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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

DEVELOPMENT OF COTTON / POLYESTER NON-WOVEN FABRIC FROM RECYCLED FIBER FOR INTERLINING OF CLOTHING APPLICATION

A THESIS SUBMITTED TO TECHNICAL AND VOCATIONAL TRAINING INSTITUTE FACULTY OF TEXTILE TECHNOLOGY
(DEPARTMENT OF TEXTILE TECHNOLOGY)
IN PARTIAL FULFILMENT FOR THE MASTER OF SCIENCE IN TEXTILE TECNOLOGY

BY: ALEMU ASAYE

ADVISOR: DR. GURUMURTHY.BR (PHD)

MARCH, 2026

ADDIS ABEBA, ETHIOPIA



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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled" development of cotton/polyester non-woven fabric from recycled fiber for interlining application'' is my original work carried out under the supervision of DR. Gurumurthy.B.R. It has not been presented for a degree of any other university and all source of materials used for this thesis are duly acknowledged. This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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DEPARTMENT OF TEXTILE TECHNOLOGY

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ACRONYMS AND ABBRIVIATIONS

RC/Rp: recycled cotton fiber/recycled polyester fiber

ASTM: American Society for Testing and Materials

LBAL: latex bonded air laid

ISO: international organization for standardization

PVA: polyvinyl alcohol

HVI: high volume instrument

EVA: Ethylene-vinyl acetate

GSM: gram per square meter

ETIDI: Ethiopian Textile Industry Development Institute

FTIR: Fourier Transform Infrared Spectroscopy

MSE: mean squared error

ANOV: Analysis of Variance

EB: Elongation at Break

HA: Alternative Hypothesis

Ho: Null Hypothesis

DP: degree of polymerization

ABSTRACT

This research study introduces the development and performance properties of 12 chemically bonded nonwoven samples manufactured from recycled Cotton/Polyester garment scraps waste for interlining application. The recycled scraps waste from cotton/polyester fibers has a possible raw material source for the development of nonwoven samples of interlining application of clothing. In the sample development process one and multi-layer nonwoven sheets are made through a chemical bonding process. The mechanical and physical properties of developed non-woven fabric samples were analyzed by ASTM and ISO standards. The samples were developed with varying fiber blend ratios (70:30, 50:50, 30:70 cotton/polyester), binder percentage (5% and 10%), and web layer counts (1 and 3) to study their influence on bursting strength, tensile strength, tear strength, thickness, and weight (GSM) of the fabric .The samples were subjected to bursting strength, tensile strength, tear strength, thickness, and weight testing to determine the ideal composition for use in garment interlining. The testing results indicated that 30:70 cotton/polyester ratio, 10% binder concentration, and 3 layers of web showed the maximum value for mechanical properties in the form of bursting strength 465 N, tensile strength 33.6 N/m2, and tearing strength 7.33 N. The thickness and weight of this sample were 0.83 mm and 86 GSM, respectively. On the other hand, the lowest performance was exhibited by the 70:30 blends, 5% binder and 1 layer with bursting strength of 146N, tensile strength of 8.16 N/m^2, tear strength of 2.95N, thickness of 0.31 mm and weight of 30 GSM. This result showed that increased polyester ratio, increased binder level and increased web layers significantly enhance non-woven fabric samples mechanical and physical performance properties.

Key words: Interlining**,** Recycled Garment Waste, Cotton/Polyester Fiber, Nonwoven, Chemical Bonding.

TABLE OF CONTENTS

CONTENTS **PAGE**

DECLARATION i

Approval sheet ii

ACKNOWLEDGEMENT iii

ABSTRaCT v

List of Figures x

List of tables xii

CHAPTER ONE 1

INTRODUCTION 1

1.1 Background study 1

1.2 Statement of problem 3

1.3 Objectives 4

1.3.1 General objective 4

1.3.2 Specific objectives 4

1.4 Significance of the research: 5

1.5 Scope of the Research 5

1.6 Basic Questions of the Research 6

1.7 Hypothesis of the research 6

1.8 Limitation of the research 7

1.9 Definition of Terms 7

2 CHAPTER TWO 8

LITREATURE REVIEW 8

2.1 Textile recycling 8

2.1.1 Mechanical recycling 9

2.1.2 Chemical recycling 10

2.1.3 Thermal Recycling 10

2.2 Theory of Nonwoven 10

2.2.1 Web-Forming Technologies 11

2.2.2 Chemical bonding 14
2.2.3 Mechanical bonding 17
2.2.4 Thermal bonding 17
2.3 Definition of interlining 18
2.4 Classification of interlining 19
2.4.1 Woven interlining 19
2.4.2 Nonwoven interlining 20
2.4.3 Knitted interlining 20
3 Chapter three 22
materials and methodology 22
3.1 Introduction 22
3.2 Materials and chemicals used 22
3.3 Machines and Equipment's used 25
3.4 Methods 25
3.4.1 Waste fabric grinding system 26
3.4.2 Carding 27
3.4.3 Fiber Web preparation 28
3.5 Methods of sample development techniques and procedures 29
3.5.1 Blending of Recycled Fibers 30
3.5.2 The fiber web formation of recycled fibers 32
3.6 Testing Methods of fibers 35
3.6.1 Characterization of the recycled fiber properties 35
3.6.2 Preparation of recycled cotton/polyester web 36
3.6.3 Preparation of binder for fiber web 36
3.6.4 Method of Chemical Bonding 36
3.7 Method of developing of cotton/polyester non-woven fabric 37
3.8 Study Area 37
3.9 Study Population 38
3.10 Research Approach 38
3.11 Variables 38
3.12 Sample size 38

3.13 Method of Analysis 38
3.14 Design of Experimental plan 39
3.14.1 Experimental observation 39
3.15 Scanning electron microscope Analysis 40
3.16 FTIR Analysis 41
3.17 Physical and mechanical properties of developed nonwoven fabrics 41
3.18 Experimental frame work 42
3.19 Testing of Physical Properties of Developed Nonwovens 43
3.19.1 Thickness Testing Measurement 43
3.19.2 Tensile strength testing of nonwoven fabric 44
3.19.3 Elongation at Break 46
3.19.4 Bursting Strength of nonwoven samples 46
Figure 3-17 Bursting Strength of nonwoven samples 46
3.19.5 Tear Strength of nonwoven sample 47
Figure 3-18 Tear Strength of nonwoven sample 47
4 CHAPTER FOUR 48
RESULT AND DISCUSSION 48
4.1 Introduction 48
4.2 Data Analysis 49
4.2.1 Analysis of variance (ANOVA) 49
4.2.2 Physical properties of developed nonwoven samples 50
4.2.3 Mechanical properties of developed nonwoven and their testing result 52
4.3 Statistical analysis of developed nonwoven fabrics 52
4.3.1 Regression Equation for strength of developed nonwoven samples 53
4.3.2 Normal Probability Plot 54
4.3.3 Histogram of the residuals 55
4.3.4 Residual plots in Minitab 55
4.3.5 Factorial Plots for strength 56
4.3.6 Fits and Diagnostics for Unusual Observations 58
4.3.7 Interaction plots for mechanical properties of developed samples 60
4.3.8 Mechanical properties of developed nonwoven 62

4.4 Discussion Based on the Results 63
4.4.1 Effect of fiber blend ratio, binder concentration and no-of web layer on tensile strength and Eb% 64
4.4.2 Effect of binder concentration and blend ratio on tensile strength and elongation at break 65
4.4.3 Effect of blend ratio, fiber web layer and binder concentration on bursting strength 67
4.4.4 Effect of blend ratio, web layer and binder concentration on tear strength of nonwoven samples 68
4.4.5 Effect of fiber blend ratio on mechanical properties of nonwoven samples.. 69
4.4.6 Effect of fiber blend ratio and binder concentration on drape coefficient of samples 70
4.5 FTIR analysis of recycled cotton fiber and recycled polyester 70
4.6 Discussions Based on the Findings 73
5 CHAPTER FIVE 76
CONCLUSION AND RECOMMENDATION 76
5.1 CONCLUSION 76
5.2 Recommendation for future works 79
5.3 REFERENCES 80
5.4 APPENDICES 84

