Mechanical properties evaluation of nonwoven industrial cotton waste produced by needle punching method

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Abstract. This paper describes the fabrication method and mechanical characterization of nonwoven fabrics from industrial fabric wastes by different machine variables. Cotton waste fibres underwent the mechanical recycling methods, needle punching process and worked into a continuous web of nonwoven fabrics. The measurement method of full factorial design of experiment was implemented in this study as a systematic and efficient way to distinguish between the interaction of more than one factor which are the fibre feeder speed and the number of stacking layers, respectively. Three different fibre feeder speed of 1.8 m/s, 2.2 m/s and 2.8 m/s and three levels of stacking layer (4, 5 and 6 layers) were examined. Analysis of variance (ANOVA) was used to determine the significant factors that influenced the mechanical properties of the web nonwoven fabrics. The mechanical properties of nonwoven web were measured by bursting strength test and puncture resistance test. The results displayed that the difference in fibre feeder speed and number of stacking layer significantly affect the puncture resistance performance. S26L web resisted the highest load during puncture resistance test which is 70.5 N while S14L resisted the lowest load of 25.5 N. Whereas, bursting strength performance was only affected by the fibre feeder speed. Lower fibre feeder speed produced stronger nonwoven fabric. Hence, the faster the fibre feeder speed and the higher number of stacking layer give good puncture resistance properties of nonwoven fabrics while the bursting properties of nonwoven fabrics shows the opposites results.

1. Introduction

The demand of new textile design keeps growing every year making the growth of the textile production inflated. The growth of the world's population in line with the rising living standards has resulted in the continued increase in global fibre utilizations to contribute to the increase in textile waste [1, 2]. Maintaining statistics, at current rates of demographic and economic growth, global annual consumption of fibre will reach 110 million tonnes in 2020 [3, 4]. Combating the situation, it is projected that global fibre supplies will increase from 87 million tonnes to 240 million tonnes by 2050 [5]. It shows that the global fibre supply is not in line with the use of fibre. More production leads to more waste and greater environmental impact [6].

“Fast fashion” phenomenon is the right term in which describes the production of low cost clothing in high volumes intended for short lifetime and made to be disposed [7] has been such a great influence on the trend changes. This resultant in higher amounts of the fabric waste in the landfills. Fibres are basically used in many other application such as the production of clothing, interior, technical textiles and household [8, 9]. Manufacturing of textile products causes a large quantity of wastes, commonly disposed into landfill or used for energy recovering [10]. Burying and land filling the textile waste had been the major concerns for the environment [11]. Morley et al. [12] reported...
that, a total amount of 7.3 million tonnes of apparel waste was generated each year in Europe and 50% of them end up being at the landfills. Landfilling is a preferred choice to dispose waste as it is cost-effective and simpler than focusing on recycling the waste into usable products [13]. Therefore, it was absolutely necessary to establish a method to handle the constantly increasing levels of textile waste which is recycling method.

According to Björquist et al. [14]; Leonas [15]; Vadicherla & Saravanan [16] there are two types of textile recycling methods which are chemical and mechanical recycling methods. For natural fibres such as cotton, the main recycling method is mechanical recycling such as weaving, nonwoven and knitting method. In mechanical recycling, fibres that are obtained by defibrillation are used for the production of new yarns, nonwovens and other textiles, upholstery stuffing, insulation and roofing felt, carpet components and lower quality blankets [17, 18]. From this standpoint the aims of this study are to produce cotton waste nonwoven web and evaluate the mechanical properties by means of mechanical recycling. Currently, less research was done using the nonwoven needle punching method to re-process the cotton waste. This research leads to a new exploration of properties and potential products from cotton wastes.

2. Materials and methodology
The cotton fabric wastes were supplied by Golden Gate Technologies Sdn. Bhd., Melaka, Malaysia. The needle punching process were made by the conversion of fibres/filaments into webs and bonded together at different ways such as subsequent bonding by chemical, thermal or mechanical means. In this study, the webs were produced by three different fibre feeder speed (1.8 m/s, 2.2 m/s and 2.8 m/s) and three different types of stacking layer were undergone the punching repetition. The different stack up web of four, five and six layers experienced the repeated punching process. This process was done to ensure the complete compactness of the cotton waste nonwoven web. The cotton waste nonwoven web underwent two types of mechanical properties test which are bursting strength and puncture strength test. The bursting strength was tested using a bursting strength test machine which followed ASTM D3786 testing method. The average of five readings were taken for each of the samples. The puncture strength performance was measured by using a Universal Testing Machine which followed ASTM D4833-07.

Factorial design is applied because it is the most effective approach in the experiment involving more than one factor. The factors or parameters in this project need to be identified, followed by selection the levels at which each factor will be examined [19]. This study has focused on two factors which are the fibre feeder speed and the number of stacking layer. Therefore, the full factorial design with 3 x 2 designs was used. The statistical analysis was carried out using one way analysis of variance (one way ANOVA) to examine the significant effects of each factor and level. It is stated that a p-value of less than 0.05 was considered significant [20]. Samples coding and formulations are presented in Table 1.

