FIBRE AND FABRIC CHARACTERIZATION OF SOIL BAGS USED FOR EROSION CONTROL OF EMBANKMENTS

Amanullah Marri[1], Gul Muhammad[2], Zubair Ali[3], Sheraz Hussain Siddique Yousfani[4], Sadia Moin[5]

[1,3,4,5] NED University of Engineering & Technology, Department of Civil Engineering, Karachi, Sindh Pakistan 75270.

[2] Ziauddin University, Faculty of Engineering, Science, Technology & Management, Department of Civil Engineering, Karachi, Sindh Pakistan 75050.

Corresponding author: Gul Muhammad,

Abstract

The erosion control of the embankments of water bodies such as coastal lines, river embankments, earthen dam embankments, etc. is a challenge. There are various methods to protect the embankments from erosion. One of the effective methods is the use of soil bags. Based on the type of soil filled in the soil bags and environmental conditions, different types of fibre and fabric are in use for the preparation of these bags. A relative comparison of different types of fibre and fabric is essential for the selection of a suitable type of soil bag. Soil bags have been used for the protection of embankments against erosion control for years; however, the selection of geosynthetic materials to be used for the bags and their fabric is not well defined in the literature and, therefore, needs to be investigated in detail. The present study aims to identify a suitable type of soil bag for erosion control of embankments. The objective of the present study is to try different fibres and fabrics for the soil bags, to check the performance of soil bags filled with different types of soils and to evaluate their performance under different environmental conditions. Polypropylene spun bond and woven fabrics were selected for the characterization to be used as soil bags. Four polypropylene and one polyester fibre consisting of three non-woven fabrics and two woven were investigated as soil bags for erosion control. The index properties of different geosynthetic fibres were determined in the laboratory. Moreover, soil bags were prepared and filled with the soils which are usually used for erosion control. The soil bags were tested in the laboratory for their performance evaluation based on their porosity, water resistance, tensile properties, tensile strength and thermal conductivity. The test results indicated that the porosity and pore area reduced with the increase in the fabric mass in grams per meter square. The case of non-woven fabrics had less porosity as compared to the woven fabrics. All types of fabrics have a higher tensile strength in the lengthwise direction as compared to the widthwise direction. The woven fabrics have less water resistance than all the fabrics. There is an increase in the thermal conductivity of the non-woven fabrics with the increase in the gram per square meter GSM. The sandbags manufactured by using 100 GSM non-woven fabrics have the highest tensile strength as compared to the woven and non-woven fabrics. From the results it may be concluded that the non-woven fibre with 100 GSM is relatively better for use in the preparation of soil bags for embankment stability and erosion control.

***Keywords*:** Fabric, Erosion, Fibre, Characterization, Embankment.

1 INTRODUCTION AND BACKGROUND

The stability of structures especially embankments against erosion has always been an immense challenge. There are various methods to prevent soil erosion such as the use of fibre as an additive material in the soil for the stability of embankment against soil erosion gives promising results in soil erosion control [1]. According to Saathoff, Oumeraci [2] and Fu, Liu [3] soil bags are permeable containers made of natural or synthetic fibers/fabrics that are filled with soil and placed on slopes or embankments to control erosion. Soil bags help to prevent soil erosion when they are packed and placed near roadways in danger of collapsing because of soil erosion [4]. The use of coarse-grained soils such as sand to fill bags has been effective due to its high permeability to flow water through it and preventing any loss of soil retained in a bag due to the large particle size of sandy soil [5]. The fibers/fabrics allow vegetation to grow through them while holding the soil in place. Characterizing the fibers/fabrics is important to understand their properties and how they will perform for erosion control. Properties to analyze include, Fiber/fabric type - Natural (jute, coir) or synthetic (polypropylene, polyester) [6]. Natural fibers biodegrade over time. Thread count - Higher thread counts result in finer, more durable fabrics. Pore size - Smaller pores better hold soil particles while still allowing plant growth. Tensile strength - How much weight/force the fabric can withstand before tearing. Degradation rate - How long the fibers/fabrics are expected to maintain integrity as they biodegrade [7]. UV resistance - Ability to withstand sun exposure without degrading. Other tests analyze water permeability, soil retention capacity, shear strength, etc. Characterization helps select the right fiber/fabric for the soil/climate conditions and erosion risk level. It provides data on how long bags will last before fully degrading. According to Oberhagemann, Hossain [8] and Krenitsky, Carroll [9] both fiber type and construction quality impact long-term effectiveness of soil bags for erosion control applications. It is worth mentioning here that fiber refers to the basic unit or constituent material that makes up the fabric whereas fabric is the woven or non-woven structure formed by interlocking or bonding fibers together. So in summary, fibers are the basic material units whereas fabric is the assembled structure formed, with its own set of performance properties for geosynthetic functions. Both characterization is important. The porosity and pore sizes are important in the infiltration and drainage applications of geotextiles [10].The porosity will also have an impact on the drainage and filtration capability of the fabric [11]. The porosity of the fabric is important in the case of soil bags because it will determine the particle size of the soil to be retained by the bag. The porosity will also have an impact on the drainage and filtration capability of the fabric. The water permeability characteristics of geotextiles are of paramount importance mainly for filtration and drainage applications of geotextiles. Since the end application involves the use of soil nets in channel embankments, the water can influence the net's stability; therefore, the water resistance of the fabrics is calculated [12]. The thermal conductivity can be influenced by the material's chemical composition and molecular structure as well. Material with simple chemical composition and molecular structure has higher thermal conductivity than the complex. Thermal conductivity is an important key property in geo-textiles. It is responsible for the heat flow at the equilibrium state and the temperature field in the geomaterial. In terms of porosity, the higher the porosity is, the lower will be the thermal conductivity. For thermal conductivity, not only the porosity is important, but the size, shape, connectivity, and distribution of the pores are also important. The thermal conductivity of textile fabrics being used for environmental purposes is important as the fabric is exposed to different conditions such as variations in temperature. Through experiments, it was observed that the thermal conductivity of geo-textiles depends mostly on the water content which means that non-woven geotextiles that are not treated exhibit lower thermal conductivity because of their hydrophobic character. The thermal conductivity of geotextiles also varies with the conditions in the surroundings [13].

