Preparation and Properties of Waterproof Coated Fabrics using Non-Woven Fabric as Base Material

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ABSTRACT--*Waterproof coated fabrics find numerous engineering applications in day to day life. In this research work acrylic polymer coating material is used with non-woven fabric as base material to develop a waterproof coated fabric. Non-woven fabric with varying layers and thickness is used in preparation of waterproof coated fabrics. Roller method of coating is employed in this research to develop waterproof coated fabrics. Numerous properties like water repellency tests, thickness test, chemical tests, peeling test, Air permeability test, coating hardness tests, thermal property tests and SEM test to observe changes in surface morphology of coated fabrics is employed. Results show that the coated fabrics possess good water repellency characteristics, resistance to chemical degradation, breaking strength, and excellent durability for wear and tear.*

Keywords-- *Water repellent properties, adhesion bond strength, Thermal properties, Acrylic polymer binder, Water repellency test*

I. INTRODUCTION

Waterproof coated fabrics are engineered materials which are made from non-woven materials or any kind of textile fabric as base material. They are normally made using layering technique coupled with application of binder to hold the layers together. These layers are held firmly by means of polymer binder usually an acrylic binder. Roller coating techniques are used to develop the waterproof coated fabrics. Coating technique is a complicated process. It normally requires careful handling and control of overall fabric weight and thickness. [1][2]

Water proof fabric materials are characterised by properties which prevent penetration of fluids and is impervious to water. Waterproof fabrics can be classified as breathable ones and the non-breathable ones. Waterproof breathable fabrics combines the functionality of waterproofness and breathability. The breathability function enables the waterproof fabric to respond to transmission of water vapour to the surroundings. These class of fabrics find their application in clothing design and development of functional fashion materials. However, the other class is the non-breathable water-proof fabric which technically is a heavy duty materials which are 100% resistant to penetration of water. These materials are made using polymer and acrylic binders which find

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Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

application in car flooring, bathroom floor lining, roofing lining which are functional in their use by providing well needed support for the steel and concrete structures of buildings, interiors, floorings,etc.

The fundamental properties that need to be considered while developing a 100% waterproof fabric [3, 4] is mainly dependent on the interaction of the adhesive with the fabric layers. Important properties that influence overall performance of a 100% waterproof fabric include, water repellence, resistant to chemicals, air permeability, coating hardness and density of materials, Thermal behaviour and layer peel adhesion tests.

Water proof fabrics that can be used for preparation for coating can be of many types. It can be made from hydrophobic fibers like polyester, nylon, etc. The selection of this base material depends on the application and coating solution compatibility. Most often polyester fiber based materials perform well in the given circumstances. The polymers and binder selection also depends on the application. The binder properties include like low water absorption, excellent crack bridging properties, low odour and compatibility with other binding materials.

The prime objective of this research work is to prepare a 100 % waterproof fabric which can perform well in structures prone to rain, heat and crack propagating finishes like the flooring, roofing, etc. The research also focusses on the evaluation of the properties of these fabrics by conducting many textile specific tests on the coated material using roller coating process.

Non-woven fabric made from polyester fiber is used as the base material for development of waterproof fabric [5, 6] along with acrylic binder to obtain engineering properties of a waterproof fabric. A brush roller is used for coating the non-woven fabric using acrylic polymer binder. The roller is dipped and rolled on the surface of the non-woven fabric. Evaluation of properties of the developed coated fabric is carried out using in-house fabricated water-repellency tester (using spray tester as per AATCC TM22 – 2017 standards). The thickness of the fabric is tested using standard thickness gauge used for textile testing. Peel layer adhesion test (ASTM D903-98(2010)) is conducted on the developed fabric to ascertain the compactness of the layers and bonding levels in the developed coated fabric. [7, 8]

Chemical tests are performed on the developed coated fabric to assess the effect of strong alkalis like sodium carbonate, bleaching agents like sodium hypochlorite and strong acids like sulphuric acid. The air-permeability test, thermal properties, peel adhesion levels are measured for the developed fabrics.

II. EXPERIMENTAL, MATERIALS AND METHODS

1.1 Raw materials

Non-woven fabric made from 100 % polyester fiber, manufactured through melt-spun and bonding process was used as a base material to develop water-proof coated fabric. Acrylic polymer binder was used for developing water-proof coated. The technical specifications of the acrylic binder is given in Table 1.

