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ANALYSIS OF WOVEN NATURAL FIBER FABRICS PREPARED USING SELF-DESIGNED HANDLOOM

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ABSTRACT

Woven fabric as composite reinforcement structure has been profoundly investigated to be utilized in automotive, aircraft, agriculture, furniture and defense industry application. Woven fabrics are formed in particular by interlacing of yarns to form a fabric layer. This interlacing of fiber bundle offered advantages in terms of good dimensional stability and high packing density. Due to environmental issues, woven fabric sourced from natural fiber (NF) had gained greater attention. However the methods of woven preparation by means of NF yarns were found to be very limited. Most of the study is focusing on woven structure from fiber strand and it was prepared without specific device. Hence, the challenge addressed in the previous works had triggered research in designing and developing a weaving device suitable for yarns of thick and coarse natural fibers. In this research, a tabletop natural fiber weaving device was designed and fabricated which capable to weave NF yarns with different fabric degree of tightness. Fabrics characterization was analyzed and the static penetration test was conducted. Results demonstrated that fabrics with lower porosity value had greater puncture resistance and higher deflection rate at failure.

***Keywords*:** Woven; natural fiber; Weaving device; Fabric puncture.

INTRODUCTION

Woven is a continuous structure type of textile engineering reinforcement which leads to the supreme characteristic such as higher intra- and interlaminar strength and damage resistance. Various researches had been conducted in identifying its engineering performance and properties (Kim and Sham, 2000; King et al., 2005; Naik et al., 2005, 2006; Tabiei & Nilakantan, 2008; Cao et al., 2008; Rao et al., 2009; Nilakantan et al., 2010; Parsons et al., 2010). Commercial applications of woven textile include products for automotive, aerospace, defense and biomedical as explained by Mohanty et al. (2000); Cao et al. (2008) and Mcdaniels et al. (2009). Since mid-1800s, research on natural fiber was found to evolve actively due to high consciousness of environmental issues includes sustainability issues and insufficient petroleum reserve. However, at its early exposure, natural fiber was used as discontinuous structure reinforcement. Until 1900s, realizing the advantages offered by continuous woven structure, efforts had been made to explore its potentials (Kamiya et al., 2000). The results displayed that continuous NF structure reinforcement had improved the mechanical properties by a factor of three to four (Goutianos et al., 2006). Complimentary works also showed that properties like fracture toughness, ductility index and damage area had been significantly improved (Kim and Sham, 2000; Liu & Hughes, 2008; Kushwaha & Kumar, 2010).

The designed device used in this research does not aim for fabric production efficiency. Nevertheless the design was focusing on research purpose for ease of weaved of complex structure of yarns produced from coarse natural fibers such as kenaf and coconut coir. The photograph of the NF yarns structure was displayed in Figure 1. It was seen that the as received yarns without treatment exhibited relatively high rate of hairiness, thick and coarse in structure. Two different fabric densities could be produced from the device using the same yarn count (fineness). Properties and characterization of the as received yarns and the fabrics produced was assessed and the puncture penetration resistance of the woven NF fabrics was studied.

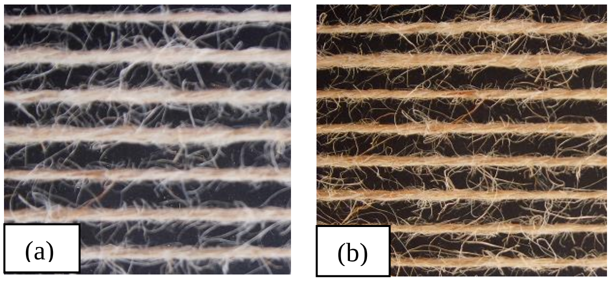

Figure 1. Yarns; (a) kenaf and (b) coir.