LIST OF FIGURES

Figure 2-1 Web formation by dry laying (carding) 12
Figure 2-2 Air laid processing line for short fiber 12
Figure 2-3 Wet laid processing 13
Figure 2-4 impregnation (saturation) bonding 15
Figure 2-5 Web consolidations and embossing by thermal bonding 18
Figure 2-6 Woven interlining 20
Figure 2-7 Nonwoven Interlining 20
Figure 2-8 Knitted Interlining 21
Figure 3-1 Polyester fibers(Kalabek and Babaarslan 2016) 23
Figure 3-2 Biella waste fabric grinding machines and grinded waste fiber 27
Figure 3-3 Fiber blending and web reparation 28
Figure 3-4 Prepared fiber web 28
Figure 3-5 Grinded and non-grinded fabric wastes 29
Figure 3-6 100% Polyester Waste 29
Figure 3-7 Development technique of chemical bonded non-woven 30
Figure 3-8 Fiber web preparation process 33
Figure 3-9 Web formation with different blend ratios 33
Figure 3-10 Fiber web coating and pressing 33
Figure 3-11 Methods of sample development techniques and procedures 34
Figure 3-12 Adhesive bonding of recycled nonwovens 36
Figure 3-13 chemically bonded nonwoven samples with different blend ratios 42
Figure 3-14 digital non-woven fabric thickness tester 43
Figure 3-15 Nonwoven fabric weight testing 44
Figure 3-16 Mesdan tensile strength tester machine 45
Figure 3-17 Bursting Strength of nonwoven samples 46
Figure 3-18 Tear Strength of nonwoven sample 47
Figure 4-1 Effect of web layer on fabric thickness and weight 51
Figure 4-2 residual plots for elongation at break 55
Figure 4-3 Factorial Plots for tensile strength 56
Figure 4-4 Factorial Plots for elongation at break 57

Figure 4-5 residual plots for bursting strength 58
Figure 4-6 residual plots for tear strength 59
Figure 4-7 fitted line and residual plots for bursting strength 60
Figure 4-8 Interaction plots for tear strength 60
Figure 4-9 Interaction plots for tensile strength 61
Figure 4-10 Main effects of plot for elongation at break (%) 61
Figure 4-11 Interaction plot for bursting strength 62
Figure 4-12 Interaction plot for elongation at break 62
Figure 4-13 Mechanical properties of developed nonwoven samples 63
Figure 4-14 Effect of fiber blend ratio, binder concentration and web layer on strength and eb% 64
Figure 4-15 Effect of binder concentration and blend ratio on tensile strength and elongation at break 65
Figure 4-16 Effect of blend ratio, web layer and binder concentration on bursting strength 67
Figure 4-17 Effect of blend ratio, web layer and binder concentration on tear strength 68
Figure 4-18 Effect of fiber blend ratio on tear, tensile and eb% of samples 69
Figure 4-19 Effect of fiber blend ratio and binder concentration on drape coefficient of samples 70
Figure 4-20 FTIR analysis of recycled cotton fiber 71
Figure 4-21 FTIR analysis of recycled polyester fiber 71
Figure 4-22 FTIR analysis of cotton /polyester nonwoven fabric 71

LIST OF TABLES

Table 3-1 chemicals used 24
Table 3-2 Equipment and materials 25
Table 3-3 Recycled fiber blending composition and sample coding 31
Table 3-4 fiber blend ratio 32
Table 3-5 Level of process factors 32
Table 3-6 Recycled cotton and polyester fiber properties 35
Table 3-7 list of factors and levels 39
Table 3-8 Experimental observations 40
Table 3-9 Machine set up of Mesdan tensile strength tester 45
Table 4-1 mechanical properties of chemically bonded nonwovens 49
Table 4-2 physical properties of developed nonwoven samples 50
Table 4-3 Mechanical properties of developed nonwoven and their testing result 52
Table 4-4 Analysis of variance for the response of tensile strength 53
Table 4-5 Model summary for Experimental Design 53

1 CHAPTER ONE

INTRODUCTION

Fabrics, clothing, textiles, and fibers are recycled and up cycled in a circular economy to preserve their high quality and save waste. Nonetheless, over 53 million tons of fibers are produced annually worldwide for the manufacture of clothing in linear value chains(Retex 2021).

The circular economy is based on optimizing the use of available resources and creating renewable flows of materials and products (Gardetti, 2019).

Because it relies so heavily on materials and procedures that need a lot of resources, the textile sector confronts substantial environmental challenges. One of the most crucial elements in the textile industry's transition to a circular economy is the reuse and recycling of textile fabric waste. The necessity to recover fabric waste primarily arises from the perspective of resource recovery and the detrimental environmental effects of landfilling and disposal(Paranjape, Mundkur, and Athalye 2024).

1.1 Background study

Due to factors including population expansion, rising living standards, fast shifting design trends brought on by shorter clothing life cycles and increasing style turnover, as well as falling costs, it is anticipated that the need for textile materials will continue to climb globally(Akram et al. 2021).
92 million tons of textile waste is produced worldwide each year. The majority of discarded clothes ends up in low-income nations, where a lack of infrastructure for waste disposal causes dumping, burning, and serious social and environmental consequences(Adolph 2016).

It is anticipated that the global output of textiles would continue to rise as it has done in recent years. Global fashion trends and styles are always evolving, which has an impact on apparel. However, before being disposed of in a landfill, this significantly reduces the garment life cycle. Because clothing is changing so quickly, the textile industry is expanding. However, there is a downside that a lot of textile waste is created.

Because of clothing and other fabrics are used more frequently, a large amount of textile waste is produced worldwide. There aren't many commercially viable techniques for recycling textiles, though. For the textile industry, developing processes to convert waste textiles into raw materials for the creation of new textile fibers is a major undertaking.

The sectors that have the most effects on the environment are housing, transportation, and food the textile industries are said to have the fourth-highest influence. Global fiber production has nearly quadrupled in the last 20 years, from 58 million tons in 2000 to 109 million tons in 2020.

For many years, the tried-and-true process of recycling textiles at the end of their useful lives involves recovering fibers and using them to create new textile products. Since replicating fibers are rare in nature, efforts to decrease their use are ongoing. When textile raw materials were few, end-of-life textile recycling became crucial, and producers and even the recycling industry tried to boost output in this way. Waste textiles were regarded as an important source of raw materials. Since there are fewer resources available to make primary synthetic fibers and the world's population is growing, it is evident that textile recycling must continue to be a top concern.

Cotton and polyester fibers have long held a leading position in the textile industry. The bulk of low-quality grey fibers, also referred to as low-value textile wastes, are composed of cotton and polyester fibers. These fibers hold significant potential for application in the manufacturing of recycled woven and nonwoven fabrics, which are now regarded as extremely promising materials, despite the fact that they cannot be directly utilized in the apparel industry .

Theoretically, it is rather simple to mechanically separate textile materials into their individual fibers. It includes breaking down and opening up materials into fibers, which alters the fibers' properties, especially weakening and shortening them. During the recycling process of raw materials, fibers break down into monomers or polymers, which are subsequently reconfigured back into fibers. These techniques may enable the restoration of fiber properties to a degree where they are the same as or similar to those of newly created fibers, depending on the process. Fibers obtained via recycling procedures can be used to create textiles and nonwoven products.

Textiles can be recycled using mechanical, thermal, or chemical methods. In mechanical textile recycling, shredded fabric is used to create fibrous forms that can be recycled into yarns or used to

make nonwoven textiles. Mechanical recycling makes it easier to recycle recycled and shredded fabrics with any kind or blend of fibers. However, shredding produces shorter and lower-quality fibers; for this reason, pre-consumer textile waste which is of higher quality than post-consumer waste and does not undergo tearing or wearing is usually recycled mechanically.

Using recycled fibers is this research project aims to build a sustainable non-woven cotton/polyester fabric by analyzing its physical and mechanical qualities.

The garment scraps wastes collected from yeka industrial college garment shops as part of my research and recycle them into nonwoven fabric that can be used as interlining in clothing. I was examined the characterizations (GSM, thickness, tear strength, tensile strength, bursting strength, etc.) of the created samples.

1.2 Statement of problem

The quantity of garment scraps and post-consumer textile wastes are increasing worldwide. 48 million tons of clothing textile wastes is the result of the fashion and textile industries present linear business strategies, which have already had detrimental effects on society and the environment. Less than 1% of textile waste in Europe is now recycled in closed-loop systems(Retex 2021).