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

Figure 1: Raw materials A) Non-woven fabric B) Layers of Non-woven fabric C) Acrylic polymer binder

The same non-woven fabric was used in layers to develop a thicker water-proof coated fabric. The acrylic polymer binder used for fabrics is unique in its nature with a white thixotropic appearance. The polymer binder cures after application, immediately and would gradually harden within 48 hours of application. The tensile and permeability properties were excellent. Fig 1 shows the details of raw material used in development of water-proof coated fabric. The acrylic binder used is a waterproof fiber compatible compound. This water-proof binder is very useful in creating fish ponds and many other water-proofing applications. This compound can be applied using roller coating process on the layers of Non-woven fabric.

Table 1: Water-proof acrylic compound Specifications

Property	Technical specification
Color	Grey
Type of fluid	Thixotropic fluid properties
Tensile strength	1.2 N/mm2 (at 1.0mm thk) (as per ASTM D 882)
Mixed density	1.75g/cc (brush able Consistency)
Curing time	30 minutes at 30º C
Adhesion bonding with concrete	2.0 N/mm^2
Water absorption	1.2% (ASTM D 570)
Toxicity	Non-Toxic
Flexibility expressed as elongation %	40

1.2 Methodology

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

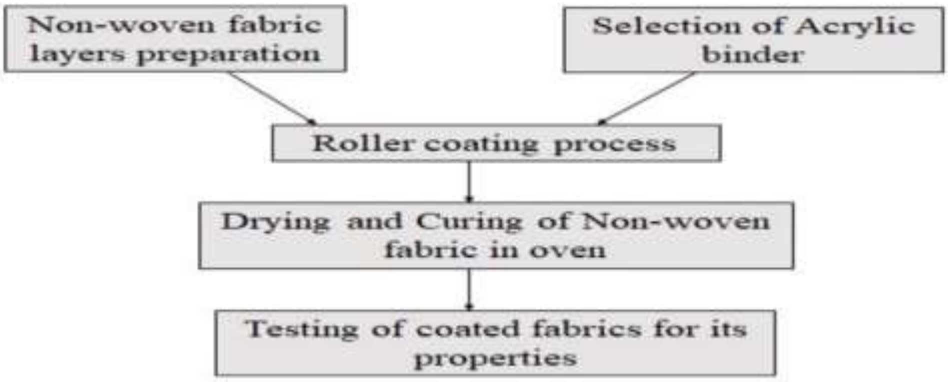

Figure 2: Methodology for development of water-proof coated fabrics

Non-woven fabrics composed of 100 % polyester made using melt-blown technology was used as a base material in this research work, These non-woven fabrics was used in single and double layers to prepare the water proof coated fabrics

Acrylic polymer binder compound which has a white thixotropic appearance was used to prepare the waterproof coated fabric. Roller coating method was used to apply the acrylic polymer binder compound to hold the layer of non-woven fabric together, which results in the formation of a thick sheet of water-proof coated fabric. The setting time was reduced by drying and curing in an oven at a temperature of 80^0C. The finally prepared coated fabric was tested for its properties like Water repellence Characteristics, Peel layer bond strength, air permeability test, Thermal behaviour, Coating hardness and Coating thickness tests. The methodology followed is shown in Fig 2.

1.3 Characterization tests on base fabrics

The basic raw material properties of non-woven fabrics and coated fabrics is shown in Table 2 and Table 3 respectively. The tensile force reported after testing the specimens on a Uni-stretch 300 tensile tester manufactured by Magsolvics, working on the principle of Constant rate of Elongation (CRE) was 12.567 Kgf with an elongation of 56.07 % and time taken to break being 22.43 sec. The coating percentage ranged from 96% to 92 %. Increase in thickness was 44 % and 65 % for single layer coated fabric and double layer coated fabric respectively. The tensile behaviour graph of the non-woven fabric used for development of water-proof coated fabric is shown in figure 3

Table 2 : Basic raw material properties

SL No	Sample Description	Fabric weight in Grams per square meter	% Coated	Thickness after curing (mm)	Increase in thickness %

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

1	Non-woven fabric (Polyester) - Uncoated	46	---	0.4	--
2	Single layer coated fabric	1163	96	0.72	44
3	Double layer coated fabric	1102	92	1.15	65

$$\% \text{ Coated} = \frac{\text{Coated fabric weight} - \text{Uncoated fabric weight}}{\text{Coated fabric weight Coated fabric weight}} \text{ x } 100 \quad (1)$$

$$\% \text{ Increase in Thickness(mm)} = \frac{\text{Coated fabric thickness(mm)} - \text{Uncoated fabric thickness(mm)}}{\text{Coated fabric thickness(mm)}} x\ 100$$

