A Study of the Factors Affecting the Bursting Strength of Bicomponent Hydroentangled Non-woven Fabrics

Subtitle: Bursting Strength of Non-woven Fabrics

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Abstract
This paper presents the bursting strength of hydroentangled non-woven fabrics made from islands-in-the-sea fibers PET/COPET and pie segmented fibers (PA6/PET), and processed using inclined water jet apparatus. The effects of basis weights, water jets pressure and water jets inclination angle on bursting strength of hydroentangled nonwoven fabrics were discussed. The comparison was made on the bursting strength of hydroentangled fabrics of 60 g/m² and 100 g/m² processed by using perpendicular water jets at 0° and inclined water jets at 20° with pressure levels of 3bars and 7bars. The results showed that the increases of water jet pressure and basis weight caused an increase of the bursting strength of the hydroentangled fabrics. Furthermore, with increasing of water jets inclination angle, the bursting strength of 100 g/m² hydroentangled non-woven fabrics were increased while the bursting strength of 60 g/m² hydroentangled fabrics decreased. Finally the bursting strength of the pie segmented (PA6/PET) non-woven fabrics showed higher bursting strength compared with islands-in-the-sea (PET/COPET) non-woven fabrics. It can therefore be concluded that degree of inclination of the water jet played an important role in hydroentanglement process.

Keywords
Hydroentanglement; Bursting Strength; Islands-In-The-Sea Fiber; Pie Segmented Fibers; Inclination Angle; Non-woven Fabrics

Introduction
Bicomponent fibers consists of two different polymers, which are selected based on the chemical and physical properties of the polymers. Some of the polymers commonly used in the manufacture of bicomponent fibers include polyesters (PET), co-polyesters (COPET), nylon, polyethylene, poly (lactic) acid (PLA) and polyamide 6 (PA6), which can be combined in a variety of formats including side by side, sheath-core, pie segmented, and island-in-the-sea fibers which can be separated in certain processing stages to facilitate the production of very fine (micro-denier) fibers. While the initial approach was to completely destroy one of the polymers and hence to be left with a micro fiber from one of the polymers, recent techniques involve the splitting or fibrillating of the polymers and hence retaining the two polymers in the non-woven structure. One of the techniques used to manufacture non-woven fabrics using bicomponent fibers is the hydroentanglement process, where high pressure water jets are used, to split or fibrillate the fibers and hence produce a fabric due to the entanglement that occurs during the splitting or fibrillating process [1-3]. Further research has been undertaken to understand the hydroentanglement process and the properties of the non-woven fabrics produced. As reported by several researchers the properties of hydroentangled non-woven fabrics are affected by the type of fiber, fabric basis weight, technology of web formation, web supporting substrate and water jets specifications (includes jets nozzles geometry, jet angle, input jet energy, water extraction and water circulation) [4-11]. The mechanical properties of hydroentangled fabrics are affected by the jet energy. Generally higher jet energy produces fabrics with higher tensile strength, while reducing the fabric basis weight will affect the fabrics tensile property. Moyo et al [12] has undertaken a study for the optimization of the usage of energy during the hydroentanglement process. It should be important to note that there is a limit to the amount of energy used, since at some level, increase in higher energy may adversely affect the
mechanical property of the fabric. Other fabric properties which include air porosity (depends on web laying techniques), water absorption and fabric density have also been investigated [13]. The simulation of the hydroentanglement process has been undertaken by Xiang et al [14], which was expected to assist researchers with a technique of reducing the cost of research by first using a process simulation, before embarking on experimental studies. While there are several reports about the study of the bursting strength of non-woven fabrics [15-16] none of the studies have considered the bursting strength of hydroentangled fabrics made from bicomponent fibers. As noted by Hutten [17], bursting strength is one of the important properties of a non-woven fabric material. Therefore it will be a useful addition to the body of knowledge if the role of inclined water jets on the bursting strength of hydroentangled nonwoven fabrics made from bicomponent fibers is undertaken. The aim of this paper was to study the effect of inclined water jets to the bursting strength of islands-in-the-sea (PET/COPET) fabrics and pie segmented (PA6/PET) produced using hydroentanglement process.

**Experimental**

**Materials**

The fibers used in this study were island-in-the-sea bicomponent fiber namely 70%PET/30%COPET of linear density 4 dtex, with 37 PET islands, and pie segmented fibers 70%PA6/30%PET of linear density 2.77 dtex, with 8 segments.

**Carded Fiber Webs Manufacturing**

The conventional sampling carding machine was used to produce the carded fiber webs of basis weights of 60 g/m² and 100 g/m². The fiber samples were weighed to produce the targeted weights, opened gently and finally processed in the carding machine. Numbers of layers were laid on top of one another on the carding roller until it attained the necessary weight. The fiber webs manufactured were in the ranges of 250mm (width) x 770mm (length).