2 MATERIALS

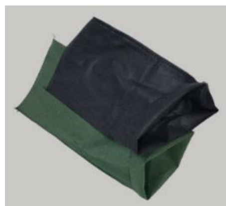
Three Polypropylene (PP) Spunbond and two woven fabrics were procured from the market. The details for different types of fabrics are mentioned in Table 1and the details of different type of soil bags are shown in Table 2.

Table 1 Details for different types of fabrics

Sample ID	Fabric type	GSM g/m²	Thickness (mm)
A	PP Spunbond	40	0.353
B	PP Spunbond	80	0.500
C	PP Spunbond	100	0.580
D	Plain weave 1/1 PP	44.5	0.393
E	Twill weave 1/1+3/1 polyester	166	0.616

*GSM = stands for grams per square meter

Table 2 Different Types of Soil bags made from different types of fabrics

				
Polypropylene Non-Woven sandbags (40 GSM)	Polypropylene Non-Woven sandbags (80 GSM)	Polypropylene Non-Woven sandbags (100 GSM)	Plain weave 1/1 PP Woven (44.5 GSM)	Twill weave 1/1+3/1 Woven Polyester (166 GSM)

3 METHODS

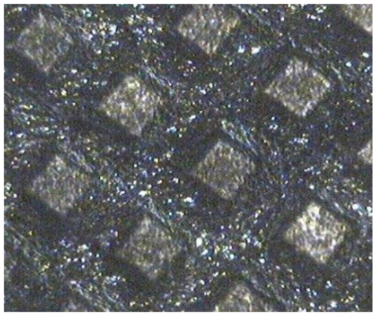
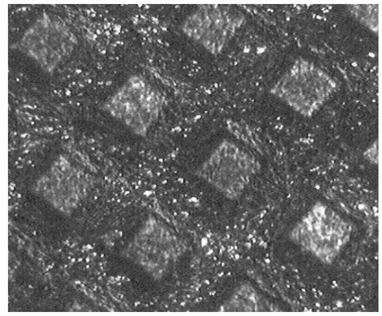
Five different types of fabric were tested for porosity, water resistance, thermal conductivity, tensile and tensile properties using ASTM standards as mentioned in Table 3.

Table 3 Soil Bags Characteristics Tested

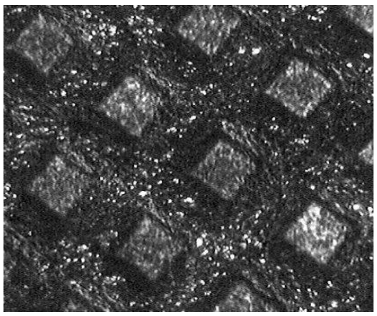
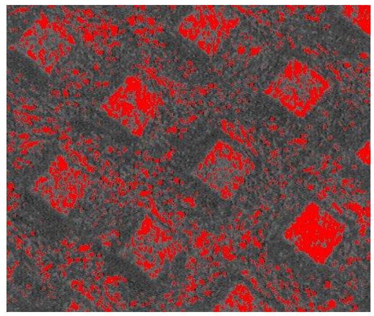
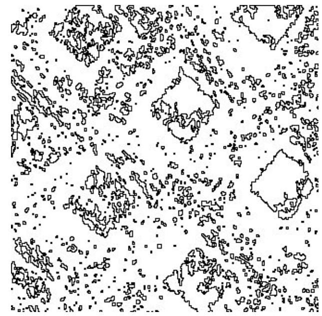
S. No.	Characteristics	Standard
1	Porosity	ASTM D4751 – 21
2	Water resistance	AATCC 127
3	Thermal characteristic	ASTM E 1530
4	Tensile strength	ASTM D 5035
5	Tensile strength	ASTM C 39 / C39 M