Table 3: Non-woven fabric strength properties

SL No	Sample Description	Breaking strength (Kgf)	Elongation (%)	Time to break(s)
1	Non-woven uncoated - melt blown, polyester fabric	12.567	56.067	22.427

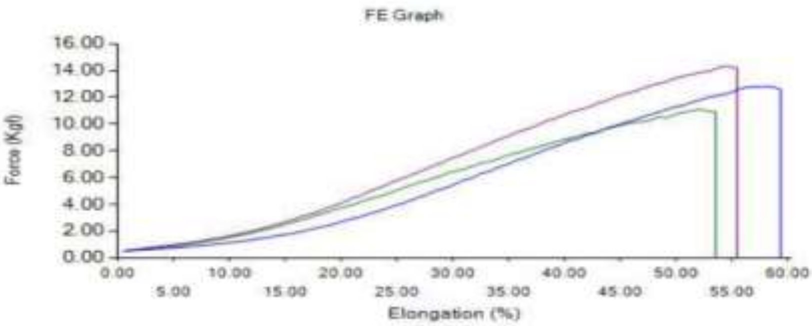

Figure 3: Tensile test graph for non-woven fabric

1.4 Water repellency tests for coated fabrics

Water repellence tests of the developed fabric was conducted as per AATCC TM22 – 2017 – spray test which was followed with an in-house fabricated device to enable and conduct the water repellence test. The test set-up is shown in Fig 4 (a). The test procedure involves the arrangement of spray device with a funnel for supply of water, a hoop and a stand inclined at an angle of 45º to the horizontal surface. All the components of experimental set-up like funnel, hoop and spray nozzles were arranged inline in accordance to AATCC TM22 -2017 standards. The distance between the spray nozzle and the sample hook maintained was 150mm. The diameter of the hoop used is

6”. The water flow rate is maintained at a rate of 250ml in 25-30 seconds. The thickness of the coated fabric was measured using digital thickness gauge tester as shown in Fig 4(b).

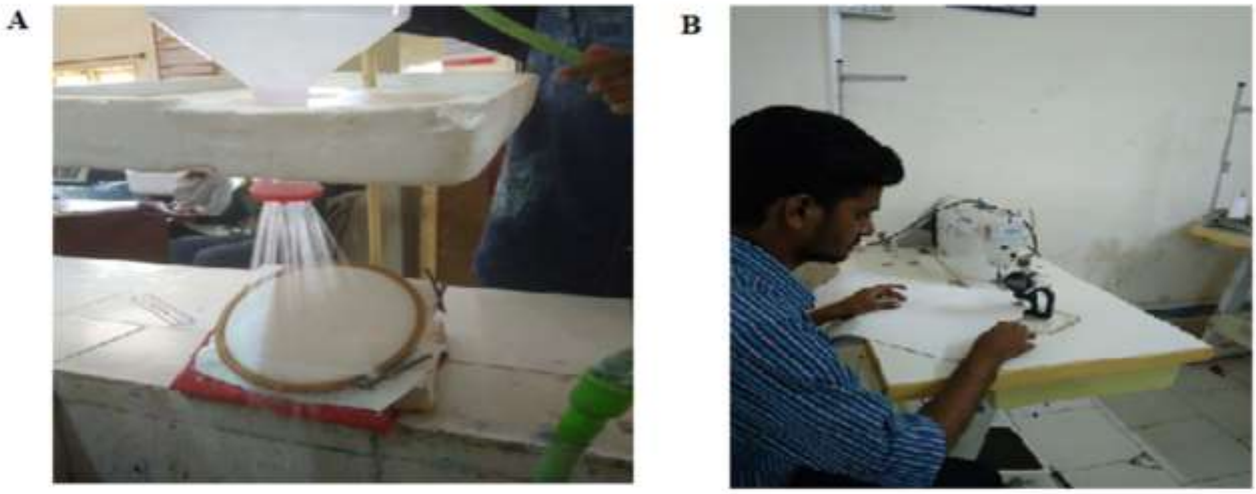

Figure 4: Coated fabric tests A) Water repellence test B) Coated fabric thickness test

Table 4 : Water repellency grades

Grade	Description
5	Fast runoff of small drops
4	Formation of large drops
3	Drops adhere to parts of the specimen
2	Specimen partly wetted
1	Specimen wet through over complete surface

Table 5 : Standard ratings

Rating	Description
100	No sticking or wetting of upper surface
90	Slight random sticking or wetting of upper surface
80	Wetting of upper surface at spray points
70	Partial wetting of whole of upper surface
50	Complete wetting of whole of upper surface
0	Complete wetting of whole upper and lower surfaces

Table 4 and Table 5 gives the grading and standard ratings used for studying the water-proof level of coated fabrics. The grades and ratings are as per the recommendations of AATCC TM22 -2017 standards.