DEVELOPMENT OF HANDLOOM

Basic Operational Process

Most of the woven NF geometry used in previous research was strictly depending on the woven mat provides by supplier. Modification in weaving device (loom) is necessary to be done to facilitate changes in the woven mat design. The need for device improvement is rapid and it gives challenges for device manufacturer due to the demand for complex shapes of natural fibers. Besides, new complex woven designs also become part of the challenges. The basic operational concept to interlace yarns to produce fabrics on any type of loom is 'shedding', 'picking' and 'beating'. These three operations are often called as the primary motions of weaving. Shedding involved opening vertical (warp) yarns direction in order to assist horizontal (weft) yarns to get in. 'Harness' was designed for this specific function. On the other hand, weft insertion of yarns or carrying yarns across the loom was called as 'picking' mechanism. Picking was usually assisted by a 'shuttle' device for simple handloom. Beating was the final process in weaving formation. Beating allows in-coming weft yarns to stay close with the other weft yarns to form fabric. 'Reed' or 'comb' was designed for this purpose.

Generally there are numerous complex weaving loom mechanisms and machines that had been developed for mass production since the industrial revolution era. Figure 2 illustrates the schematic of weaving device. Though numerous machines had been developed, the fundamental of the weaving concept is still within the boundary of the three steps as mentioned earlier. Shedding process is vital to defer the pattern of the produced fabric. It could be divided into two categories which are the fixed shedding and programmable shedding. For fixed shedding, heald frames move in the opposite direction, bringing together all yarn to respective frame. This action creates a pathway for the shuttle to interlace the yarns. Unlike the fixed shedding, programmable shedding has loose heddles and could be solely moved depending on the written program.

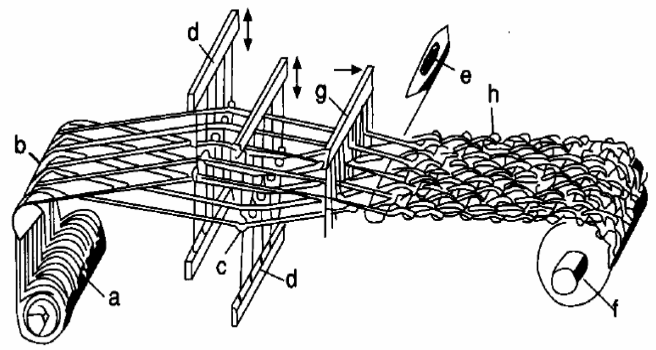

Figure 2. Essential parts of a loom; a-weaver's beam, b-back rest, c-healds (heddle), d-heald frames, e-shuttle weft yarn, f-cloth beam, g-reed and h-woven cloth. (http://textilelibrary.wordpress.com/)

The easiest picking or wefting process is done by moving the shuttle manually across the warping yarns. In advanced design, the motion of the shuttle is driven by other mechanism such as pneumatic or hydraulic drivers. Seyam & El-Shiekh (1990) reported that shuttleless loom is not efficiently weavable for yarns having variations of thickness. Hence, this research employed shuttle handloom for weft insertion due to the thickness discrepancies on natural fibers. Next, beating process allows the formation of fabric. The size of the reed or comb that used to pull yarns close to each other must consider the yarn fineness and fabric size. Bigger reed size resulted in fabrics with porous structure. On the other hand, smaller reed size could induce higher friction between the reed wire and yarns ended to hairiness problems and loose tensioning of warp yarns. Another issue that must take into consideration is the balance pulling force of the reed. Any imbalanced force during the beating process could produce fabric with high porosity as well as fabric disorientation.