3.1 POROSITY TESTING PROCEDURE

For the fabrics to be used in the field for soil reinforcement the Apparent Opening Size (AOS) is determined by using ASTM D4751 – 21[14]. The image analysis method was used to determine the porosity of the fabric. In the image analysis method, the fabric samples of 2 inches by 2 inches were cut and the image of these fabric samples was taken by using the electronic microscope at 15X magnification. Image J software was used to process the image and the image of 320 by 320 was taken from the main image. The image was calibrated with a scale of 80 pixels per millimeter for the size of the image was 4mm by 4mm. The images were converted to an 8-bit grey level, and the contrast of the image was enhanced to make the pores prominent. The image was the threshold to separate the fibres and pores. Then the number of pores, porosity in percentage and the area of pores were determined with the help of Image J software. The method is shown diagrammatically in Figure 1. This procedure was followed to calculate the porosity of all types of fabrics.

A B

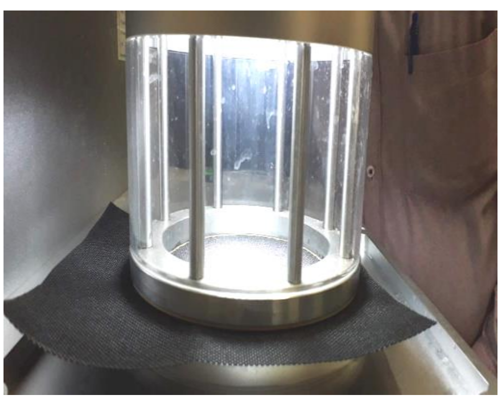
  

C D E

Figure 1. A Original image B Greyscale image C Enhanced contrast image D Image after threshold E image of the pores

3.2 WATER RESISTANCE TESTING PROCEDURE

The resistance of the fabric to the penetration of water under hydrostatic pressure was determined using the AATCC 127 test method [15]. A hydrostatic head tester was used to determine the water resistance for different types of fabric. The size of the specimen was taken as 200 mm by 200 mm. The test setup is shown in Figure 2.

A B

Figure 2. A Specimen clamped in hydrostatic head tester B water drops appearing on the sample

3.3 THERMAL CONDUCTIVITY TESTING PROCEDURE

The thermal conductivity for different types of fiber/fabrics was determined using the steady-state technique (ASTM E 1530) and [16]. A heat flux transducer with two plates was used to perform this test with the fabric specimen size of 6cm by 6cm.

3.4 TENSILE PROPERTIES TESTING PROCEDURE

The tensile properties of different fabrics were determined using the ASTM method[17]. Five samples were tested lengthwise and five samples were tested widthwise for each category. The soil bags 6 inches in diameter and 20 inches in length were prepared according to the ASTM Standard[18]. The clay was used to fill these soil bags. The compression load was applied to these bags using a universal strength tester (UH-500 KNI). The tensile load at break was determined in kilo Newton (kN) and the stroke size in mm was also determined. The test setup is shown in Figure 3.

A

B

Figure 3. Before Application of tensile load (A), After application of tensile load (B)

4 RESULTS AND DISCUSSION

4.1 POROSITY OF WOVEN AND NON-WOVEN FABRIC

Porosity of the fabric was investigated by using image analysis software using high color image to find out porosity [19]. The porosity in percentage and the average area of pores in square micrometers are compared in Figures 4 and 5. From The Figures 4 and 5 it can be seen that for nonwoven fabrics, the porosity and pore area reduced with the increase in gram per meter square. In the case of woven fabrics, polypropylene fabric had less porosity as compared to polyester fabric. Because of the open design of the polyester fabric, it seems that it had the highest porosity and highest pore area among all the fabrics used. It is believed that this fabric will have a higher apparent opening size than other fabrics used for this research work.