One of the biggest problems facing the textile and fashion industries is how to get rid of waste made of textiles, such as manufacturing scraps and post-consumer clothing. Textile waste builds up in landfills without efficient recycling and reuse options, aggravating environmental problems and accelerating the loss of natural resources. Closing the waste cycle of the fashion industry requires finding creative ways to convert textile waste into non-woven textiles.

Because it uses a lot of raw resources and traditional manufacturing techniques, the textile sector has a lot of sustainability and environmental impact concerns. Sustainable textile production methods are becoming more popular as a result of the need to minimize resource use, encourage eco-friendly practices, and limit waste output.

Customers today are becoming more aware of how their purchases affect society and the environment. Demand for ethically made, environmentally conscious fashion items that also adhere

to the principles of the circular economy is rising. Fashion brands must incorporate environmental friendly materials and methods into their supply chains in order to meet this demand.

By addressing these interconnected problems through the development and promotion of recycled cotton/polyester non-woven fabric, I aim to offer a sustainable solution that addresses environmental concerns, reduces textile waste, meets consumer demand for eco-friendly fashion, and maintains high performance standards in textile production.

Through the development and promotion of recycled cotton/polyester non-woven fabric, I hope to provide a sustainable solution that meets consumer demand for eco-friendly fashion, reduces textile waste, addresses environmental concerns, and upholds high performance standards in the textile production industry. These interconnected problems were addressed.

1.3 Objectives

Offer a sustainable solution that satisfies consumer demand for eco-friendly fashion, lowers textile waste, addresses environmental issues, and maintains high performance standards in the textile production industry by developing and promoting recycled cotton and polyester non-woven fabric.

1.3.1 General objective

To design and develop a sustainable, eco-friendly non-woven interlining fabric using recycled cotton and polyester fibers for clothing applications.

1.3.2 Specific objectives

- To recycled cotton and polyester fibers from garment scraps waste.
- To clean, sort, and characterize recycled cotton and polyester fibers.
- To minimize environmental burden and encourage the most efficient use of resources
- Optimize the blending ratio of recycled cotton and polyester fibers to achieve desired fabric properties
- To ensure the fabric meets the functional requirements for interlining applications.
- To evaluate the effect of the binder concentration, number of layer and blend ratio of fabric on the fabric's mechanical and physical properties.

1.4 Significance of the research:

- Environmental sustainability since, the created nonwoven fabric made of a combination of cotton and polyester is made from recycled fibers, ensuring that the problem of textile waste, landfills, and pollution is alleviated. Resource and cost efficiency even though historians using recycled fibers reduce our use of virgin raw materials, increases production efficiency, and preserves natural materials like cotton and petroleum-based polyester
- Researchers might use it as a start to locate and look into additional research.
- Establish a closed-loop system for gathering and processing textile waste to feed into the creation of recycled fabric, further lowering the material's environmental impact, by working with recycling facilities and waste management firms.
- Contribution of the business idea as a means of job creation.
- A sustainable non-woven fabric made of cotton and polyester that satisfies performance requirements and lessens its environmental impact.

In order to meet the growing consumer demand for eco-conscious products, reduce environmental impact, promote circular economy concepts, and advance sustainable practices within the textile sector, it is imperative that these difficulties be addressed. The development of non-woven fabric made of cotton and polyester using recycled fibers has the potential to transform the textile manufacturing industry and pave the way for a more ecologically friendly and sustainable future.

1.5 Scope of the Research

In order to meet the growing consumer demand for eco-conscious products, reduce environmental impact, promote circular economy concepts, and advance sustainable practices within the textile sector, it is imperative that these difficulties be addressed. The development of non-woven fabric made of cotton and polyester using recycled fibers has the potential to transform the textile manufacturing industry and pave the way for a more ecologically friendly and sustainable future.

1.6 Basic Questions of the Research

The goal of the project is to create a cotton/polyester nonwoven fabric sample using recycled fiber, and then analyze the successes that went into creating the sample. Thus, the purpose of this study is to evaluate the following fundamental research questions.

- What is the best way to prepare the PVA latex binder?
- What impact does the no of layer of the web on the fabric mass of nonwoven fabric?
- How can we mechanically recycle cotton and polyester to create dry-lay web?
- What impact does a different blend percentage of polyester and cotton have on nonwoven fabrics?
- What impact does the percentage of binder have on the physical and mechanical performance features of the developed samples of fabrics?

1.7 Hypothesis of the research

It is hypothesized that nonwoven fabrics made from developed recycled cotton and polyester can be excellent sources for interlining applications in apparel. When testing methods are used, the research will predict and confirm the convenience of the cotton/polyester developed sample while taking into account independent variables (fiber composition and binder concentration) to find a relationship with dependent variables and fulfill all necessary ASTM and ISO standards.

Physical and mechanical qualities are the nature of dependent variables. By using the quantifiable independent variables independently to guide proper experimental analysis, the result can be quantified and associated directly.

Hypothesis: 1

Hypothesis Statement: If the amount of binder concentration increases, then the physical and mechanical properties of the nonwoven fabric also increase.

H1: Binder concentration has a positive relationship and has a significant effect on the physical and mechanical performances of nonwoven fabric.

Ho: Binder concentration has no positive relationship and has a no any significant effect on the tensile strength of nonwoven fabric.

Hypothesis: 2

Hypothesis Statement: If the blend ratio of cotton/polyester fiber increases, then their physical and mechanical property also increases.

H1: fiber blend ratio of cotton/polyester has a positive relationship and has a significant effect on the quality of physical and mechanical properties of the produced non-woven fabric.

Ho: fiber blend ratio of cotton/polyester has no positive relationship and has no significant effect on the quality of physical and mechanical properties of the produced non-woven fabric.

1.8 Limitation of the research

Since every study has limitations that prevent it from producing the desired results the following are some limitation of this study.

- ❖ Financial and time constraints for testing of all necessary parameters
- ❖ Lack of manufacturing machine and testing equipment.

1.9 Definition of Terms

Nonwoven: fabrics are often produced by assembling minuscule fibers into a sheet or web, akin to what is produced by a paper machine, and then binding them together using various bonding procedures.

Textile recycling: One method to prevent the waste of potentially valuable resources is through textile recycling, which involves processing used materials (waste) into new products.

Chemical binding: Refers to the process of applying a liquid-based bonding agent to fabric by various methods such as impregnating, foaming, spraying, or print bonding.

Interlining: Fabric used between inner and outer layers of apparel to impart weight or stiffness, shape retention, warmth and bulk to the garment.

Blend: Two or more fiber types combined together.

2 CHAPTER TWO

LITREATURE REVIEW

2.1 Textile recycling

To prevent wasting potentially valuable resources, recycling is the act of converting waste used materials into new products. Energy consumption, the need for new raw materials, air pollution from burning, water pollution, and land pollution from filling in gaps in the land are all reduced. Recycling is crucial to contemporary trash reduction and is the third phase in the "Reduce, Reuse, Recycle, and Recover" (4R's) waste hierarchy(R and A 2017).

pre-consumer waste, which is produced during the creation of fiber, yarn, fabric, and clothing before the product is purchased, and post-consumer waste, which is produced when customers discard the clothing after using it at the end of its useful life(Cao et al. 2022).

The production of clothing and other textile items generates enormous volumes of waste each year. Cotton and its blends with synthetic fibers are among the primary contributors to textile waste. The textile sector is finding it increasingly difficult to dispose of such massive volumes of waste. Environmental issues arise when textile waste is buried or dumped in landfills(Washim Akram, Hasan Mahmud, and Easmin 2022).

The most straightforward technique for recycling polyester-cotton textiles was mechanical de-fiberating without the need of virgin fiber; yet, this down-cycling result in subpar products. Because cellulose and PET are complex polymers, separating them from polyester-cotton blends is quite difficult(Srichola et al. 2023).

Environmental sustainability is provided by the reuse and recycling of textile waste. Potential recycling methods that optimize resource conservation, including raw materials, water, and energy, while having the least negative effects on the environment are up cycling and closed-loop recycling(Juanga-Labayen, Labayen, and Yuan 2022).

2.1.1 Mechanical recycling

Without significantly changing the polymer chemical structure of the fibers, textile waste can be mechanically recycled into secondary raw materials. Mechanical recycling is a partially variable combination of primary processing activities, such as collection, sorting, identification, grinding, carding, blending, and re-spinning into new fibers. Without significantly changing the material's chemical structure, textile waste can be mechanically recycled into valuable goods (Baloyi et al. 2023).