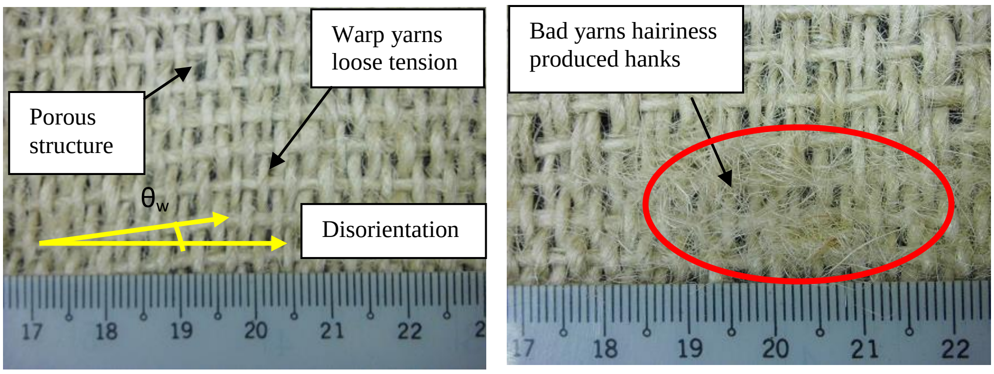

Figure 3. Failure of woven fabric.

Problems Associated With Current Loom

Existing weaving device in laboratory was found to be not ideally fit for respective NF yarns used in this research. Figure 3 pointed up problems occurred during the woven preparation process. High friction rate arises during installing yarns to the floor loom had lead to the very bad yarn hairiness. The condition became worse when the beating process was done where the hairiness form fiber hanks and restricted the movement of the reed. More force was being exerted during beating causes the yarns to loose in tension. Therefore, weft yarns were unable to stay close to each other to form a denser fabric structure. As a result, the yarn interlacing was less tight and the structure was porous. This was in turn increased inter-yarn flow channel and the permeability of the fabric geometry which led to a deterioration of mechanical properties.

