break.
- Two main types of failure behavior of nonwovens are observed; tearing of the fabric starting from the weakest part and rupturing of the fabric at once.
- This study was performed with the selected PP spunbond nonwoven fabrics and the correlations are provided for this type of fabric. For the generalization of correlations and providing mathematical expressions for estimation of the areal weight, grab tensile strength and elongation at break for nonwovens with different para-meters (bonding shape, fiber diameter, fiber orientation, production type etc.), a more comprehensive study needs to be performed.

This study is the starting point for estimation of strength and elongation at break properties of spunbond nonwoven fabrics. For better estimation, more fabric parameters should be investigated. Unlike the similar studies, which use images during the tensile test, images before the tensile strength measurements are used in this article. Therefore, this study suggests that strength and elongation values could be predicted without the testing the PP spunbond nonwoven fabric. Online nonwoven property measurements should be performed by using hardware based digital image analysis; typically composed of camera, analog to digital hardware processor, computer/software, and monitor/ printer. The nonwoven fabrics that are used in this research are produced from polypropylene, which has zero percent moisture intake. Therefore, these nonwovens fabrics will not be affected by any environmental conditions unless the temperature is more than 70 ˚C. Since hardware based digital image analysis will be used during production, the angle of nonwoven and the light conditions will affect the images. However, whatever the angle and light conditions are during the production of nonwoven fabric, the same conditions will be maintained therefore the comparative analysis will still be possible. As a result, the proposed method can also be used for nonwovens in an ongoing discontinued band system. By using online measurement system, customers can predict the strength, elongation at break values and weak region of the nonwoven roll while the spunbonding process is running. Therefore, PP spunbond nonwoven fabric producer would be able to change the process parameters as soon as the system detects the nonuniformities. As a result, prediction of image processing for estimation of fabric properties will eliminate experimental testing and therefore decrease the waste of time and money.

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REFERENCES

1. Pourmohammadi A. Nonwoven materials and joining techniques. In Jones I and Stylios GK (eds) *Joining Textiles: Principles and Applications*. 1st ed. Woodhead Publishing, 2013, pp. 565–581.
2. Ajmeri JR and Ajmeri CJ. Nonwoven personal hygiene materials and products. In Chapman R (eds) *Applications of Nonwovens in Technical Textiles.* CRC Press, 2010, pp. 85-102.
3. Jasinska I and Stempien Z. An alternative instrumental method for fabric pilling evaluation based on computer image analysis. *Text Res J* 2014; 484: 488.
4. Konda A, Xin LC, Takadera M et al. Evaluation of pilling by computer image analysis. *J Textile Mach Soc Japan* 1990; 36(3): 96–107.
5. Hsi C, Bresee R and Annis P. Characterizing Fabric Pilling by Using Image-analysis Techniques. Part 1: Pill Detection and Description. *J Text Inst* 1998; 89(1): 80–95.
6. Gloy YS, Gries T and Spies G. Non Destructive Testing of Fabric Weight in the Weaving Process. In *13th International Symposium on Nondestructive Characterization of* Materials (NDCM-XIII), *Le Mans, France,* 20-24 May 2013.
7. Kang TJ, Kim CH and Oh KW. Automatic Recognition of Fabric Weave Patterns by Digital Image Analysis. *Text Res J* 1999; 69(2): 77-83.
8. Turan RB, Okur A, Deveci Ret al. Predicting the intra-yarn porosity by image analysis method. *Text Res J* 2012; 82(16): 1720–1728.
9. Jeong SH, Choi HT, Kim SR et al. Detecting fabric defects with computer vision and fuzzy rule generation part I: Defect classification by image processing, *Text Res J* 2001; 71(6): 518-526.
10. Zhang XM, Wang RW, Wu HB and Xu B. Automated measurements of fiber diameters in melt-blown nonwovens. *J Ind Text* 2014; 43(4): 593-605.
11. Wang R, Xu B and Li C. Accurate fiber orientation measurements in nonwovens using a multi-focus image fusion technique. *Text Res J* 2013; 84(2): 115–124.
12. Tunak M, Antoch J, Kula J et al. Estimation of fiber system orientation for nonwoven and nano fibrous layers: local approach based on image analysis. *Text Res J* 2013; online: 1-18.
13. Pourdehyhimi B, Dent R, Jerbi A et al. Measuring Fiber Orientation in Nonwovens Part V: Real Webs. *Text Res J* 1999; 69(3): 185-192.
14. Xu B. Measurement of Pore Characteristics in Nonwoven Fabrics Using Image Analysis. *Cloth & Textiles Res J* 1996; 14(1): 81-88.
15. Aydilek AH, Oguz SH and Edil TB. Digital image analysis to determine pore opening size distribution of nonwoven geotextiles. *J Comput Civil Eng* 2002; 16(4): 280-290.
16. Lien HC and Liu CH. A method of inspecting non-woven basis weight using the exponential law of absorption and image processing. *Text Res J* 2006; 76: 547-558.
17. Wang H, Jin X, Mao N et al. Differences in the tensile properties and failure mechanism of PP/PE Core/Sheath bicomponent and PP spunbond fabrics in uniaxial Conditions. *Text Res J* 2010; 80(17): 1759–1767.
18. Rawal A, Lomov S, Ngo T et al. Mechanical Behavior of Thru-air Bonded Nonwoven Structures, *Text Res J* 2007; 77(6): 417-431.
19. Kim HS, Deshpande A, Pourdeyhimi B et al. Characterizing structural changes in point-bonded nonwoven fabrics during load-deformation experiments, *Text Res J* 2001; 71(2): 164-173.
20. Liao T and Adanur S. Computerized failure analysis of nonwoven fabrics based on fiber failure criterion. *Text Res J* 1999; 69(7): 489-495.
21. Chhabra R. Nonwoven uniformity - Measurements using image analysis. *Int Nonwovens J* 2003; 12(1): 43-50.
22. Militky J and Klicka V. Nonwovens uniformity spatial characterization. *J Inf Comput Sci* 2007; 2(2): 85-92.
23. Ghassemieh E, Acar M and Versteeg H. Microstructural analysis of non-woven fabrics using scanning electron microscopy and image processing. Part 1: development and verification of the methods. *Proc Instn Mech Engrs* 2002; 216: 199-207