**Hydroentangled Nonwoven Fabrics Preparation**

![FIGURE 1. ASSEMBLY OF DESIGNED WATERJET APPARATUS](image)

The designed inclined water jets apparatus shown in Figure 1 was used for the preparation of hydroentangled fabrics. The pressure levels of 3 and 7 bars and water jets of inclination angles of 0° and 20° were used during preparation of hydroentangled nonwoven fabrics. The pressure water tank was filled with fresh water, through
valve 1 and the height of water in the tank was controlled using valve 2 while valve 4 was closed. The compressed air from the air compressor drove some water downward through the hose fixed at the bottom of the pressure water tank when valve 4 was opened. The water was forced through the small manifold where the constricted water jets were obtained through the jet plate having small orifices of 0.3 mm in diameter and different inclination angles fixed in the small manifold. The water jet pressure was controlled by the flow meter between the air compressor and water tank, as well as the pressure gauge on the water tank. The water jets forced through the orifices and struck the fiber web fixed on the fiber web support.

Figure 2 shows some of the examples of water jets profile images taken by high speed camera (HG Camera System, Model: HP-LE (CLOLR) made by Redlake MASD Ltd (USA)). The shutter speed of 250 fps and the aperture F. 2.8 were used and all the images taken were processed and saved in the personal computer. Other specifications of HG Camera System included: minimum distinction of 752 × 1128 pixel, maximum memory of 1GB and photo speeds of 30-1000 fps and high speeds of 30-100000 fps for small photos (micrographs). The manifold was small therefore the shifting of the carded fiber webs in crosswise direction was carried on until the fiber web was totally hydroentangled on one side and then the consolidation continued on the opposite side. Two passes for each side were used so as to attain good hydroentanglement efficiency. The length between nozzle orifice exit and fiber web (standoff distance) was fixed at 20 mm.

The processing parameters used for making hydroentangled fabrics using designed inclined water jets apparatus during hydroentanglement process were jet density (3jets/cm), web velocity (0.72 m/min), nozzle orifice diameter (0.3mm), jet pressure (3 and 7bars), water jet inclination angle (0 and 20 deg), number of passes (2 in each side) and one manifold. The pressure levels of 3 and 7 bars and water jets of inclination angles of 0° and 20° were used during
preparation of hydroentangled nonwoven fabrics.

The water jet pressure was controlled by the flow meter between the air compressor and water tank, as well as the pressure gauge on the water tank. The water jets forced through the orifices and struck the fiber web fixed on the fiber web support. Figure 2 shows some of the examples of water jets profile images taken by high speed camera and the schematic setting diagram for capturing water jets profile is shown in Figure 3 where the capturing of images was done using the same procedure discussed earlier. It can be noted that, the values of processing variables are not typical as the same as those used in commercial hydroentanglement machine, but we used these preliminary results to reflect the importance of inclined water jets during hydroentanglement process. After hydroentanglement the webs were squeezed within perforated wires to remove excess water and then were left to dry at room temperature.

Physical Measurement

The bursting strength is the force which is applied at right angles to the plane of the fabric under specific conditions which will results in the rupture of a fabric and the test is used for the evaluation of a wide variety of fabrics. The specimens of nonwoven fabrics of diameter 60mm were securely fixed without tension between the holes of circular plates of the ball burst attachment secured on the tensile testing machine basement of Electronic Fabric strength tester (Hongda Tensometer), model: HDO26N made by Nantong Hongda Experiment Instruments Company Ltd in China. A force was exerted against the specimen by a polished, hardened steel ball that was attached to the clamp of the tensile testing machine which moved downwards until rupture occurred in the sample and went back to its original position. Five samples for each collection were tested as explained in ASTM Test Method D 3787 at the standard atmosphere of 20±2°C and 65±2% RH. The average bursting strength of the five specimens from each sample was recorded.

Images During Hydroentanglement

1) Fabric Images

The photos of the samples before and after hydroentanglement were taken using JSM-5600LV Scanning Electron Microscope (SEM) of resolution 3.5- 4.5 nm and range of magnification 18-300000. Based on the photos the splitting/fibrallating behaviors of the bicomponent fibers were investigated.

2) Water Jets Profile Images

In order to understand the water jet profiles during hydroentanglement process, a high speed (discussed earlier) was used to capture the images of water jets in different processing conditions. The capturing of images was done using the angled nozzle orifices jet plate of 0° and 20° in which every plate had 7 nozzle orifices with different pressure levels.

Results and Discussion

The test results of the non-woven fabric samples are presented in this section. Figure 4 shows the SEM micrographs for the fibers before the hydroentangled process, while Table 1 gives the the bursting strength of carded fiber webs before hydroentanglement.