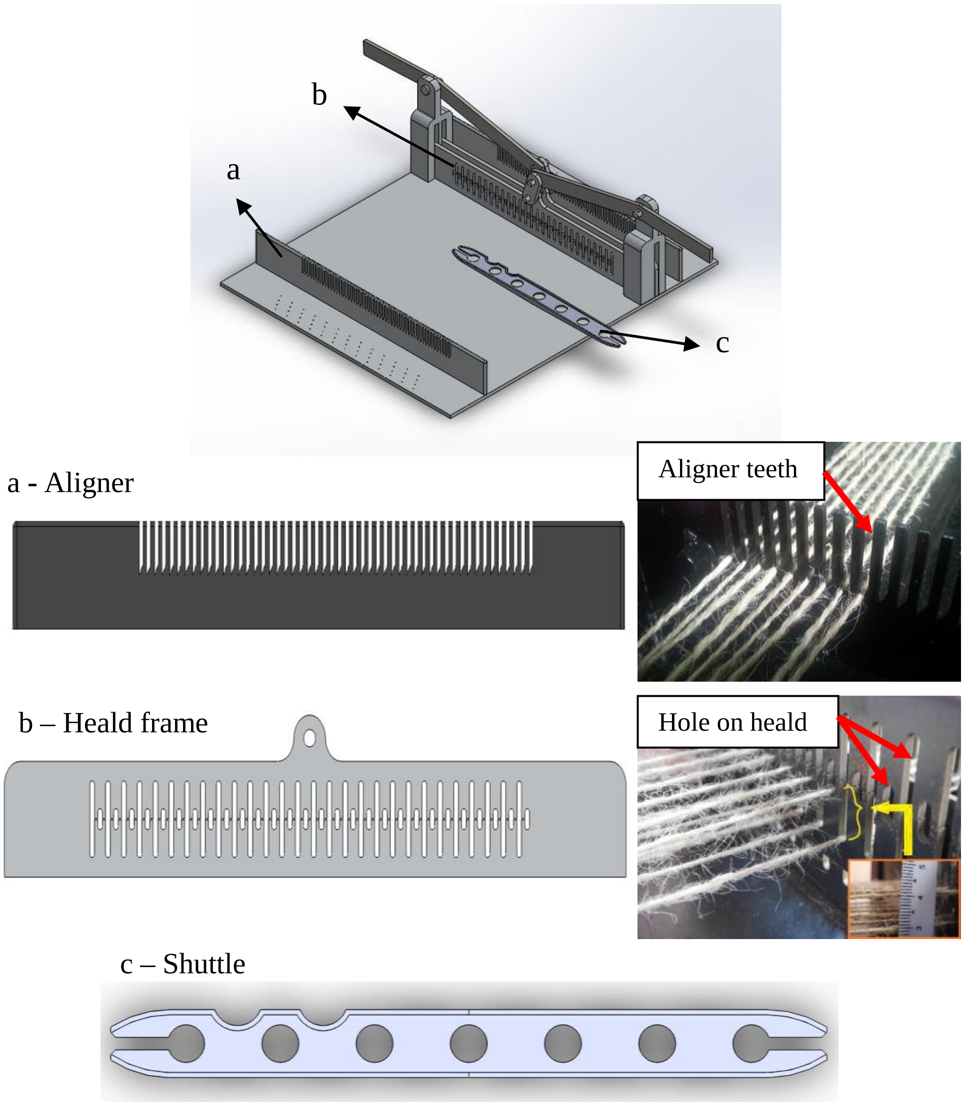

Figure 4. Representation of main parts of self-designed handloom.

Proposed Handloom Design and Its Advantages

The proposed design utilizes manual actuation for all the three basic weaving operations. This prototype manages to produce fabric dimension of 230 mm x 230 mm. The overall size of the weaver is 465 mm x 400 mm x 145 mm (L x W x H). It consists of five major components which are the base with pin holder, front reed aligner, rear reed aligner and two heald frames (Figure 4). The base was made from mild steel to retain the components' positions during weaving. Pin holders were attached at both ends of the base to tie the yarn in Y-axis position. In order to ensure the aligned yarn is in the right position, an aligner was fixed near the finishing end pin holder. As this prototype was designed for laboratory woven sample, no rolling mechanism was attached at the end pin holder. Heald frames were located 265 mm from the front aligner so that the produced sample would have a length around 230 mm in Y-axis. Both frames were actuated using lever-pivot mechanism. The maximum lift elevation recorded between the two frames was a 10 mm gap. The proposed handloom design was found to eliminate disorientation of yarns and the woven structure produced was less porous. Fabrication of close tight woven structure was achieved using the self-designed handloom.

EXPERIMENTAL PROCEDURES AND MATERIALS

Materials and Woven Fabrication

Coir and kenaf natural yarns were supplied from BTex Engineering Ltd., India and Juteko Co. Ltd., Bangladesh respectively. As mentioned earlier, fabrics were produced in two different types; type 1 and type 2. Selection of woven type was based on the highest degree of woven tightness the device can produce. The extensive report from previous work had shown that fabric tightness is highly correlated to fabric properties. It also revealed that fabric tightness significantly impacts weaving resistance (Seyam & El-Shiekh, 1994). Fabric type 1 was having a warp distance of 10 mm, produced using an aligner size of 10 cm gaps between each tooth and heald size of 10 mm gaps between each hole. On the other hand, fabric type 2 (warp distance of 5 mm) was produced using 5 mm gap size between teeth on aligner and 5 mm gaps between holes on heald frame.

Testing and Characterization of As Received Yarns

Characterization of as received yarns was carried out in this research. Yarn fineness (in Tex) was conducted according to ASTM D 2260. It is determined by weighing specified lengths of yarns and converting the data to the appropriate unit. On the other hand, yarn type and yarn twist direction was also been observed. Coir and kenaf yarns were randomly selected for tension test using Universal Testing Machie Llyod 30K. Load cell of 500N was used. A uniform pretension of 2N was applied and gauge length was 100 mm. Selected crosshead speed was 2 mm/min. Specified gauge length was chosen in referring to study done by Subaida et. al. (2008) where they found that most of the strongest fibers are of length between 100 and 150 mm. Breaking strength (MPa), breaking strain (%) and Young's modulus data were recorded.