Mechanical recycling, which entails shredding and carding the waste without the use of chemicals to extract the fibers from the fabric, is the most widely used technique for recycling waste textile fabric produced at the pre- and post-consumer levels. The extracted fibers can be mixed with virgin fibers to make nonwoven fabric for a number of applications. To get good yarn strength and fineness, more virgin fibers must be added. Increasing the proportion of recycled fibers is still challenging. Woven fabric is much harder to recycle than knitted fabric, which results in inferior yarns and inefficient recycling(Subramanian et al. 2022).

Reproducing yarns from the acquired fibers is more difficult when textiles are mechanically fractionated. Using post-consumer garbage makes this challenge more noticeable. The degree of polymerization (DP) of cellulose or terephthalate in blends (which may include PET, as well as polypropylene terephthalate PPT and poly butylene terephthalate PBT) is decreased by the mechanical forces during shredding in conjunction with the ageing and wear of fibers brought on by the detergent's effect on the chemical structure during laundering (Kahoush and Kadi 2022).

Due to their comfort, usefulness, and durability, cotton and polyester are the two fibers most frequently found in textile items(Sankauskaitė et al. 2014).

The primary motivations for recycling textile waste are resource conservation, landfill reduction, tipping fee payment, and the supply of inexpensive raw materials for goods(Feleke Fera, Zeleke, and Girmay 2022).

2.1.2 Chemical recycling

The technique of transforming polymeric waste into monomers that can be utilized as raw materials to create new polymers by altering its chemical structure is known as chemical recycling. fibers can be broken down into monomers or building blocks through chemical recycling, which subsequently re-polymerizes them into new fibers of comparable or higher quality(Baloyi et al. 2023).

2.1.3 Thermal Recycling

By using heat to melt and bend synthetic fibers into new shapes, thermal recycling provides a special route for them. Because consistency makes processing easier, this method works especially well for pre-consumer trash from industrial wastes. After being mechanically shred, the chips and pellets go through a high-temperature process called melt extrusion, which transforms the molten polymer into new fibers. This technique greatly aids in the recycling of materials like as polyester, nylon, elastin, polypropylene, and polyurethane and has benefits including cost-effectiveness and adaptability (Paranjape, Mundkur, and Athalye 2024).

2.2 Theory of Nonwoven

The word "nonwoven" acquired popularity more than 50 years ago when nonwovens were perceived as less costly alternatives to traditional fabrics. However, nonwoven fabric technology is now the most sophisticated method used in this sector of the textile business. Nonwoven technology is available to duplicate the look, texture, and strength of traditional woven and knitted fabrics, and nonwoven materials are disposable, have fewer production stages, are very efficient, and share similar qualities. Laminations, multi-layer nonwoven composites, and three-dimensional nonwoven textiles are examples of commercially accessible goods(Cheng et al. 2016).

Generally speaking, nonwoven textiles are employed in applications that do not call for the creation of clothing. Naturally, compared to woven or knit, there are fewer manufacturing stages, which results in a shorter production time and lower cost(Venkataraman, Shabani, and Park 2023).

Like paper on a paper machine, non-woven materials are typically created by combining tiny fibers into a sheet or web. Following that, these fibers are either mechanically bound (as in felt, where the fibers are interlocked with sharp needles to create a stronger fabric) or thermally bound (by applying

a binder, which can be a paste, powder, or polymer melt, and turning the binder onto the web by increasing the temperature)(Syed, Parte, and Sayed 2015).

2.2.1 Web-Forming Technologies

- Traditionally, there are two processes in the non-woven production process.
  The process of gluing the fibers together to create the web cohesiveness comes after web formation, which first enables the arrangement of the fibers in a web. Four primary technologies are used to create a web:
- Air-lay technologies for short fibers,
- Wet-lay technologies,
- Spin-lay and
- Melt-blown technologies(Le Blan et al. 2007).

Dry laid Technologies

Technologies that were first created for the textile, and more specifically the spinning, industry have been used to design dry lay systems. Fiber preparation and web forming are the two successive stages of the dry lay system. Separated fibers are spread out into a rapidly moving air stream during the air-laid forming process, and they are subsequently moved to a moving screen using pressure or vacuum. Usually, the fibers are bonded together using heat-sensitive binders(Santos, Maloney, and Jose 2021).

The objectives of the preparation phases are:

- To open the compressed fibers
- To blend the different fibers to reach the maximum homogeneity
- To clean fibers, especially for natural fibers
- To feed regularly the web-forming machine.

Dry laid webs are mainly produced using staple fibers, natural or manmade. There are mainly three types of web laying techniques or dry-laid webs viz. Parallel laid webs Cross laid webs randomly laid webs or air laid webs.

- Parallel laid webs: A long queue of carding machines is positioned one behind the other. A conveyor that runs the entire length of the production line beneath the cards is where the web from the first card is set to fall. The second card's web is superimposed on the first card's web as it passes through the second card. Until a fleece with the proper mass per unit area is obtained, this process is repeated along the line.

- Webs that are cross-laid: In cross-laying, the web is first placed on an inclined lattice as it exits the card, and then it is set crosswise on a broader lattice that is travelling perpendicular to the initial laying direction.

  Randomly laid webs: Machines that use aerodynamic feed of the fibers provide another method of making fleeces. In this instance, air currents carry the fibers from a carding cylinder and deposit them onto a condenser cage, where they are then extracted in sheet form. Typically, the condenser cage is a hollow cylinder made of mesh(Syed, Parte, and Sayed 2015).



Figure 2-1 Web formation by dry laying (carding)



Figure 2-2 Air laid processing line for short fiber

Spun laid webs: Using a high velocity air or gas current, a melt solution of a fiber-forming polymer is extruded via a series of spinnerets. To create a web, the fibers are placed onto a structure, which could be a screen drum (condenser cage), a conveyor, or scrim (a cloth with a very open weave).

Melt-blown webs: These are made by first extruding polymer into a high-velocity air current through holes in a spinneret, much like spun-laid webs.

These two approaches differ in that instead of simply bringing the filaments together to create staple fibers of different lengths, a greater stress applied by the current fractures the filaments, preventing a real continuous filament wet(Syed, Parte, and Sayed 2015).

Wet laid

Wet laid nonwovens are made by depositing diluted slurry of fibers and water on a moving wire screen, then draining the mixture to create a web. By squeezing the web between rollers, it is further dried and solidified. A further step of the procedure frequently involves impregnation with binders.

A Large variety of fiber orientations, from very random to nearly parallel, possible with wet lay web formation. Numerous fibers of different lengths, both natural and man-made, can be utilized(Wood 2009)

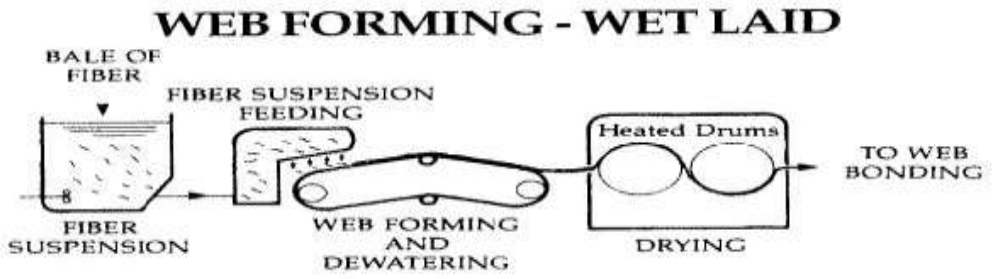


Figure 2-3 Wet laid processing

Strength and coherence can be added to a fibrous web by three bonding methods:

- Chemical bonding
- Mechanical bonding
- Thermal bonding

One of the main determinants of fabric integrity (strength), porosity, flexibility, softness, and density (loft, thickness) is the degree of bonding. Although bonding can be done alone, it usually happens in conjunction with web creation.

2.2.2 Chemical bonding

Chemical binders are used in amounts ranging from 5% to 60% of the web's weight. The most common polymer binders used in aqueous dispersions include vinyl polymers, acrylic esters, natural and synthetic rubber, and starch. Due to its versatility, affordability, ease of application, and efficacy as an adhesive, latex is widely utilized.

Chemical bonding is one of various techniques for applying a liquid-based bonding agent to fabric, including impregnating, foaming, spraying, and print bonding. The most widely used chemical binder is water-borne latex. It is cheap, versatile, and easy-to-use glue. Most latex binders are made of vinyl polymers, such as polyvinyl acetate, polyvinyl chloride, styrene/butadiene resin, and poly acrylic, or their blends.