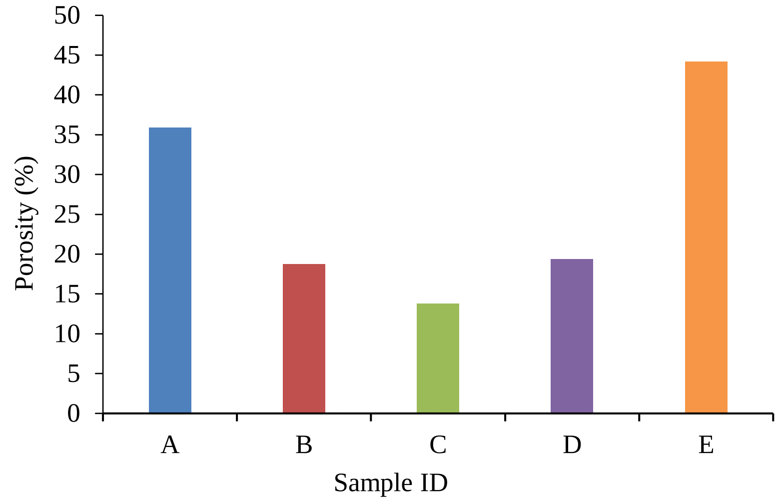


Figure 4. Porosity for different fabric samples in percentage

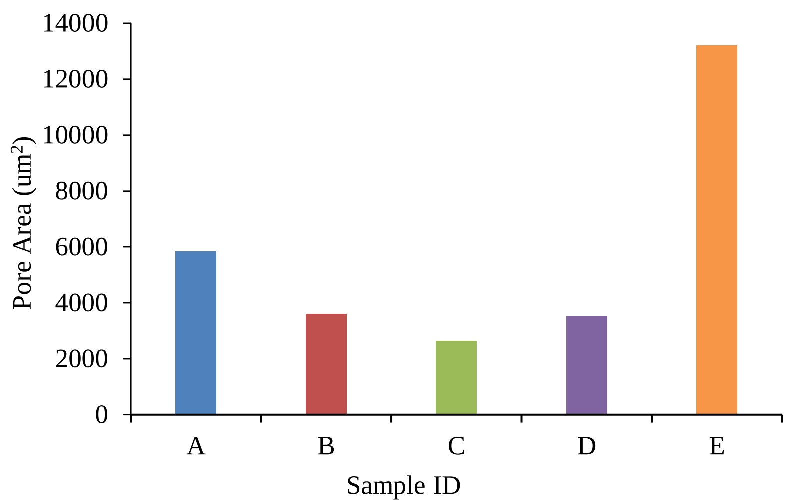


Figure 5. Pore area in square micrometer for different types of fabric samples

4.2 WATER PERMEABILITY

The water resistance for different types of fabrics was determined in terms of millibar pressure per time in seconds. However, the resistance of a fabric to water was calculated in terms of millibar per minute (mb/min.). The results are compared in Figure 6.

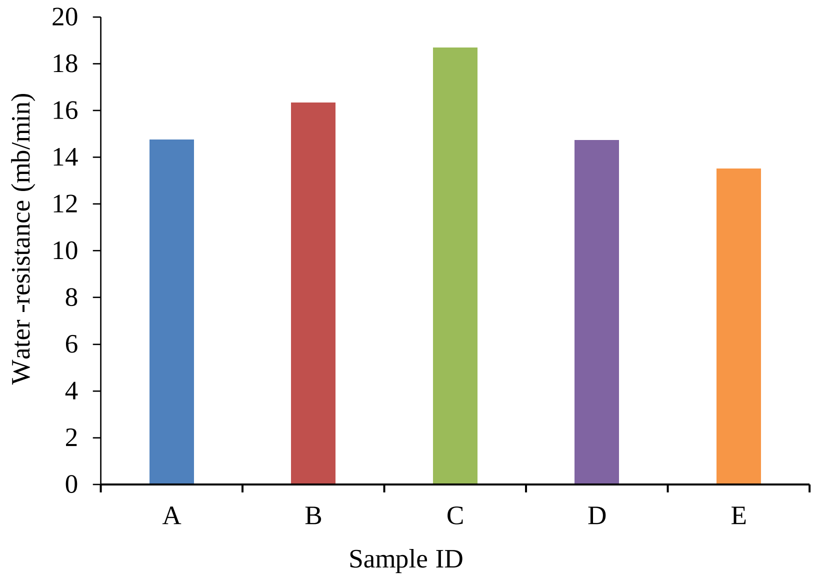


Figure 6. Water resistance in millibar per minute

From Figure 6, it was observed that in the case of nonwoven fabrics as the GSM increases the water resistance of the fabric also increases. For the woven fabrics, the polyester fabric has shown less water resistance among all the fabrics. This means that when this fabric experiences water flow under pressure, the polyester fabric will show less resistance. This property could also be related to the porosity of fabrics. As shown in Figure 4, it was observed that for nonwoven fabric the porosity had decreased with an increase in GSM, and the polyester fabric had higher porosity than polypropylene fabric and thus it shows lower water resistance. It was observed from Figure 6 that the water resistance had increased with the decrease in porosity.

4.3 THERMAL CONDUCTIVITY

The thermal property of a fabric is defined as the rate at which heat is transferred through the unit cross-section of any material by conduction. The thermal conductivity for different types of fabrics was determined in terms of watts per Meter-Kelvin (W/mK). The results are compared in Figure 7. From the figure it was observed that the thermal conductivity of the nonwoven fabrics increased with the increase in the GSM. For the woven fabrics polyester fabric had higher thermal conductivity as compared to polypropylene woven fabric due to higher GSM. This means the polyester fabric has reasonable thermal conductivity, and it will allow the heat to flow and will offer less resistance to the flow of heat as compared to propylene fabric.