Testing and Characterization of Fabric Produced

Figure 5 illustrates a model of plain weave fabric. P_1 and P_2 represent the distance between warp yarns and weft yarns. Meanwhile, d_1 and d_2 denotes warp and weft yarn circular diameter. t refers to fabric thickness while λ indicates fabric wavelength. The wavelength of weft is defined by the distance over which the warp pitch wave repeat. The fabric characterization analysis involved fabric thickness testing, fabric weight, fabric density, fabric wavelength and inter-yarn fabric porosity. Fabric thickness (t), was measured using a digital caliper. Fabric weight on the other hand was determined by weighing fabric specimens of predetermined size on a balance. Fabric weight in grams/meter^2 was calculated from the weight of the area measured. The density of a fabric is weighted relative to thickness, expressed in grams/centimeter^3. In contrast, warp and weft density were reported separately and expressed in warp/weft per inch. Weft wavelength was also measured in order to see the crimp effects of the structure. Finally, inter-yarn fabric porosity, ε was calculated using Eq. (1). Porosity is defined as the ratio of the projected geometrical area of the opening across the material to the total area of the material (Çay & Atav, 2007).

$$\varepsilon = \frac{\text{open pore area}}{\text{total area}} = \frac{P_1 - P_2}{(P_1 + d_1)(P_2 + d_2)} \quad (1)$$

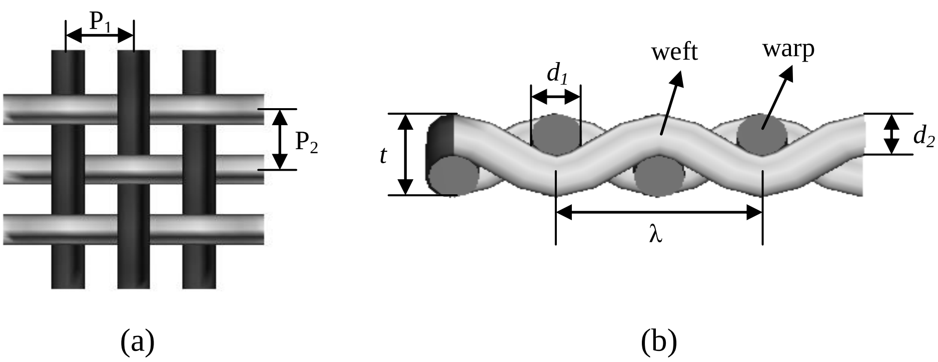

Figure 5. Model of plain weave fabric; (a) top view and (b) cross section view.

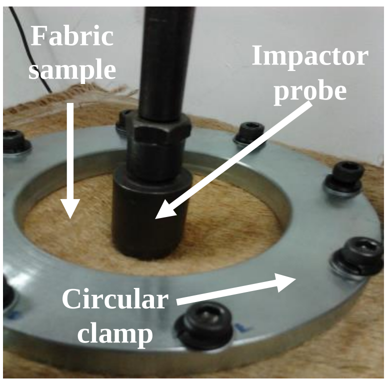

Figure 6. Puncture test on fabric.

Fabric puncture test was performed on an Instron Tensile Machine (Model 5582) according to procedures and dimensions described by Briscoe and Motamedi as mentioned in Hassim et al. (2011). It was a modified puncture resistance test according to ASTM F1342. The test was conducted to measure the force required to penetrate or puncture the dry woven fabric and the amount of deflection that the fabric gains upon penetration. Details of the methods were well explained in Hassim et al. (2011). 5 kN load cell was used at a constant speed of 50 mm/min. The probe used is conical shaped made of stainless steel with a diameter of 25.4 mm. It was positioned with its tip just touching the fabric's surface as shown in figure 6.

RESULTS AND DISCUSSION

Characterization and Properties of As Received Yarns

Characterization and properties of the as received yarns were depicted in Table 1. The overall properties differences between both yarns were found to be not too significant. Coir was found to exhibit a slight higher in Young's modulus in comparing to kenaf yarns. Coir yarns were also found to be a little bit finer than kenaf yarns.