Chemical bonding is the process of applying an adhesive to the created web. Chemical binders are the most often used technique for air-laying webs, while there are various ways to construct the web. The binder is applied to the web to strengthen or join the component elements. It might be solid (powder, film, or fibers), liquid (emulsion, dispersion, or solution), or foam(Santos, Maloney, and Jose 2021).

Blends of binders and additives can be made to improve the binding between fibers. The final web will be influenced by the binder's chemical composition, glass transition temperature, attritional and thermal properties, and wet and dry mechanical properties after curing. Drying and curing are necessary after applying chemical binders. Impregnation bonding is used when maximum fibers encapsulation, strength, and stiffness are needed for fabric applications and rapid binder application is required. This is achieved by either fully immersing the web in a binder bath or flooding it when it gets close to the nip point of a set of pressure rollers (Figure)(Eryılmaz et al. 2013).

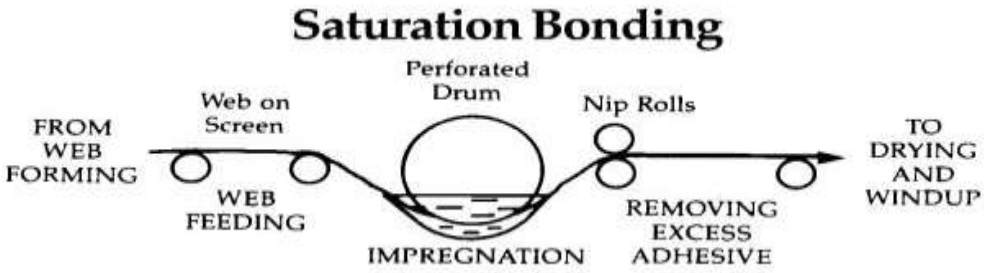


Figure 2-4 impregnation (saturation) bonding

For fabric applications where maintaining a high loft or bulk is desired, spray bonding is utilized. A number of nozzles atomize and apply the binder to the web's upper surfaces. The web is passed through heating zones after spraying in order to cure the binder and remove any remaining water.

The most popular bonding method in air lay technology, chemical bonding, involves spraying latex across the web's two surfaces. The so-called Latex Bonded Air Laid (LBAL) nonwoven is sprayed on both sides, dried, and then wound. LBAL is commonly used in domestic products, industrial wipes, and dry and wet wipes. The fabric's softness and dry/wet strength are crucial for these kinds of applications(Çelikten et al. 2018).

A soft fabric grip, consistent binder distribution, and precise binder application are all features of spray adhesive bonding. Care is made to prevent too much or too little adhesive from flowing through the sprayer(Sakthivel et al. 2020).

Ethylene-vinyl acetate (EVA) co-polymer is the most commonly used latex for air-laid non-woven because it is inexpensive and has outstanding absorption, strong wet and dry strength, and exceptional durability. Numerous different co-polymers, such as acrylates, vinyl-based polymers, and styrene-butadiene rubbers, are employed. Compared to other chemical binders, EVA has demonstrated significant promise in recent decades, and its production has increased the greatest(Ingo 2021).

Print bonding is used for fabric applications where some parts of the fabric must be binder-free and only applies binder in certain locations. The purpose of printing patterns is to improve drape, softness, absorbency, strength, and fluid transfer.

Applying a binder at low water and high binder-solids concentration levels is known as foam bonding. Both water and air are utilized as the carrier and binder diluting media. By mechanically stirring the binder solution and adding air to the latex, foam is produced. The bonded fabric will have more loft and robustness if a stabilizing agent is added to the binder solution(Wood 2009).

System of chemical binder

The application process for binders consists of three parts.

1. Application of the binder to the nonwoven web

2. Curing and solvent or moisture removal and

3. Establishment of a solid connection between the binder and the nonwoven web

Strength, elasticity, durability, ageing, and stiffness/softness qualities are all influenced by the monomer's chemical makeup. The binder's cross-linking nature, adhesion properties, and solvent resistance are all determined by its functional group.

Webs can have varying ratios of chemical binders put to them, ranging from roughly 5% to 60% by weight. The most popular bonding methods include print, foam, spray, saturation, and powder bonding(Mercimek 2010).

The most important traditional binders are waterborne, fine dispersions of certain polymers. Depending on the application technique and intended use, the final binder polymer content might vary from 5% to 15. The polymer may sift deeply into thick and dense webs due to its viscosity, which is similar to that of water.

The binder polymer forms an adhesive coating between neighboring fibers segments when the water evaporates, and when this layer dries, binder bonds and sheet consolidation are formed(Paunonen et al. 2022).

Binder viscosities

One essential characteristic of a binder solution is its viscosity. When the air deposited sheet is viewed as a collection of tiny capillaries, the viscosity can be seen in the denominator of the penetration rate formulae. Thus, raising the viscosity prevents the flow of the binder. Both

commercial acrylic binders have viscosities that are nearly comparable to water, which improves wetting and penetration into the air-lay sheet(Paunonen et al. 2022).

2.2.3 Mechanical bonding

Needle punching, barbed needles enter and exit the web vertically, hooking and tangled fibers. Usually, heavy webs larger than 100 g/m2 are not woven but rather needle-punched.
Hydro-entanglement: Fibers are mechanically entangled using highly pressurized water jets that act as incredibly fine needles.
The web must then be dried. This method allowed the processing of light webs.
Stitch bonding: Fibers are entangled by knitting needles with hooks, which travel through webs and pull bundles of fibers back through. There's no binding thread. This process is facilitated by long fibers, particularly for heavy webs (Le Blan et al. 2007).

Using needle punch technology, the soft fibers that had been separated were turned into fabric. It has gone through two procedures. The creation of needle-punched non-woven fabrics and the generation of laps. The right manufacturing technology for Areca needle-punched non-woven adds value in addition to producing a variety of Areca goods(Sundarraj and Annapoorani 2015)**.**

2.2.4 Thermal bonding

Using thermal energy to activate an adhesive system, thermal bonding techniques connect fibers.
Low-melting thermoplastic fibers, particularly polypropylene and polyethylene, are frequently processed using this method. Fibers are fused and bonded primarily at their crossing places where the pressure is highest when the fiber web is passed between heated metal cylinders, a process known as thermal bonding. As an alternative, binder powders or fibers could serve as the glue.
A fibrous web is run through a hot calendar featuring an embossed design to create thermally calendar-bonded nonwovens. The elevated sections of calendars are where bonding mostly takes place, creating bound spots known as "bond points." The permeable portion known as the fiber matrix, which serves as a connection between the bond sites, is made up

of other portions of the web that were not in contact with the hot etched pattern(Farukh, Demirci, and Sabuncuoglu 2014).

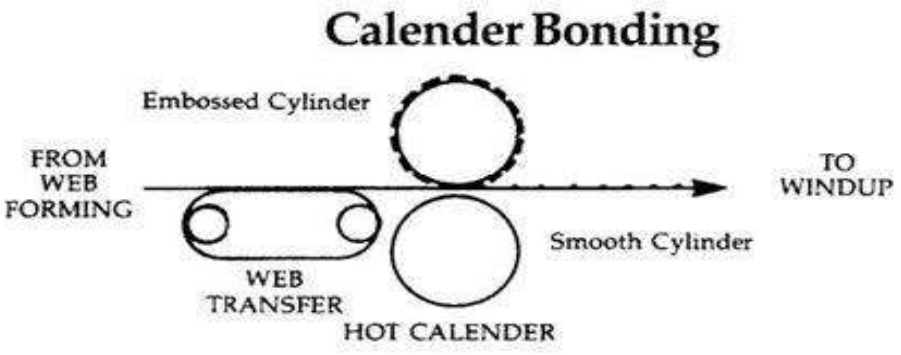


Figure 2-5 Web consolidations and embossing by thermal bonding

2.3 Definition of interlining

For stability and a suitable look, an interlining layer of fabric is positioned between the shell fabric and the lining of an article of clothing. Depending on the substrate and use, it has a long history and can take many different shapes. The most widely used and well-liked interlinings are fusible interlinings.