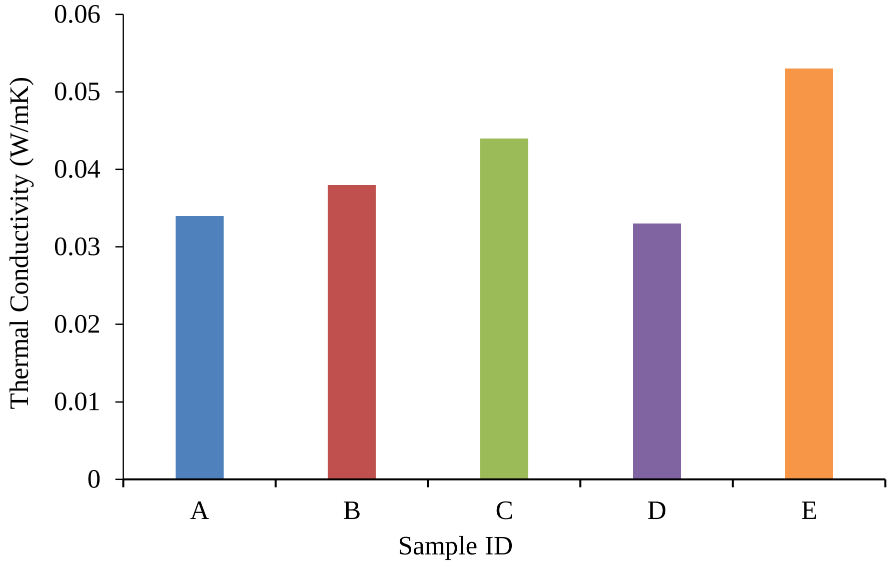


Figure 7. Thermal conductivity in W/mK.

4.4 TENSILE PROPERTIES

The tensile properties i.e. tensile strength, strain and modulus were determined for different types of fabrics to be used as soil bags. The results are shown in Figure 8 , Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13 . These properties were determined in both length and width directions. From Figure 8, Figure 10 and Figure 12 it was observed that all types of fabrics have a higher tensile strength in the length direction as compared to the width direction. It was also observed that an increasing trend is observed in the case of nonwoven fabrics that with the increase in gram per square meter (GSM) the tensile strength of the fabric is increasing. The tensile strength of woven fabrics is higher as compared to non-woven fabrics, as the process of weaving involves the interlacement of yarns which makes the fabric stronger. The fabric E i.e. polyester fabric has the highest tensile strength because of higher GSM amongst all fabrics used in this research work.

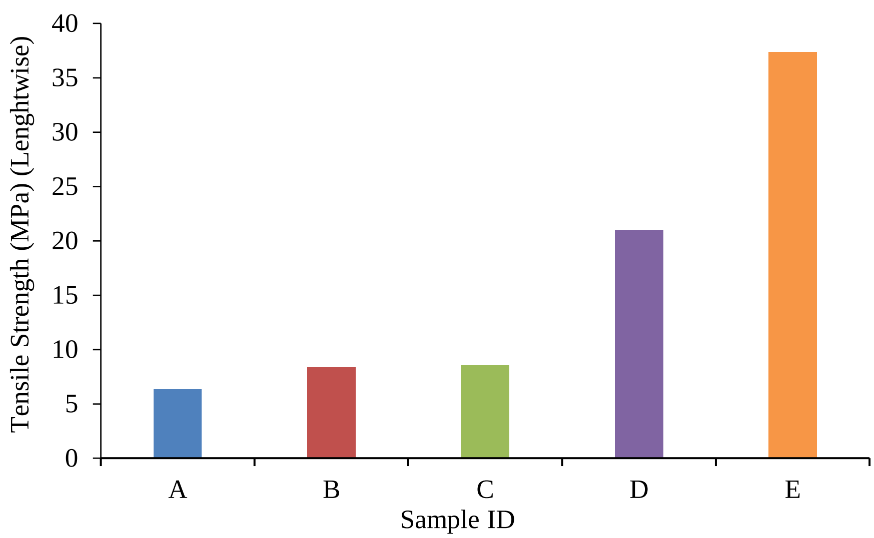


Figure 8 .Tensile Strength in MPa (Lengthwise)