Table 1. Properties of as received yarns.

Properties	Kenaf	Coir
Yarn fineness (Tex)	946	923
Yarn type	1 ply spun	2 ply spun
Twist direction	Z-twist	S-twist
Average breaking strength (MPa)	139	129
Average breaking strain (%)	4.2	3.0
Young's modulus (GPa)	5.6	6.6

Characterization and Properties of Produced Fabric

Table 2 illustrates the physical characterization of woven fabric produced using the self-designed handloom. T1 refers to woven type 1 whereas T2 refers to woven type 2. Results depicted that type 1 fabric exhibited higher thickness and weight. This was due to the greater number of yarns in weft direction but a slightly lower amount of warp per inch. As reported by Kotb (2012), density of warp ends has negative effects on fabric thickness and it shows agreement with this research. However, the effects of weft density towards fabric thickness found in this research displayed a contradict results due to irregular warp density employed in this research. Fabric type 1 also represents higher inter-yarn fabric porosity compare to type 2 fabrics. On the other hand, type 2 structures presented higher crimp effects as a result of lower wavelength.

Table 2. Characterization of woven fabric produced.

Characterization	Kenaf T1	Kenaf T2	Coir T1	Coir T2

Thickness, t (mm)	2.7	2.1	2.4	2.2
Weight (g/m^2)	5800	4400	5600	4600
Density (g/cm^3)	2.1	2.1	2.3	2.1
Warp density (warp/inch)	3	5	3	5
Weft density (weft/inch)	31	21	31	21
Wavelength, λ (mm)	20	10	20	10
Inter-yarn fabric porosity (ε)	0.346	0.198	0.346	0.198

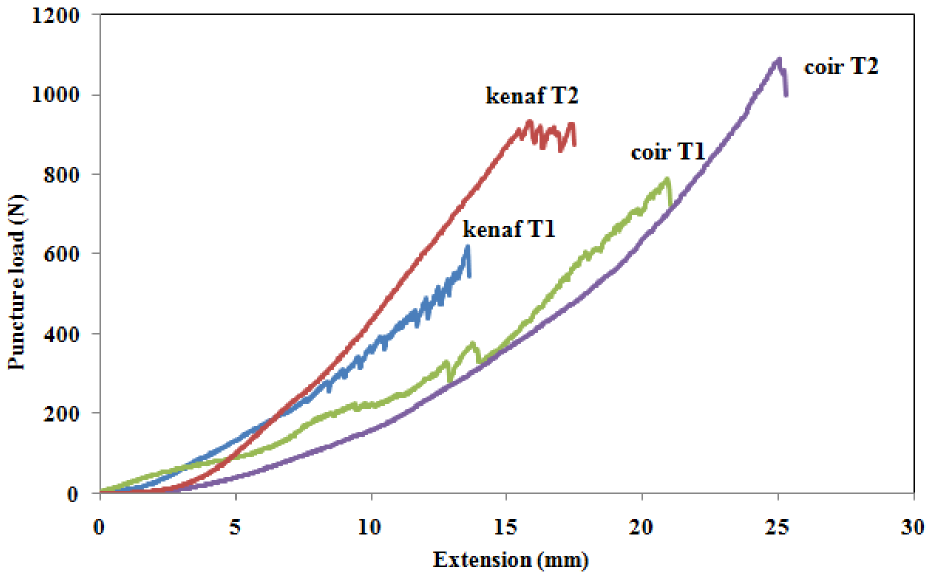

Figure 7. Puncture load versus extension of woven type 1 and type 2.