Interlinings, an invisible part of clothing, are essential to improving the item's appearance and functionality. These are performance materials based on textiles that can be nonwoven, knitted, or woven. They are positioned between shell cloth and layers of facing or lining fabric. Sewn-in interlining and fusible interlining are the two primary varieties. The fabric's bulk, softness, insulating properties, handiness, and durability are all improved by interlining(Barnard 2018).

The bulk or volume, stiffness, and dimensional stability of the garment component are all enhanced by the use of woven interlinings. Although cotton or cotton blends make up the majority of its composition, they can also be made of wool, acrylic, viscose, polyester, and animal hair. Knitted interlinings include heavy, robust knits made of polyester and weft-inserted knits made of lightweight elastic polyamide. Lightweight clothing that needs to be elastic and supple, as well as have improved formability and sewing ability, frequently uses knitted interlinings. Knitted interlinings are less expensive than woven ones since knitting has reduced production costs.

Woven interlinings improve the bulk or volume, stiffness, and dimensional stability of the clothing component. Although they can also be made of animal hair, wool, acrylic, viscose, and polyester, they are primarily composed of cotton or cotton mixes. There are two types of knitted interlinings: lightweight, elastic polyamide knits that are inserted into the weft and heavy, sturdy knits made of polyester. Knitted interlinings are commonly used in lightweight clothing that needs to be supple and elastic, as well as having better formability and sewing ability. Because knitting costs less to make than weaving, knitted interlinings are more affordable than woven ones(Sudhakar and Renjini 2022)

2.4 Classification of interlining

Stitched interlining: To make the sewn interlining, a piece of cloth is coated with starch, left to dry, and then sewn with the main fabric. In addition, fusible interlining is a substance that may be attached to garment parts by heating and exerting pressure for a set period of time. Fusible interlinings outperform sewn interlinings overall, and the fusing process is easier.

Fusible interlinings work better overall than sewn interlinings, and the fusing process is easier. Essentially, the classification of interlinings is determined by the base fabric, also known as the substrate. A substrate is an interlining substance that has been coated, sprayed, or printed with thermoplastic resin. There are several different types of interlinings, the first four of which are knitted, non-woven, woven, and non-general interlinings.

2.4.1 Woven interlining

Woven interlining is a woven substrate basis for fusible interlining. Weaved interlinings are used at different places along the fabric warp. Every zone has distinct qualities in terms of handling, drape, and resilience. In the most demanding applications, such as front shirt bands, collars, outerwear plackets, waistbands, and jackets, lightweight materials are usually used for woven interlinings. An excellent example of its use is an interlining with soft handles in the warp and firm handles in the weft. For the front length and also prevents the lateral portions of the chest and shoulders from folding. The garment functions quite well thanks to the woven interlinings. However, it is fairly pricey in comparison to other types that are available. Nevertheless, in contrast to other varieties that are accessible, its cost is very high(Barnard 2018).



Figure 2-6 Woven interlining

2.4.2 Nonwoven interlining

Non-woven, as the name suggests, is not composed of textile fabric. Composite, random, parallel, and cross fibers are among the many types of fibers that make up a nonwoven substrate. Non-woven interlinings are usually less expensive than knitted or woven fabrics due to their manufacturing process. Polyamide materials, ranging from heavier mixtures to ultra-fine coatings, make up the entirety of superior non-woven interlinings. These are thermally or chemically attached, depending on the use. Due to a shortage, non-woven interlinings which originated in the paper industry were developed and used by clothing manufacturers.



Figure 2-7 Nonwoven Interlining

2.4.3 Knitted interlining

Because they provide the perfect stretch basis for efficient manufacturing, fusible knitted interlinings are typically used in knitted garments. The stretch and recovery properties of circular and jersey knit fusible interlinings enable stretchable joining territories. By easily permitting limb and body movements, the knitted interlining architecture significantly increased the flexibility of the fused

components. The growing popularity of knitted textiles for both men's and women's clothes led to the introduction of knitted interlinings in the early 1960s. This type of interlining was first used in warp-knitted goods, but it wasn't until weft-inserted fibers were incorporated into the warp-knitted structure that it became widely recognized as a fusible for woven textiles(Barnard 2018).



Figure 2-8 Knitted Interlining

3 CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Introduction

Fibers are the main material used to make nonwoven textiles. By connecting or interlocking the fibers via mechanical, chemical, or thermal methods, web-shaped fibers are transformed into fabric(Ghosh and Patra 2016).

Nonwoven is a kind of fabric with orientation or random arrangement of fibers bonded by means of chemical bonding. The structures of nonwovens are three-dimensional netted and multi-porous structures, which is very suitable for the application as thermal insulation materials with its porosity, plasticity and elasticity. Also, nonwovens have the advantages of using recycled fibers as basic raw materials. Different variety of simple manufacturing technologies, higher productivities, multiple technologies and numerous applications.

In this chapter, the development of nonwovens by using recycled garment waste fibers of different cotton/polyester blends which were recycled from the garment wastes and the analysis of their strength, elongation, weight and other physical as well as mechanical properties to know the conformity of the nonwoven sample for interlining application properties of the developed nonwovens were discussed in detail in this chapter.

3.2 Materials and chemicals used

Materials which were used for this research were recycled cotton, recycled Polyester waste fibers from garment scraps that I have collected from Yeka industrial college garment shops and grinded at Yirgalem Addis textile factory and an adhesive for the production of nonwovens.

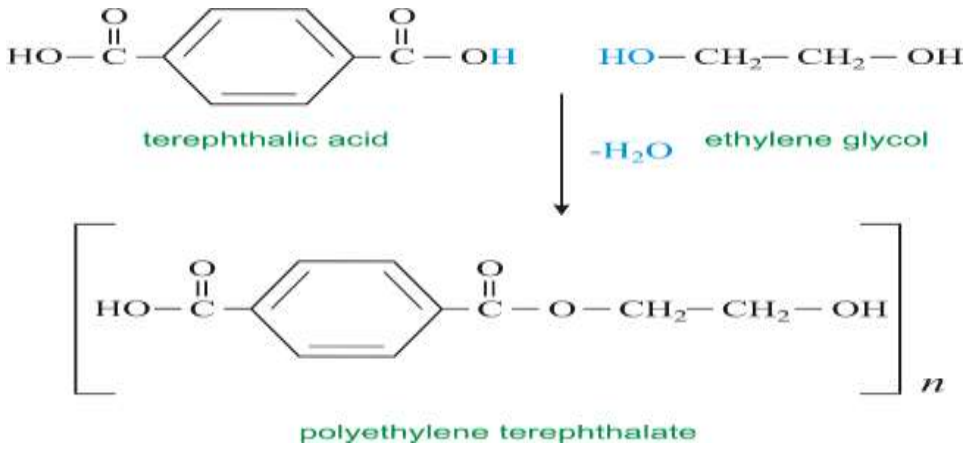
Properties of cotton fiber

Raw cotton contains the following substances

- Cellulose (80-90%)
- Water (6-8%)
- Hemicellulose and pectin (4-6%)
- Ash (1-10%)
- Waxes and fats (0.5-1.0%)
- Proteins (0-1.5%)(Kalabek and Babaarslan 2016).

Polyester fiber properties

As its name indicates, this type of fiber consists of macromolecules of esters which are chemicals made of acids and alcohol. If many of these basic molecules are combined, they will form polyesters. Physical properties of polyester fibers are important while producing nonwoven materials. For example, the lengths of cut are adapted to the respective manufacturing procedure. Fibers are also available in different of luster and cross-sectional forms(Kalabek and Babaarslan 2016).



1. Figure 3-1 Polyester fibers(Kalabek and Babaarslan 2016)

Two recycled fibers, cotton and polyester were selected for the preparation of nonwoven fabrics. Cotton and polyester both fibers were most widely used fiber in clothing and other textile industry, may be this was the reason that most of the textile waste comprised of these two fibers.

The raw materials were collected and sourced from Yeka industrial college garment shop and grinded at Yirgalem Addis textile factory. First post consume garments and scraps as well as textile wastes are sorted and opened by means of mechanical processes. These garment scraps has been converted to recycled fiber mechanically using Biella grinding, opening and blending machine. The input raw materials were fed manually through a rubber conveyor belt of the first grinder and opener to be automatically transferred to the bottom of the spiked roller. The roller was responsible for tearing and opening the garment scraps into fiber form.