2.5 Peel Layer Adhesion Test

Peel layer adhesion test is a mechanical test applied for measuring the adhesion strength of the coated layer. In the peel layer adhesion test the sample is prepared in the form of 'T' joint and force is applied in-between the jaws at 180 ^{o} angle. Through this test one can determine the stripping strength required to peel of the coated layer. The test is defined in ASTM D903-98(2010)

A B

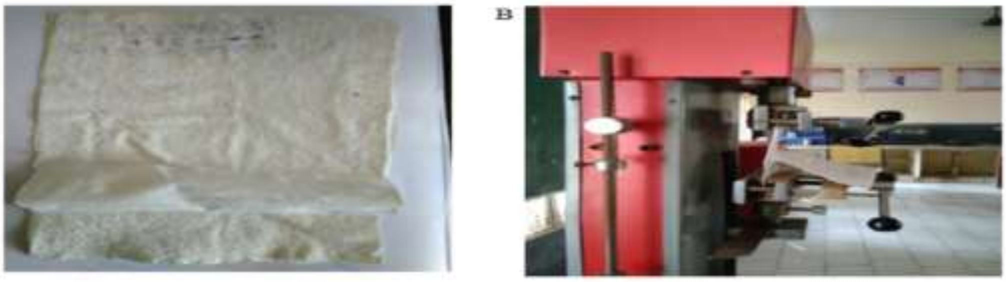

Figure 5: Peel layer Adhesion Test A) Test Sample B) Adhesion peel test set-up

2.6 Surface Morphology Observations

In order to observe the changes in the surface features of the coated fabrics before and after coating, TES SCAN VEGA – 3 scanning electron microscopes was used for capturing the surface morphology of the Non-woven fabric and coated fabrics. The SEM used works on the principle of thermionic emission of electrons. The apparatus has the flexibility of being operated in different modes. The SEM is supported with state-of –art software to capture images and analyse the sample at different stages of experiment. Experiments were conducted on the non-woven fabric and water-proof coated fabrics at different magnifications and resolutions, so that clear observations on the surface features could be carried out.

2.7 Chemical Test

Chemical tests on developed waterproof coated fabrics was carried out at in-house Textile Chemical laboratory. Laboratory reagents were used in the tests. Some of the laboratory reagents used included strong sodium carbonate solution, strong alkali (sodium hydroxide), Concentrated HCL and Concentrated sulphuric acid. Fig 6 shows the samples subjected to different chemicals

A B C D

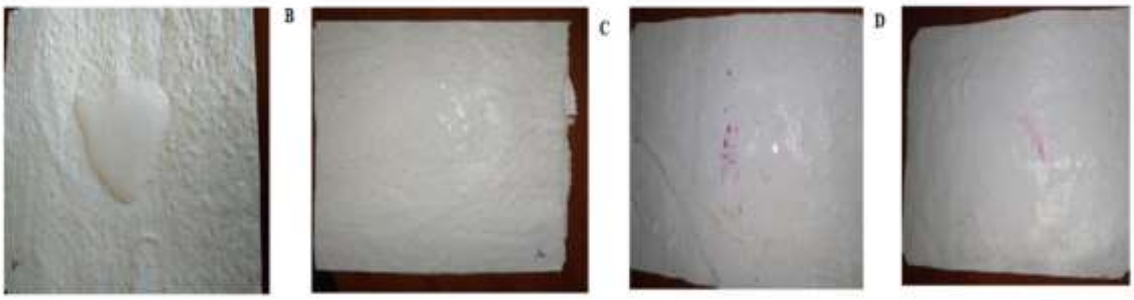

Figure6: Chemical test A) Reaction to Sodium Carbonate B) Reaction to Sodium Hydroxide C) Reaction to Concentrated HCL D) Reaction to Conc Sulphuric acid

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

2.8 Air permeability tests

Figure 7: Air permeability test apparatus

Air permeability tests for coated fabrics was conducted as per ASTM D737 standards. This test was conducted to check the presence of pores in the coated fabric. The test involves the passage of air through the coated fabric. The coated fabric is fixed on the test rig of air permeability tester. Air is passed through a vacuum pump and the water columns present on the instrument indicates the flow of air. In the coated fabrics the air could not pass and the fabric showed 100 % resistance to passage of air.