Typical curves of puncture load (N) versus extension (mm) for the puncture resistance test of all woven fabric samples are shown in Figure 7. It can be seen that fabrics with lower inter-yarn fabric porosity leads to higher penetration resistance. In this case, coir type 2 exhibited the highest impact load followed by kenaf type 2. The reason was most likely because higher forces are required to penetrate fabrics with tight structure. This result is in accordance with the study done by Fatahi and Yazdi (2010) which explained that the fabric strength decreased with an increment of fabric inter-yarn channel (pore value). In comparing kenaf and coir fabric, coir was found to resist higher penetration load. Previous research particularly on kenaf and coir composite also proven that coir demonstrated better impact strength resistance compare to kenaf (Azrin Hani et al., 2012). Extension at maximum load for type 2 fabrics had shown a considerable increment in comparing with type 1 fabric. Coir type 2 presented the highest extension value at peak load. Research done by Abou Nassif (2012) reported that when the fabric weft density reached 71 weft/inch, the fabric breaking elongation decreased. This research had revealed that the higher weft density contributed to lower elongation at maximum load. From the result, coir displayed better elongation at failure compare to kenaf and this is in accordance with the previous work (Akil et al., 2011).

CONCLUSION

The self-designed handloom could produce tight NF woven structure with thickness of as low as 2.1 mm and density of 2.1 g/cm^3 for approximately 1.0 to 1.3 mm yarn diameter. The woven tightness can be varied by adjusting the healds frame and aligner. Woven type 2 was found to achieve lower fabrics inter-yarn porosity with lower wavelength. Type 2 woven structures also demonstrated the highest puncture resistance with superior extension at maximum load.

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REFERENCES

Abou Nassif, G.A. 2012. Effect of weave structure and weft density on the physical and mechanical properties of micro polyester woven fabrics. Life Science Journal, 9(3): 2–7.

Akil, H.M., Omar, M.F., Mazuki, A.A.M., Safiee, S., Ishak, Z.A.M., and Abu Bakar, A. 2011. Kenaf fiber reinforced composites: A review. Materials and Design, 32(8-9): 4107–4121. doi:10.1016/j.matdes.2011.04.008.

Azrin Hani, A.R., Chan, T.S., Ahmad, R., and Mariatti, M. 2013. Impact and flexural properties of imbalance plain woven coir and kenaf composite. Applied Mechanics and Materials, 271-272: 81–85. doi:10.4028/www.scientific.net/AMM.271-272.81.

Cao, J., Akkerman, R., Boisse, P., Chen, J., Cheng, H.S., De Graaf, E.F., Gorczyca, J.L., et al. 2008. Characterization of mechanical behavior of woven fabrics: Experimental methods and benchmark results. Composites Part A: Applied Science and Manufacturing, 39(6): 1037–1053. doi:10.1016/j.compositesa.2008.02.016.

Çay, A., Atav, R., and Duran, K. 2007. Effects of warp-weft density variation and fabric porosity of the cotton fabrics on their colour in reactive dyeing, Fibres & Textile, 15(1): 91–94.

Fatahi, I., and Alamdar Yazdi, A. 2010. Assessment of the relationship between air permeability of woven fabrics and its mechanical properties. Fibers and Textiles, 18(6): 68–71.

Goutianos, S., Peijs, T., Nystrom, B., and Skrifvars, M. 2006. Development of flax fibre based textile reinforcements for composite applications. Applied Composite Materials, 13(4): 199–215. doi:10.1007/s10443-006-9010-2.

Hassim, N., Ahmad, M.R., Wan Ahmad, W.Y., Samsuri, A., and M Yahya, M.H. 2011. Puncture resistance of natural rubber latex unidirectional coated fabrics. Journal of Industrial Textiles, 4(2): 1–14. doi:10.1177/1528083711429144.

Kamiya, R., Cheeseman, B.A, Popper, P., and Chou, T-W. 2000. Some recent advances in the fabrication and design of three-dimensional textile preforms: a review. Composites Science and Technology, 60(1): 33–47. doi:10.1016/S0266-3538(99)00093-7.

Kim, J-K., and Sham, M-L. 2000. Impact and delamination failure of woven-fabric composites. Composites Science and Technology, 60(5): 745–761. doi:10.1016/S0266-3538(99)00166-9.