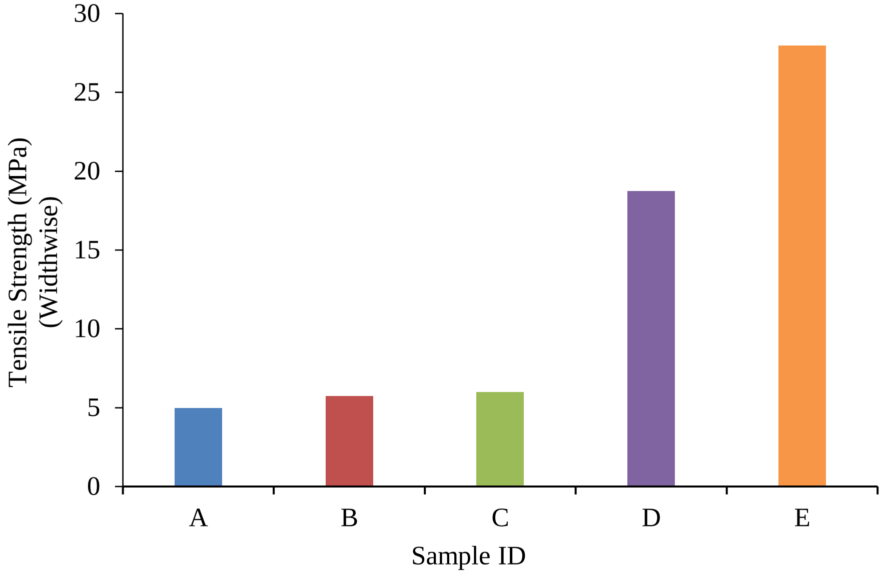


Figure 9. Tensile Strength in MPa (Widthwise)

From Figure 10 and Figure 11, it was observed that the tensile strain for the nonwoven fabrics increases with the increase in the GSM. However, in the case of lengthwise testing, this trend was not followed. For the woven fabrics polyester fabric had high strain as compared to polypropylene fabric. This might be perhaps due to the organized structure of the fabric. The strain for the nonwoven fabrics was higher than for woven fabrics. This was perhaps because the nonwoven fabrics do not have a proper structure and therefore they elongate more as compared to the woven fabrics.

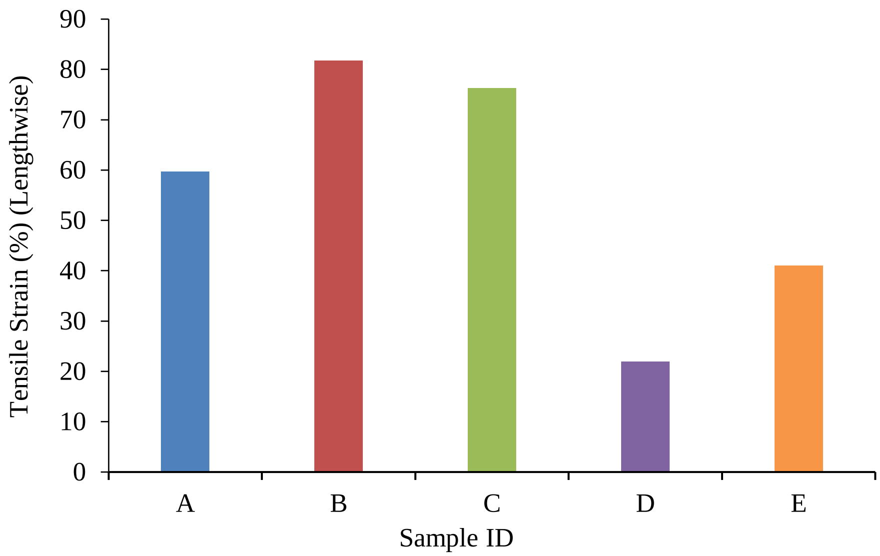


Figure 10. Tensile Strain in %age (Lengthwise)

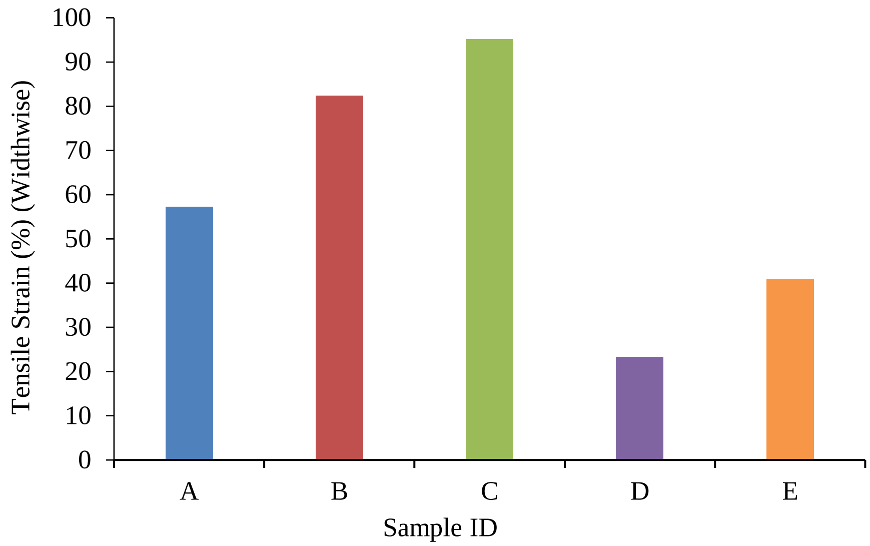


Figure 11. Tensile Strain in %age (Widthwise)

From Figure 12 and Figure 13, it was observed that the tensile modulus of nonwoven fabrics has shown an increasing trend in the length direction; however, this trend was not followed in the width direction. The modulus of nonwoven fabrics was much lower than the woven fabrics because the woven fabrics have higher strength and lower strain. For woven fabrics, polyester fabric has a higher modulus in the length direction and a slightly lower modulus in the width direction. It seems from the results that the polyester fabric has the highest strength and modulus.