Table 1. Samples coding and formulation.

| Machine speed | Repeat punching by number of layers | Samples coding |
|---------------|----------------------------------|----------------|
| S1 (1.8 m/s)  | 4                                | S14L           |
|               | 5                                | S15L           |
|               | 6                                | S16L           |
| S2 (2.2 m/s)  | 4                                | S24L           |
|               | 5                                | S25L           |
|               | 6                                | S26L           |
| S3 (2.8 m/s)  | 4                                | S34L           |
|               | 5                                | S35L           |
|               | 6                                | S36L           |
3. Results and discussions

The results of bursting and puncture were calculated to the mean grouping using analysis of variance (ANOVA). Table 2 shows summarization of the statistical analysis (ANOVA) results of the mechanical properties at difference samples of cotton waste nonwoven web. Fibre feeder speed shows significant effects ($p < 0.05$) for bursting strength and interactions of factors were also present. In contrast, ANOVA results for bursting shows that the factors of stacking layer did not affect the response. The $p$-value denotes more than 0.05. However, R$^2$ value was recorded as 70.92%, which indicated the data is stable with intermediate degree of variability. Main effect plot of mean data and interaction plot are displayed in Figure 1(a) and 2(a). The machine speed, S1 and S2 produced similar values of bursting strength, while S3 yielded lower bursting strength value. This is because the lower fibre feeder speed, the higher punching density at the same spot on the web which resulting in higher fibre interlocking activities. Thus, this result shows that higher bursting strength is required to break the bonding between fibres in the web. Das et al. [21] reported that higher punching density will not only resulted in higher mechanical performances, but also in greater amount of fibre damage and breakage. It is also proved that some research stated that the strength of a nonwoven web increase proportionally to the punch density [22].

Table 2. ANOVA test for; (a) bursting test; (b) puncture test.

| Sources                                      | Df | SS      | MS       | F      | P      |
|----------------------------------------------|----|---------|----------|--------|--------|
| (a) Bursting test                            |    |         |          |        |        |
| Fibre feeder speed                           | 2  | 1.0783  | 0.53915  | 16.44  | 0.000  |
| Stacking layer                               | 2  | 0.1057  | 0.05284  | 1.61   | 0.214  |
| Fibre feeder speed*Number of stacking layer  | 4  | 1.6959  | 0.42397  | 12.93  | 0.000  |
| Error                                        | 36 | 1.1806  | 0.03280  |        |        |
| Total                                        | 44 | 4.0605  |          |        |        |
| (b) Puncture test                            |    |         |          |        |        |
| Fibre feeder speed                           | 2  | 6978.6  | 3489.28  | 148.71 | 0.000  |
| Stacking layer                               | 2  | 1191.8  | 595.90   | 25.40  | 0.000  |
| Fibre feeder speed* Number of stacking layer | 4  | 320.4   | 80.11    | 3.41   | 0.018  |
| Error                                        | 36 | 844.7   | 23.46    |        |        |
| Total                                        | 44 | 9335.5  |          |        |        |

Df: degree of freedom; SS: sum of squares; MS: mean square; F: F-test; p: $p$-Value.

In Table 2, the puncture test result shows that both of the fibre feeder speed and stacking layer were proven to affect significantly the puncture resistance of the nonwoven webs ($p < 0.05$). The analysis also showed the presence of factor of interaction. Figure 1(b) and 2(b) displayed main effects plots and interaction plots for puncture resistance of mean data. S2 produced higher puncture resistance values and gradually drop as the speed increases. This is due to the same reason as stated by Das et al. [21]. When needling density is too high (which is related to the speed of the fibre feed), the bonding structure of the nonwoven tend to damage and the puncture resistance of nonwoven will decrease accordingly [23, 24]. This reason proved that S3 produces lower puncture resistance as compared to S2. As for the number of stacking layers, the interaction also shows that higher stacking layers gives nonwoven web with higher puncture resistance value. Figure 2 and 3 show the highest mean of bursting strength observed at S14L while the highest mean of puncture resistance is S26L, respectively. However, from the results of the thickness proved that the optimum speed to be used was 2.2 m/s.
4. Conclusions
In this study, the cotton waste nonwoven web was successfully measured and prepared by using needle punching method. The processing parameters of the fabrics affected the mechanical properties of the fabrics. Both fibre feeder speed and number of stacking layers were found statistically significant \((p < 0.05)\) based on puncture strength test while the only significant results for bursting test is fibre feeder speed. The increasing number of stacking layers exhibited the higher of puncture properties but oppositely to the bursting properties. As a conclusion, the optimum speed is 2.2 m/s and the optimum number of stacking layer is six layers of cotton waste nonwoven web.

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