King, M.J, Jearanaisilawong, P., and Socrate, S. 2005. A continuum constitutive model for the mechanical behavior of woven fabrics. International Journal of Solids and Structures, 42(13): 3867–3896. doi:10.1016/j.ijsolstr.2004.10.030.

Kotb, N.A. 2012. The Perception of plain woven fabrics' performance using regression analysis, 2(1): 20–26.

Kushwaha, P.K., and Kumar, R. 2010. The studies on performance of epoxy and polyester-based composites reinforced with bamboo and glass fibers. Journal of Reinforced Plastics and Composites, 29(13): 1952–1962. doi:10.1177/0731684409342006.

Liu, Q., and Hughes, M. 2008. The fracture behaviour and toughness of woven flax fibre reinforced epoxy composites. Composites: Part A, 39: 1644–1652. doi:10.1016/j.compositesa.2008.07.008.

Mcdaniels, K., Downs, R.J., Meldner, H., Beach, C., and Adams, C. 2009. High strength-to-weight ratio non-woven technical fabrics for aerospace applications. Cubic Tech Corp.

Mohanty, A.K., Misra, M., and Hinrichsen, G. 2000. Biofibres, biodegradable polymers and biocomposites: An overview. Macromolecular Materials and Engineering, 276-277(1): 1–24. doi:10.1002/(SICI)1439-2054(20000301)276:1<1::AID-MAME1>3.0.CO;2-W.

Naik, N.K, Shrirao, P., and Reddy, B.C.K. 2005. Ballistic impact behaviour of woven fabric composites: Parametric studies. Materials Science and Engineering: A, 412(1-2): 104–116. doi:10.1016/j.msea.2005.08.019.

Naik, N.K, Shrirao, P., and Reddy, B.C.K. 2006. Ballistic impact behaviour of woven fabric composites: Formulation. International Journal of Impact Engineering, 32(9): 1521–1552. doi:10.1016/j.ijimpeng.2005.01.004.

Nilakantan, G., Keefe, M., Bogetti, T.A., Adkinson, R., and Gillespie Jr., J.W. 2010. On the finite element analysis of woven fabric impact using multiscale modeling techniques. International Journal of Solids and Structures, 47(17): 2300–2315. doi:10.1016/j.ijsolstr.2010.04.029.

Parsons, E.M., Weerasooriya, T., Sarva, S., and Socrate, S. 2010. Impact of woven fabric: Experiments and mesostructure-based continuum-level simulations. Journal of the Mechanics and Physics of Solids, 58(11): 1995–2021. doi:10.1016/j.jmps.2010.05.006.

Rao, M.P., Nilakantan, G., Keefe, M., Powers, B.M., and Bogetti, T.A. 2009. Global/Local Modeling of Ballistic Impact onto Woven Fabrics. Journal of Composite Materials, 43(5): 445–467. doi:10.1177/0021998308097684.

Seyam, A., and El-Shiekh, A. 1990. Mechanics of woven fabrics: Part I: Theoretical investigation of weavability limit of yarns with thickness variation. Textile Research Journal, 60(7): 389–404. doi:10.1177/004051759006000704.

Seyam, A., and El-Shiekh, A. 1994. Mechanics of woven fabrics: Part IV: Critical review of fabric degree of tightness and its applications. Textile Research Journal, 64(11): 653–662. doi:10.1177/004051759406401105.

Subaida, E.A, Chandrakaran, S. and Sankar, N. 2008. Experimental investigations on tensile and pullout behaviour of woven coir geotextiles. Geotextiles and Geomembranes, 26(5): 384–392.

Tabiei, A., and Nilakantan, G. 2008. Ballistic impact of dry woven fabric composites: A review. Applied Mechanics Reviews, 61(1), 010801. doi:10.1115/1.2821711.
Textile Library. http://textilelibrary.wordpress.com/, accessed on 14-01-2013.