The bursting strength of carded fiber webs of basis weight of 100 g/m² was higher than that of fiber webs of basis weight of 60 g/m² in all types of carded fiber webs. This could be created due to higher fiber packing density in the carded fiber webs of 100 g/m² compared with carded fiber webs of 60g/m². The more openness or pore spaces within carded fiber webs of 60g/m² caused them to be weaker, when compared with the more denser 100 g/m² samples. It can also be noted that the bursting strength of island-in-the-sea (PET/COPET) carded fiber webs was higher than that of pie segmented (PA6/PET) carded fiber webs. Figure 4 indicated that the PA6/PET fibers were cracked to form thin fibers, which were characterized with uneven fiber distribution within fiber webs probably due to weak interfacial bonding between polyamide (PA6) and polyester (PET). Interaction of the fibers and carding wires, during carding might also have caused a weaker PA6/PET fiber carded webs. PET/COPET fibers did not show any fibrillating behavior due to their strong interfacial bonding between polyester (PET) and co-polyester (COPET). The coefficients of variations for bursting strength were in the range of 3.09% to 9.35% for all carded
webs (see Table 1), probably due to non-uniformity of fiber distribution and uneven thickness of fiber webs.

**TABLE 1. BURSTING STRENGTH OF FIBER WEBS BEFORE HYDROENTANGLEMENT**

<table>
<thead>
<tr>
<th>Fiber web type</th>
<th>Weights (g/m²)</th>
<th>Bursting strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average value (N)</td>
<td>Coefficient of variation (%)</td>
</tr>
<tr>
<td>PET/COPET</td>
<td>60</td>
<td>3.26</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>13.98</td>
</tr>
<tr>
<td>PA6/PET</td>
<td>60</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>11.08</td>
</tr>
</tbody>
</table>

**FIGURE 4. SEM MICROGRAPHS OF FIBER WEBS BEFORE HYDROENTANGLEMENT (a) PA6/PET, (b) PET/COPET**

**Effect of Basis Weight on Bursting Strength**

**FIGURE 5. THE EFFECT OF BASIS WEIGHT ON BURSTING STRENGTH OF PA6/PET FABRICS**

**FIGURE 6. THE EFFECT OF BASIS WEIGHT ON BURSTING STRENGTH OF PET/COPET FABRICS**

Figure 5 and Figure 6 show the effect of varying basis weight of hydroentangled fabrics on bursting strength,
where the bursting strength of PA6/PET and PET/COPET fabric samples showed an increasing trend.

Comparisons of the effect of fiber types on the properties of the non-woven fabrics, the PA6/PET fabrics (Figure 5) showed higher bursting strength than PET/COPET fabrics (Figure 6) processed using the same pressure levels and inclination angles. This could be produced due to weak interfacial bonding between PA6 and PET polymers which caused pie segmented fibers (PA6/PET) to fibrillate during hydroentanglement process forming micro-denier fibers. The micro-denier fibers have a tendency of being easily entangled even at low pressure hence the formation of fabrics with higher bursting strength.

**Effect of Inclination Angle on Bursting Strength**

The results of the study of the inclination angle on the bursting strength is given in Figure 7, while in Figure 8 and Figure 9 selected micrographs of the hydroentangled fabric sample are given.

Figure 7, it shows that as the angle of inclination of water jets increased from 0⁰ (perpendicular water jets) to inclined jets of 20⁰ the bursting strength increased for all 100 g/m² hydroentangled fabrics processed using the same pressure levels. The increase of bursting strength may be produced due to the following reasons:

(a) It can be assumed that during hydroentanglement in inclined mode, the impact of the turbulence effect of water jets of 20⁰ was higher compared with that of perpendicular water jets (0⁰). Therefore as the inclined water jets of 20⁰ struck on the fiber web support, they tended to contribute more effect of reflected water jets which caused more fibers to be entangled forming more bonding points than perpendicular water jets of 0⁰. This would have lead to an increase of the bursting strength of the fabric samples.

(b) For the inclined water jets of 20⁰, the water jets have to travel a longer distance through the fiber webs compared with perpendicular water jets at 0⁰, which tends to twist, rotate and knot the fibers together leading to a more stronger fabric.