2.9 Coating Hardness and Density measurement tests

Figure 8: Rockwell hardness tester

Table 6: Density measurements of test samples

Fabric	Density of fabric in gm/cm^3	Volume (cm^3)	Mass(gms)
Non-woven uncoated fabric	0.11	4	0.44

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

Single layer coated fabric	0.169	72	12.2
Double layer coated fabric	0.095	115	100.96

Density measurements of test samples was measured using gravimetric method. The Gravimetric test method (ASTM D792) was used to calculate density of sample. The samples were weighed using digital balance to calculate mass and area being calculated using geometric scales. The density of the sample is expressed in gm/cm^3

Coated fabric hardness tests was performed using the Rockwell hardness tester. The hardness of the test specimen was measured under B load scales as per ASTM D785 standard. B scale is used for textile coated materials with the help of steel ball as an indenter at 100 kg load. The results are expressed in HRB values.

2.10 Thermal property tests

Thermal analysis using DSC and TGA is one of the convenient methods to study the thermal behaviour of the coated samples and polymeric compounds when subjected to heat [9] [10].

2.10.1 Differential Scanning calorimetry (DSC)

The heat flow rate difference in the sample against a reference material is measured using Differential scanning calorimetry. Exstar DSC7020, Hitachi HTG, Japan make instrument is used in this research to record the results of non-woven and coated fabrics.

2.10.2 Thermogravimetric Analyzer (TGA) and Differential Thermal Analyzer (DTA)

The thermal behaviour of a sample when rate of change of mass as a function of temperature when heated and cooled is measured using a thermogravimetric analyser. Differential thermal analyser measures the change in temperature on the sample when the material is heated and cooled. Simultaneous thermal analyser, Hitachi HTG, Japan, STA7200 was used to test the samples for TGA and DTA measurements.

Differential scanning calorimetry is used to measure some of the thermal parameters like melting temperature, heat of fusion, crystallization temp, etc. However, the thermogravimetric analyser gives indications of the thermal stability of the material when heated.

III. RESULTS AND DISCUSSION

3.1 Scanning electron micrographs

Observing the images, one can clearly recognize the presence of coated material, distributed randomly and unevenly in single layer and double layer waterproof coated fabrics. In the SEM image of non-woven fabric, the fibers are randomly aligned and bonded together. The fiber sections resemble the longitudinal section of polyester fiber. The coated surface appears to be uneven with marks of fiber being seen in double layer micrograph (Fig 7)

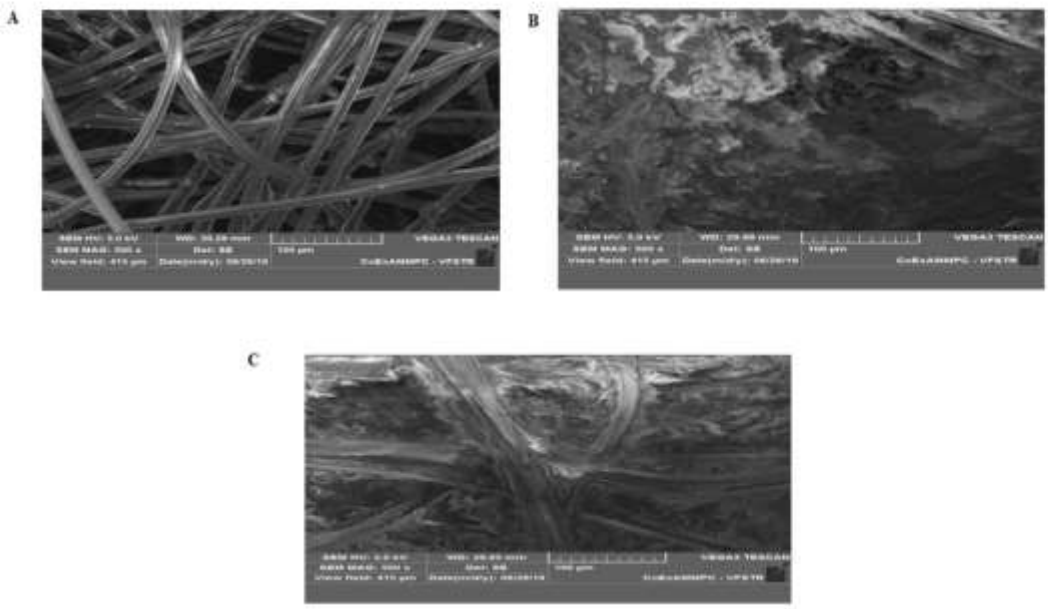

Figure 9: SEM Micrographs A) Non-woven fabric uncoated B) Single layer coated fabric C) Double layer coated fabric