The research was involved sourcing recycled cotton and polyester fibers from post-consumer waste streams and blending them to create a non-woven fabric. A poly vinyl alcohol chemical binder was also developed and applied to bind the fibers together, ensuring structural integrity and performance. The developed fabric were undergo testing for tensile strength, bursting strength, tear strength , weight(GSM), and other key properties to evaluate its suitability for interlining of clothing application.

Table 3-1 Chemicals used

s/n	chemicals	Measurement	quantity	uses
1	Polyvinyl alcohol	gm.	500	To bind recycled fiber web together
2	Distilled water	ml	1000	As PVA solvent
3	Glycerol	ml	500	To impart the softness of the sample
4	Calcium carbonate	gm.	300	to increase the viscosity of the PVA

3.3 Machines and Equipment's used

Table 3-2 Equipment and materials

Name of equipment	Equipment function	Where it is found
❖ Grinding machine	➢ for grinding garment wastes	✓ Yirgalem Addis textile company
❖ Carding machines	➢ for dry laid web formation	✓ ETIDI Lab
❖ High volume instrument	➢ for fiber property testing	✓ ETIDI physical Lab
❖ Digital thickness tester	➢ Thickness test	✓ FTI Textile Lab
❖ Nonwoven fabric weight tester	➢ GSM /areal density	✓ FTI Textile Lab
❖ Stirrer	➢ To steer PVA solution	✓ FTI Textile Lab
❖ FTIR machine	➢ Used to characterize recycled fibers and functional group	✓ AASTU
❖ Scissor	➢ Used to cut samples	
❖ Tensile Strength tester	➢ To know strength of sample	
❖ Brush roller	➢ To coat PVA on fiber web	✓ ETIDI Lab

3.4 Methods

The garment wastes and scraps have been processed through the sequence of different methods. First, the wastes were cleaned. Because, it contains many unwanted materials. And then cotton and polyester wastes were separated carefully. Then after, garment wastes were loaded in to Biella waste fabric grinding machine to convert garment wastes to fibers. After that, the fibers have been processed in a mini laboratory carding machine for the preparation of nonwoven webs. During the production process of nonwovens from recycled cotton (R- cotton) and recycled polyester (R-polyester) fibers were blended with cotton and polyester with a proportion of 50/50, 70/30, 30/70 cotton/polyester respectively by using an electronic balance in grams of fibers.

In addition nonwoven fabric were developed that having different layers and binder concentration.

3.4.1 Waste fabric grinding system

After the wastes were cleaned sorted and separated. It grinded by Biella waste fabric grinding machine at yirgalem Addis textile factory to convert waste garment scrapes to required fiber by using its sharp and strong blades.

3.4.1.1 Biella Waste fabric grinding machine

An Italian company called Biella Waste Fabric Grinding Machine specializes in textile machinery, including waste cloth handling textile processing equipment. Through the conversion of textile waste into raw materials for new product production, the equipment has excellent applications in the textile recycling industry, helping to preserve resources and offer sustainability. The following are the machine's major components.

Feeding System: To ensure adequate grinding, waste cloths were distributed equally and fed into the machine via a conveyor belt, making sure to avoid any jams in the process. The automated system then monitored the grinding to ensure a consistent output of recycled fibers.

Grinding Chamber: The heart of the system is the grinding chamber, where grinding tools that rotate (e.g., blades) are positioned. The grinding tools are designed to tear, cut, and grind the cloth into pieces or fibers.

Hammers or revolving blades: The fabric is torn into tiny pieces by high-speed rotating blades. The speed of the blades and the distance between them can be changed to control the size of the output material.

Screen or Sieve: To regulate the output's particle size, a screen or sieve is positioned at the bottom of the grinding chamber. The smaller particles are permitted to flow through the screen, while the bigger particles are held for further grinding.

Airflow System: Light fibers and heavy particles are separated using an airflow system. Additionally, it keeps the device from overheating while grinding.

Collection System: A bag or container that is customized for the machine is used to collect the

ground fabric fibers or particles. There may also be incorporated in some systems a cyclone separator for increasing the collection efficiency.

Dust Extraction: To provide a healthier working environment and lower health hazards, a dust collecting system is used to extract the fine dust and particles that are produced as a by-product of grinding.

Control Panel: To adjust variables such particle size, feed rate, and grinding speed, the machine has a control panel (Source from Yirgalem addis textile factory).



Figure 3-2 Biella waste fabric grinding machines and grinded waste fiber

3.4.2 Carding

Mini Carding machine was employed in the present research work. It consists of feeding rollers covered with iron spikes for opening, cleaning and web preparation. Fiber mass was placed evenly on feeding plate of carding machine. This machine worked as to make web of fibers and also it removes dust and other impurities.



Figure 3-3 Fiber blending and web reparation

Carding machine helped in straightening and parallelization of the fibers into thin web known as lap. To make a good quality non-woven fabric, this is very essential to card fibers properly to prepare even web.

3.4.3 Fiber Web preparation

Layers of recycled cotton and recycled polyester web were feed into the chemical bonding machine for cohesion b/n fibers and bind them by means of adhesive called poly vinyl alcohols.



Figure 3-4 Prepared fiber web

Garment wastes

The garment scraps wastes and post- consumer garment wastes obtained from Yeka industrial college garment shops were collected, sorted and grinded to convert woven and knitted waste garments to desired fiber. The waste garment scraps separated and cleaned manually to remove non- cotton and colored materials present in the cotton waste out of cotton threads. The cleaned cotton waste then grinded and opened into fibrous form

using a grinding machine.



Figure 3-5 Grinded and non-grinded fabric wastes

3.4.3.1 Polyester garment scraps wastes

The polyester lining scrape wastes and post- consumer garment wastes are sourced from the post-consumers such as t-shirts, trousers, dresses etc. was collected, sorted and cleaned manually to remove non-polyester and colored cotton materials present in the recycled polyester waste. The cleaned polyester wastes were grinded and opened into fibrous form using a Biella grinding machine. The photographic images of recycled polyester waste and cleaned polyester wastes are shown in figure 3.5 below.



Figure 3-6 100% Polyester Waste

3.5 Methods of sample development techniques and procedures

The nonwoven samples were developed by using chemical bonding techniques and the sample development flow chart is shown in figure bellow.

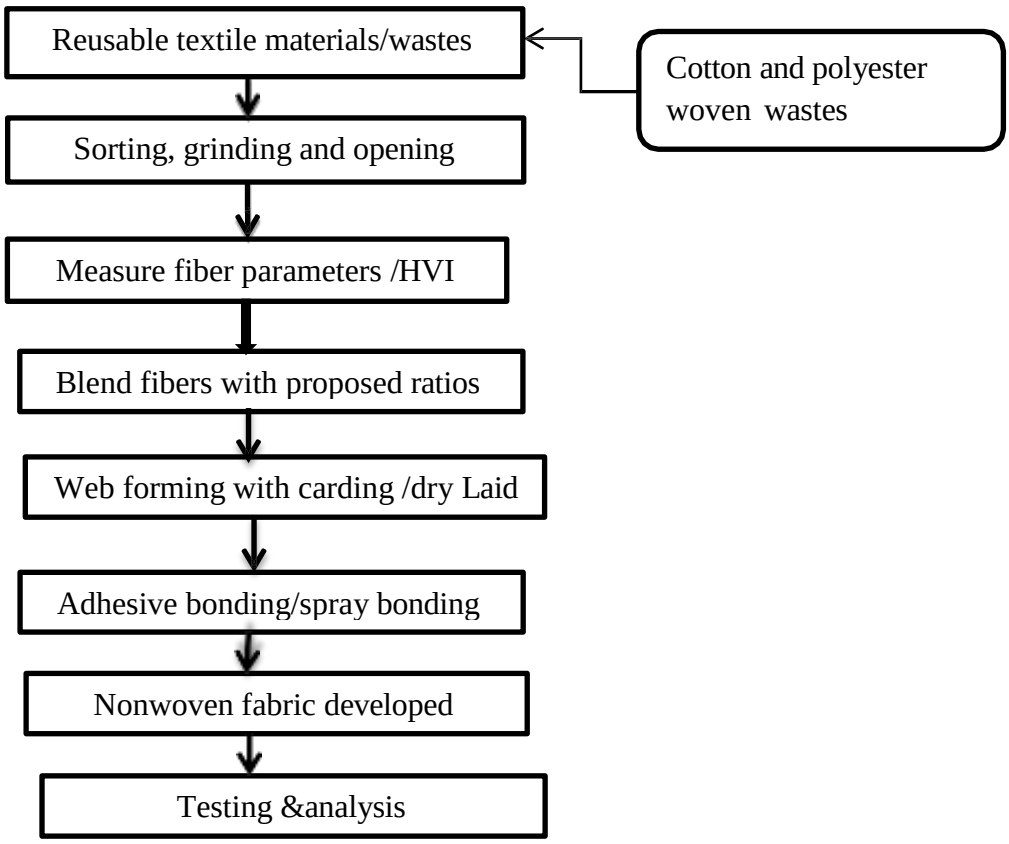


Figure 3-7 Development technique of chemical bonded non-woven

3.5.1 Blending of Recycled Fibers

Recycled cotton and polyester fibers were blended manually in three different ratios to prepare web for nonwoven fabrics. Blending ratios are of 70:30 30:70 50:50 i.e., in first ratio 70% recycled cotton and 30% recycled polyester and 30% recycled cotton and 70% recycled polyester then equal amount of each fiber 50% recycled cotton and 50 recycled polyester fibers.