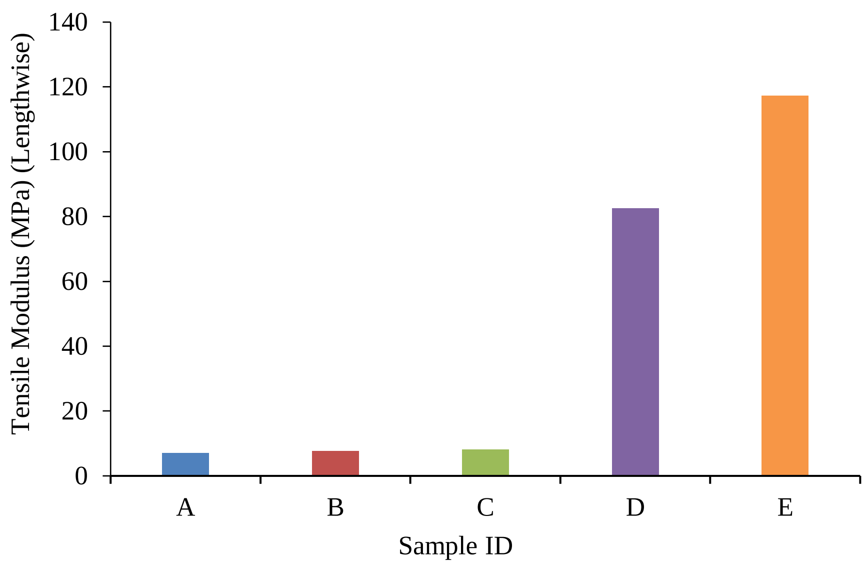


Figure 12. Tensile Modulus in MPa (Lengthwise)

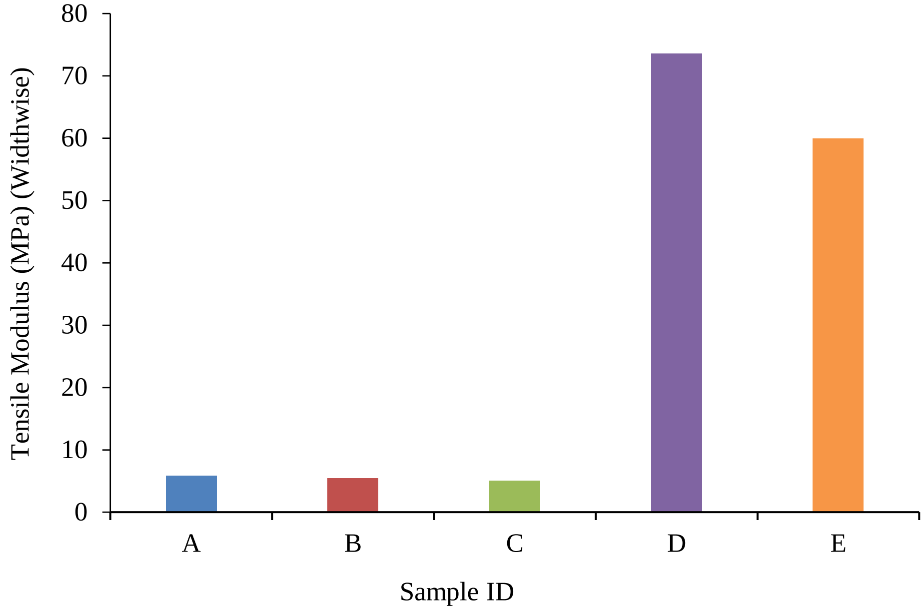


Figure 13. Tensile Modulus in MPa (Widthwise)

4.5 TENSILE STRENGTH

Tensile strength of the fabric plays important role in resist the tension force induced by the absorption of water which will effect on the serviceability of the fabric. It was found out that tensile strength of fabric was reduced to 2.7% when fabric was submerged in water for 24 hours as compared to dry state [20]. The soil bags were tested to measure the tensile strength and stroke displacement. The results are shown in Figure 14 and Figure 15 .