**FIGURE 7. THE EFFECT OF WATERJETS INCLINATION ANGLE ON BURSTING STRENGTH OF HYDROENTANGLED FABRICS**

In the case of 60 g/m² fabrics of PET/COPET and PA6/PET, the trend was different showing that with increase of inclination angle from 0⁰ to 20⁰ of water jets in the same pressure levels, the bursting strength decreased. This may be attributed to lower fiber packing density in the fiber carded webs. As the water jets of 20⁰ strikes the fiber webs, they tend to flush out the fibers due to severe fiber reorientation during processing which caused the damage on the fiber webs structures and form very few bonding points as the result a decrease of the fiber web strength occurred. Furthermore during the comparison of bursting strengths of fiber types in Figure 7a and Figure 7b, it showed that the bursting strength of PA6/PET fabrics were higher than that of PET/COPET fabrics in the same pressure levels and inclination angles. The main reason for higher bursting strengths of PA6/PET hydroentangled fabrics treated by the pressure levels of 3 bars and 7 bars with inclined water jets of 20⁰ may be the water jets striking the fibers at an angle to their fiber segments that easily break the polymer interfacial bonding so the fiber fibrillating increased compared with the impact of vertical water jets. It may also be produced due to the higher pressure of 7 bars caused higher impact force on the fibers which caused more splitting of PA6/PET fibers.
compared with the pressure of 3 bars. The increase of fiber splitting caused more thin fibers to be entangled and formed very strong bonding points resulting into very strong PA6/PET web structures. The explanations can be concluded from Figure 8 and Figure 9, which showed the SEM photos or images of pie segmented (PA6/PET) hydroentangled fabric structures of 60 and 100 g/m² processed at pressure levels of 3 and 7 bars and inclination angles of 0° and 20° which caused fiber splitting after hydroentanglement even at very low pressure levels. From Figure 8 and Figure 9 it can be noticed that the increase of water jets pressure and water jets inclination angles the fiber fibrillating of PA6/PET improved. From image analysis, all hydroentangled non-woven fabric samples made from PET/COPET of 60 g/m² and 100 g/m² showed no fiber fibrillating; therefore in this paper only one example in Figure 10 is shown.

Figure 10 shows no fiber fibrillating, which confirmed the strong interfacial adhesion of polyester (PET) and co-polyester (COPET).
Effect of Water Jets Pressure on Bursting Strength

From Figure 7, the effect of water jet pressure on bursting strength of both 60 g/m² and 100g/m² of pie segmented (PA6/PET) and island-in-the-sea (PET/COPET) hydroentangled fabrics, indicated that with increase of water jets pressure from 3 bars to 7 bars in the same inclination angle, the bursting strength of the hydroentangled fabrics samples increased. This could be produced due to the fact that increase of water jets pressure could have caused an increase of the impact force and drag forces which caused many fiber to be displaced, bend, twisted and knotted or entangled on themselves and/or with other neighboring fibers to form a strong network structures of higher bonding strength because of high turbulence effect during processing. Also in Figure 7 it can be noticed that, the PA6/PET fabrics have higher bursting strength than PET/COPET fabrics, this may be created due to fibrillating of PA6/PET fibers during hydroentanglement process (see Figure 8 and Figure 9), which caused strong network structure of high elasticity compared with PET/COPET fabrics which did not fibrillate (see Figure 10).

Further consideration of Figure 7, revealed that as the water jets inclination angle increased from 0° to 20° in the same pressure level, the hydroentangled fabrics bursting strength of 60 g/m² fabrics decreased while for 100 g/m² fabrics bursting strength increased.

Conclusion

The results obtained in this research project can be summarized as follows:

(a) As the basis weight increased, the hydroentangled fabrics bursting strength increased.
(b) When water jet pressure increased, the hydroentangled non-woven fabrics bursting strength increased,
(c) The water pressure used in this research work (3 bars and 7 bars) could fibrillate the (PA6/PET) but not the (PET/COPET) bicomponent fibers during hydroentanglement.
(d) As the water jets inclination angle increased from 0° to 20° at the same pressure level, the hydroentangled fabrics bursting strength of 60 g/m² fabrics decreased while for 100 g/m² fabrics bursting strength increased.

From this preliminary work, it can be concluded that inclined water jets may play a very important role in hydroentanglement process and more work is still needed using high water jets pressures and different inclination angles in the commercial industrial hydroentanglement machines to find out the capability and importance of inclined water jets in the hydroentanglement process.

REFERENCES

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BIBLIOGRAPHY

Mbwana, S. Ndaro, was born in The Northern part of Tanzania, where he received his earlier education. He received his low level and high level secondary education in Tanzanian regions of Shinyanga and Kibaha respectively. He did his bachelor degree and Master Degree in Russia, where his major field of study was machine design. To broaden his knowledge in Textile processes, Mbwana registered for another Master Degree in China Textile University now known as Donghua University where his major field of study was Textile engineering. He thereafter registered for a PhD degree in Donghua University, and wrote a thesis covering the processing of non-woven fabrics. Ndaro has worked in several textile factories in Tanzania, and is the current Head of Department, for the Textile and Leather Division at Tanzania Industrial Research and Development Organization (TIRDO), Dar-es-salaam, Tanzania. He has authored over 25 referred papers in journals and international conferences and is currently one of the renowned textile consultants in Tanzania.

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