3.2 Water repellency test results

Table V gives the rating of spray test results which is rated by both the standards. The coated samples show maximum rating and with not wetting observed. Hence the coated fabrics find good application in bathroom flowing and other automotive flooring application since it does not absorb any kind of water

Table 7: Spray Test results

Rating	Single layer sample	Double layer sample
Standard rating	100	100
ISO grade	5	5

3.3 Peel layer Adhesion Test

Figure 8 shows the peel layer adhesion test results of coated fabrics. About 16kgf is required to peel off the coating layer from a single layer coated fabric. However, 17kgf is enough to peel of the double layer coated fabric. The results indicate the robustness of the coated fabric showing excellent durability to peeling and chipping of layers when tiles or concrete is put on the fabric layers

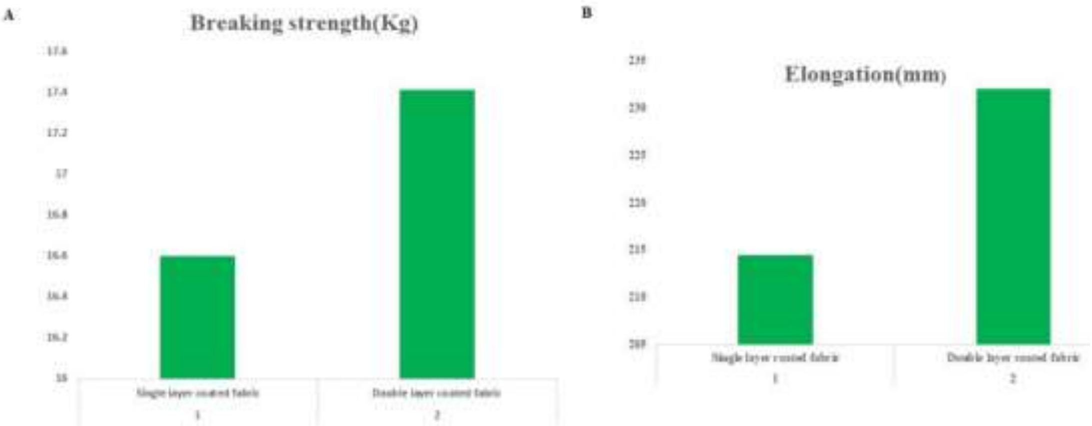

Figure 10: Peel layer adhesion test results of coated fabrics A) Breaking strength (kg) B) Elongation (mm)

3.4 Chemical test results

The chemical test results are given in Table VI which shows no damage done to the waterproof coated fabrics by chemicals.

Table 8: Chemical Test results on coated fabrics

Chemical	Single layer sample	Double layer sample
NAOH	No Damage observed	No Damage observed
Na_2CO_3	No Damage observed	No Damage observed
HCL	No Damage observed	No Damage observed
H_2SO_4	No Damage observed	No Damage observed

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

In order to see the chemical changes or reaction of the waterproof coated material and polymer compound, the observations where made against chemicals as shown in Table 8. The results show that there is no chemical changes or any such reactions observed during the test conducted in the laboratory.

3.5 Air permeability test results

It is observed during air permeability test, the waterproof coated fabric does not show any signs of passage of air through the specimen. The fabric is compact and highly non-porous. The fabric even though is flexible, the polymer binder compound locks the non-woven pore area and hardens the porous area of the fabric. Hence one can conclude the 100% water proof behaviour of coated fabric.

3.6 Coating hardness test results

Coating hardness of the material is the property of the materials which resists plastic deformation and penetration of sharp objects. Coating hardness test also indicates the stiffness level of coating and resistance to cutting, abrasion and scratching. The higher the hardness values the better the ability of the material to resist higher loads and lower deformation. Table 9 gives the hardness test values for the waterproof coated fabrics. The HRB hardness values for single layer coated fabric is reported at 31.4, however, the double layer coated fabric has a value of 68.2 HRB. This indicates the double layer coated fabric is harder as compared to single layer coated fabric.