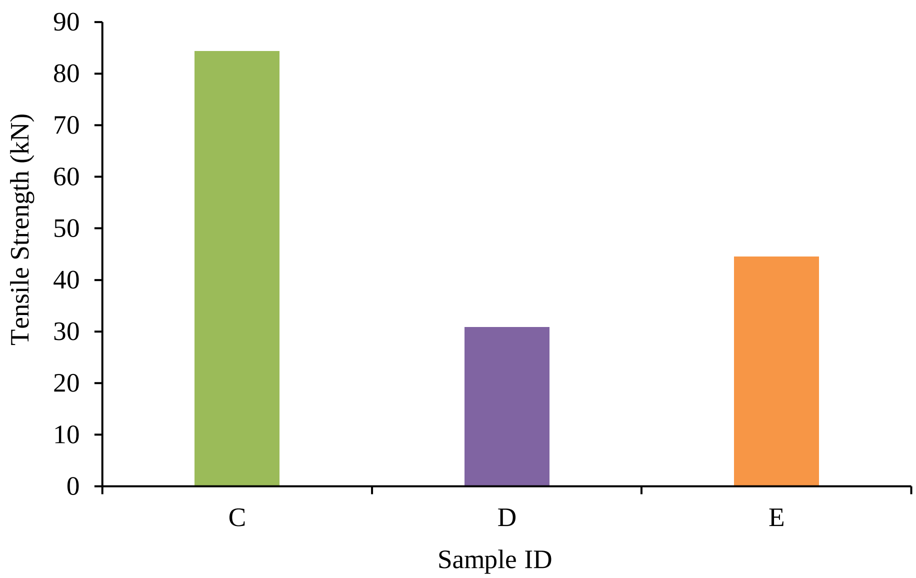


Figure 14. Tensile strength for different types of soil bags in kN

From Figure 14, it was observed that the soil bags manufactured by using 100 GSM nonwoven fabrics have the highest tensile strength as compared to the woven PP and polyester fabrics. From the earlier results, it seems that the polyester and polypropylene fabrics had higher strength as compared to the nonwoven fabrics in the case of index testing. However, in the case of performance testing, nonwoven soil bags have higher tensile strength. This was perhaps due to the higher elongation of the nonwoven fabrics as compared to the woven fabrics.

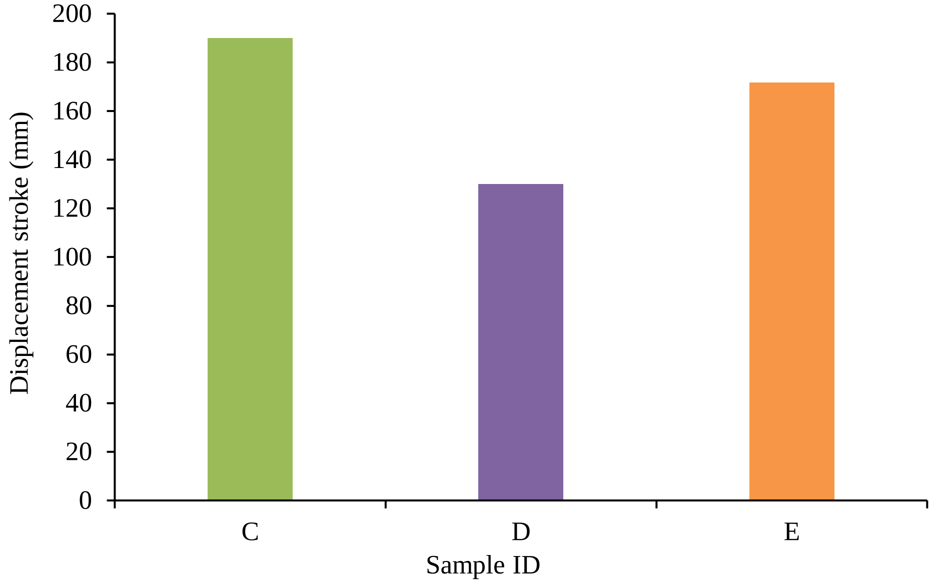


Figure 15. Displacement stroke in mm for different types of soil bags

From Figure 15 , it was observed that the soil bags manufactured from 100 GSM nonwoven fabric have the highest displacement during the compression test as compared to other woven fabrics. This was perhaps due to the elongation of these fabrics.

5 CONCLUSIONS

Four polypropylene and one polyester fibre consisting of three non-woven fabrics and two wovens were investigated as soil bags for erosion control. The first three sample ID A, B, and C non-woven fabrics and the last two sample ID D, E woven fabrics were investigated. From the experimental results, it may be concluded that:

1. The porosity and pore area were reduced with the increase in the fabric mass in grams per meter square. Non-woven fabrics had less porosity as compared to the woven fabrics.
2. All types of fabrics have a higher tensile strength in the lengthwise direction as compared to the widthwise direction.
3. The woven fabrics have less water resistance than all the fabrics.
4. There is an increase in the thermal conductivity of the non-woven fabrics with the increase in the GSM.
5. The sandbags manufactured by using 100 GSM non-woven fabrics have the highest tensile strength as compared to the woven and non-woven fabrics.

The non-woven fibre with 100 GSM is relatively better for use in the preparation of soil bags for embankment stability and erosion control.

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