Non-Biodegradable Plastic Bag Waste into Upcycled Non-Woven Textiles: Their Viability for Wearable Products

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Introduction and background. Plastic production surpasses 400 million metric tons annually worldwide (Undas et al., 2023), leading to plastic waste emerging as a significant environmental concern (Geyer et al., 2017). One of the effective strategies to minimize plastic waste on the landfill is upcycling them into new materials of greater quality for wearables (Sezgin & Yalcin-Enis, 2022). Within the textiles sector, diverse techniques such as weaving (Afriyie, 2022) and melt spinning (Soekoco et al., 2017) were explored for regenerating non-biodegradable plastic waste into woven textiles. However, little research exists exploring the way to circle back non-biodegradable plastic bag waste into upcycled non-woven textiles for wearables. Furthermore, durability of upcycled non-woven textiles made of non-biodegradable plastic bag waste has not been previously examined despite the importance of the newly developed material's mechanical properties, especially tensile strength and seam strength, which are related to the performance and aesthetic appearance of wearable products (Sitotaw & Adamu, 2017; Sular et al., 2014). Thus, this study aimed to explore the viability of upcycled non-woven textiles made of non-biodegradable plastic bag waste for the wearable product development. The specific objectives were to: (a) develop upcycled non-woven textiles using non-biodegradable plastic bag waste through a heat-fusing technique (Jevšnik et al., 2016) and (b) examine durability of upcycled non-woven textiles in terms of tensile strength and seam strength.

Method. This experimental study consisted of two phases: the development of upcycled non-woven textiles and the evaluation of their mechanical properties. The Cradle to Cradle Apparel Design (C2CAD) (Gam et al., 2009), which incorporates the concepts of cradle to cradle (C2C) model (McDonough & Braungart, 2002), was the foundation to develop the upcycled non-woven textile samples for this experiment. Non-biodegradable plastic bags made of polyethylene (PE) were collected through consumers and local grocery stores and used for developing the upcycled non-woven textile samples using a heat-fusing method (Jevšnik et al., 2016). The plastic bags were ironed at 400°F and cut into 7" x 1.5" for fabricating the upcycled non-woven textile samples.

Afterward, the experimental design, consisting of 4 (textile samples) x 5 (repetition), was employed to examine their tensile strength and two types of seam strength that are highly relevant to wearables' durability (Akter & Khan, 2015). The 4 textile samples consisted of 3 types of upcycled non-woven textiles (PE): 2 layers (2L) with M = .05 mm thickness, 4 layers (4L) with M = .07 mm thickness, and 6 layers (6L) with M = .16 mm thickness, along with one control with M = .15 mm thickness. The control was non-woven textiles made of ethylene-vinyl acetate (EVA), which is widely used for water-resistant textiles (Ozen, 2012), footwear (Lopes, 2015), and protective clothing due to its high durability (Nga & Van Thuc, 2023). Stitched seam with 2 mm per stitch length for light weigh fabric (Jana & Khan, 2014) and welded seam (Jevšnik et al., 2016) were used to compare the seam performance of the upcycled non-woven textiles (PE) with the control (EVA) commercially used for raincoat. A constant rate of extension machine (INSTRON 5565) was used to examine tensile strength and seam strength of the samples with an identical sample size of 7” x 1.5” in accordance with the principle of ISO 13934-2:1999 (strip method), with the maintained load and extension speed of 5000 N and 4 inch/min, respectively. SPSS 29 statistical software was used for statistical analysis at $p < .05$. The F-test in ANOVA was performed to determine the significant difference in tensile strength and seam strength among the 4 types of textile samples. The post-hoc comparison with Tukey HSD test was also performed to compare tensile strength and seam strength of all the 4 samples.

Results. The heat-fusing technique (Jevšnik et al., 2016) used for the upcycled material development in this study enabled developing viable non-woven textiles, which can be an alternative of EVA used for commercial raincoat. The upcycled non-woven textiles (PE) exhibited superior durability to that of the control (EVA) after heat-fusing (Jevšnik et al., 2016). For different layers (2L, 4L, and 6L), tensile strength varied from 17 N to 21 N, 49 N to 72 N, and 77 N to 98 N, respectively, while the control had tensile strength ranging from17 N to 28 N. The F-test in ANOVA revealed the statistically significance difference of all the 4 textile samples in tensile strength ($F(3,16) = 109.03$, $p < .001$). The post hoc comparison with Tukey HSD test indicated that tensile strength of 4L ($M = 58.67$, $SD = 9.54$) and 6L ($M = 88.80$, $SD = 8.74$) were significantly higher than that of the control ($M = 23.50$, $SD = 5.51$). There was no significant difference in average tensile strength between the 2L sample ($M = 18.12$, $SD = 1.49$) and the control ($M = 23.50$, $SD = 5.51$). The result discovered that tensile strength of the 2L upcycled non-woven textiles was comparable to that of the control (EVA) used for commercial raincoat. The 4L and 6L upcycled non-woven textiles could be a better option when additional strength is required.

Regarding stitch seam strength, the strength ranged from 10.14 N to 15.59 N, 13.89 N to 17.53 N, and 26.56 N to 34.01 N for the upcycled textile samples with 2L, 4L and 6L, respectively, while the strength for the control was ranged between 7.30 N and 9.33 N. The statistically significant difference in stitch seam strength of all the 4 textile samples ($F(3,16) = 97.22$, $p < .001$) was found. Furthermore, according to the post hoc comparison with Tukey HSD test, stitch seam strength for the samples with 2L ($M = 14.29$, $SD = 2.33$), 4L ($M = 16.15$, $SD = 1.46$), and 6L ($M = 30.65$, $SD = 3.15$) were significantly higher than that of the control ($M = 8.35$, $SD = 0.96$). This finding can be interpreted as upcycled non-woven textiles irrespective of the number of layers outperform the control (EVA) used for commercial raincoat.

The range of strengths for welded seams was 6.35 N to 29.47 N, 14.78 N to 31.95 N, and 5.74 N to 52.08 N for the samples with 2L, 4L, and 6L, respectively, while the control had the strength ranging from 3.25 N to 12.51 N. According to the F-test in ANOVA, welded seam strength did not differ significantly ($F(3,16) = 2.69$, $p = .081$) among all the 4 textile samples. More specifically, welded seam strength for the samples with 2L ($M = 18.53$, $SD = 8.38$), 4L ($M = 24.16$, $SD = 7.55$), and 6L ($M = 25.38$, $SD = 19.97$) was comparable to that of the control ($M = 6.74$, $SD = 3.71$).

Conclusion. For this experimental study, upcycled non-woven textiles were first developed using non-biodegradable plastic bag waste and their durability was examined by comparing with the non-woven textiles (EVA) commonly used for raincoat. According to the study findings, upcycled non-woven textiles are stronger, and their stitched seam strength outperforms that of the control (EVA) while they present the comparable welded seam strength to that of the control. The findings showcase the potential to use upcycled non-woven textiles as an alternative to EVA-based textiles commonly used for raincoat. Moreover, this study provides further insights for textiles and apparel developers and manufactures to use this upcycled material while developing raincoat, which well aligns with the environmental sustainability movement worldwide. This study only employed the technical nutrient component of McDonough & Braungart's (2002) C2C model for upcycling non-biodegradable plastic waste into the new textile development. In future studies, it is encouraged to incorporate the biological nutrient component for the full implementation of C2C approach into the new material development.

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