Table 9: Hardness test results

Fabric (1/16 "steel ball and 100 kgf, B scale values	Hardness value (HRB value)
Single layer coated fabric	31.4 HRB
Double layer coated fabric	68.2 HRB

3.7 Thermal test results

3.*7.1 DSC test graphs of samples*

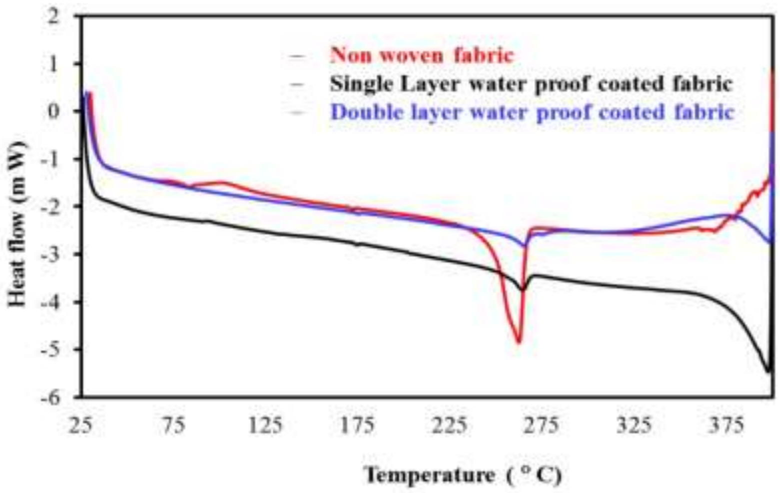

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Figure 11: Differential scanning calorimetry (DSC) graphs of samples

The DSC curve shows an endothermic of melting which is indicated at a temperature range of 275 °C in figure 11. The melting temperature is defined by the extrapolated beginning of the curve (225°C), being defined by the intersection if tangent to the point of maximum slope. Similar behaviour can be observed for non-woven fabric and woven fabric. However, the peak length for non-woven fabric is longer than that of the coated fabric. The amount of heat absorbed by non-woven fabric during melting is higher as compared to that of coated fabric. The coated fabric is stable and will not melt up to a temperature range of 275 °C, hence enabling its use for applications where the material can withstand even when high heat is applied on this material.

3.7.2 DTG test graphs of samples

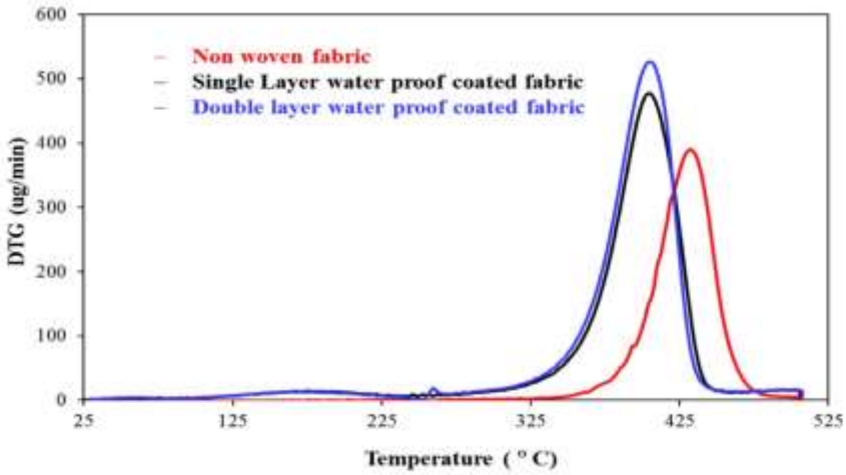

Figure 12: Derivative Thermo Gravimetric graph of samples

DTG plots of the samples shown in figure 12 indicate well-resolved peaks. The major peaks occur at a temperature corresponded to the thermal decomposition of the non-woven fabric. The non-woven fabric show a much higher thermal decomposition temperature as compared to coated fabrics. The DTG plots of coated fabrics with different layers show similar behaviour. The water proof coated materials are thermally stable.

3.7.3 TGA graphs of samples

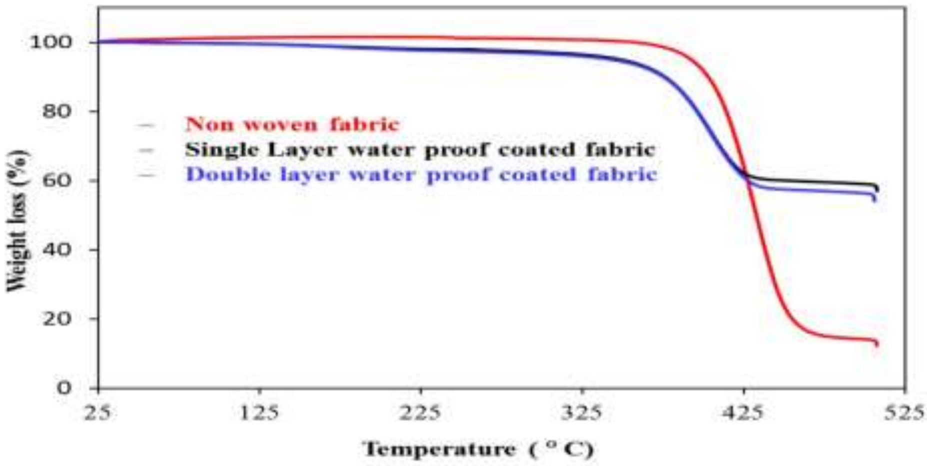

Figure 13: Thermogravimetric analysis (TGA) of samples

Figure 13 shows the Thermogravimetric analysis curve of the samples under study. The transition temperature of the samples are reported in a range of 400- 425°C, there is also major weight loss at this temperature due to decomposition of the material. Non-woven fabric curve shows sharp drop in weight as compared to coated materials. The difference in the fall of the curves shows that the coated material is more stable to weight loss as compared to non-woven material.

3.7.4 DTA graphs of samples

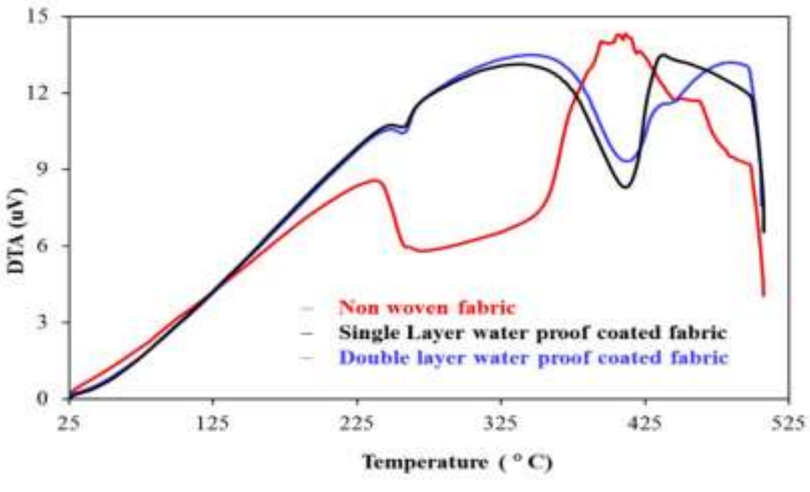

Figure 14: Differential Thermal Analysis Graphs (DTA) graphs of samples

In the DTA curves shown in figure 14, the transition point for nonwoven fabrics can be observed at 230 °C and 425°C indicating different events of thermal behaviour. For the coated fabric transition events are observed at 425°C. The event of heating run is followed by cooling run. The non-woven fabric starts melting at 230 °C, however the coated fabric starts melting at around 425°C showing higher thermal stability as compared to base non-woven fabric.

Received: 27 Feb 2019 | Revised: 20 Mar 2019 | Accepted: 30 Apr 2020

IV. CONCLUSIONS

In summary, the present research work has resulted in development of 100% water proof coated fabrics. The developed waterproof fabric has numerous potential applications. The waterproof coated fabric was prepared using non-woven fabric base material in single and double layer configurations. The roller coating method seems to be very effective due to the fact that more than 95% of polymer acrylic binder compound was deposited on the fabric. The performance of the waterproof coated fabric with respect to hardness, flexibility and bonding properties are excellent. The Scanning electron micrographs show the firm bonding of the polymer acrylic binder compound on the non-woven fabric. The thermal behaviour of the coated fabrics are excellent which is clearly evident from the thermal graphs shown in Figure 11 – 14. The water repellency test results confirm 100% waterproof characteristics of the coated material. The waterproof coated fabric show excellent resistant to strong acid and alkali. Finally, this research has resulted in development of waterproof coated fabric using roller coating process with excellent performance properties.

V. ACKNOWLEDGEMENTS

The authors wish to acknowledge Department of Textile Technology, Vignan's Foundation for Science Technology and Research (VFSTR) (Deemed to be University) and FTVET, Institute/University, Addis Ababa, Ethiopia for providing research avenues and facilities to carry out this research work

VI. AUTHOR CONTRIBUTIONS

Roller coating experiments, characterization tests on non-woven and water-proof coated fabrics, water repellence tests and testing equipment fabrication, peel layer adhesion test, SEM micrograph observations and experiments, chemical test, air permeability test, coating hardness and density measurements, thermal property tests were performed by all the authors together in respective laboratories.

VII. DATA AVAILABILITY STATEMENT

In this research work the experimental data reported are all generated during the process and recordings made on the apparatus. The data that supports the discussion and plots within this research work and other findings of this study are available from the corresponding author upon reasonable request.

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