Along with that different samples with maximum binder concentration and minimum binder concentration with maximum number of web layer and minimum number of web layer were used. Cotton and polyester fibers were blended together with different percentages using a mini laboratory carding machine.

The different blends of cotton and polyester fibers used for the manufacturing of nonwoven fabrics were given in Table 3-3. Three times the fiber blend was carded to enhance web uniformity, and all the operations were also carried out with an electrical balance in grams.

Table 3-3 Recycled fiber blending composition and sample coding

s/n	Fibber blend composition	c/p	Sample code
1	50% recycled cotton fiber and 50% recycled polyester fiber and	50:50	B1L1P10
2	50% recycled cotton fiber and 50% recycled polyester fiber and with 10% binder concentration with layer 3	50:50	B2L3P10
3	70% recycled cotton fiber and 30% recycled polyester fiber and with 5% binder concentration with layer 3	70:30	A2L3P5
4	30% recycled cotton fiber and 70% recycled polyester fiber and with 10% binder concentration with layer 1	30:70	C2L1P10
5	30% recycled cotton fiber and 70% recycled polyester fiber and with 10% binder concentration with layer 3	30:70	C2L3P10
6	70% recycled cotton fiber and 30% recycled polyester fiber and with 10% binder concentration with layer 1	70:30	A2L1P10
7	70% recycled cotton fiber and 30% recycled polyester fiber and with 10% binder concentration with layer 3	70:30	A2L3P10
8	50% recycled cotton fiber and 50% recycled polyester fiber and with 10% binder concentration with layer 3	50:50	B2L3P10
9	30% recycled cotton fiber and 70% recycled polyester fiber and with 5% binder concentration with layer 3	30:70	C2L3P5
	30% recycled cotton fiber and 70% recycled polyester fiber and with 5% binder concentration with layer 1	30:70	C1L1P10

10			
11	50% recycled cotton fiber and 50% recycled polyester fiber and with 5% binder concentration with layer 3	50:50	B2L3P5
12	70% recycled cotton fiber and 30% recycled polyester fiber and with 5% binder concentration with layer 1	70:30	A1L1P5

Table 3-4 fiber **blend ratio**

Code	Cotton (%)	Polyester (%)
A	70	30
B	50	50
C	30	70

Table 3-5 Level of process factors

Sn.	No-of layer	Binder concentration (%)
1	1	5
2	3	10

3.5.2 The fiber web formation of recycled fibers

Recycled cotton and polyester fibers and the blended cotton/polyester fibers were fed into a mini laboratory carding machine to obtain carded webs. For the period of carding process, the fiber blending was extra open and individual fibers were combed to make parallel fiber webs. The fiber blending was carded three times to improve web uniformity. With different webs, layers are superimposed one above the other to obtain the required thickness in the final nonwoven fabrics, and the parallel or random laying techniques allows nonwovens with range of mass per unit area to be manufactured, in which fiber orientation can be made with more random than in the case of the traditional web layering. The nonwovens manufactured by this technique.

Twelve different types of web were manufactured, 50/50 R-Cotton/Polyester, 70/30 R-Cotton/Polyester, and 30/70 R-Cotton/Polyester blended materials. This mini card web produces better fibrous webs as shown in the figure 3.7 below.



Figure 3-8 Fiber web preparation process



Figure 3-9 Web formation with different blend ratios

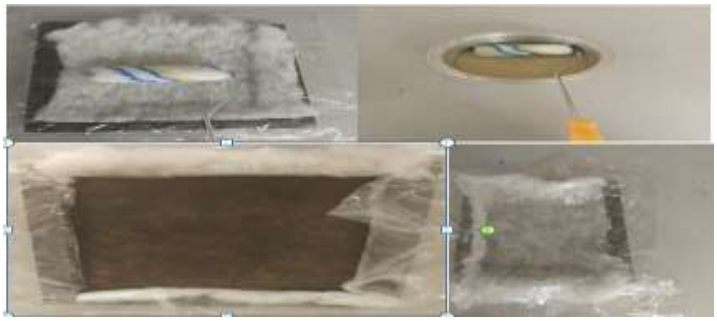


Figure 3-10 Fiber web coating and pressing



Figure 3-11 Methods of sample development techniques and procedures

3.6 Testing Methods of fibers

The recycled cotton and polyester fibers were tested according to the standard procedures of HVI and tested with the physical properties. Like fiber length, fiber strength, fiber elongation and fiber microniare values. And the nonwoven samples of recycled cotton and polyester recycled fiber from different garment scraps according to the required samples were tested for tensile behavior and other conformity physical and mechanical properties. Like thickness, fabric weight, tear strength and tensile strength with respect to the ASTM and ISO standard. In order to study the influence of fiber type, fabric thickness, fabric weight, tensile strength , bursting strength, tear strength of the samples of recycled fiber nonwoven were produced and measured with the above parameters.

3.6.1 Characterization of the recycled fiber properties

The recycled waste fibers were tested in relation to their fiber length, fineness, elongation, diameter, fiber strength by using standard test procedures. The test was important as the fiber characteristics directly affect the properties of developed nonwoven fabric. Before testing recycled 100% cotton, 100% recycled polyester fibers were kept in standard conditions for 24 h, i.e., 21±1°C temperature and 65% ± 2 RH. This was done to avoid deviation in results.

Table 3-6 Recycled cotton and polyester fiber properties

No-	Properties	Recycled cotton fiber	Recycled polyester fiber
1	Length (mm)	24.31 ±0.871	60.4 ± 0.47
2	Elongation (%)	5.81 ±0.048	16.26 ±0.775
3	Fiber fineness/count (d/tex)	1.428 ±0.04	2.98 ± 0.060
4	Fiber strength (cN/dtex)	2.97 ± 0.213	4.97 ± 0.0721
5	Diameter (microns)	14.69 ± 0.148	21.38 ±0.204

3.6.2 Preparation of recycled cotton/polyester web

Recycled blended cotton/ polyester fibers were feed into mini laboratory carding machine to get carded web. During carding process, the fiber should be opened in to individual fibers and combed to be somewhat to makes it parallel. The fiber blended was carded repeatedly to enhance the web uniformity. With different webs layers are superimposed one above the other to obtain required thickness in the final nonwoven fabric.

3.6.3 Preparation of binder for fiber web

Polyvinyl Alcohol (PVA)

PVA solution is prepared by dissolving PVA powder in water at elevated temperatures (80-120°C) with constant stirring. PVA plays a crucial role in enhancing the performance of nonwoven samples by improving cohesion b/n fibers, increases mechanical and physical properties, of nonwoven samples. Its versatility and environmental benefits make it a valuable component in the production of high-quality of developed nonwoven samples.

- Chemical binder prepared from PVA for fiber web binding.it is prepared in required concentration, mixed with water for about 5 minutes and cooked at high temperature 80-120°C in order to melt small granules of PVA chemicals.
- Then chemical binder is applied on web by manual spraying method or roller coating technique

3.6.4 Method of Chemical Bonding



Figure 3-12 Adhesive bonding of recycled nonwovens

The general term for inter-connecting fibers with the use of a chemical binder is "chemical" or "resin" bonding. Water-borne latex is currently the chemical binder most commonly employed to consolidate fiber webs. Vinyl compounds including polyvinyl acetate, polyvinyl chloride, styrene/butadiene resin, butadiene, and poly acrylic, or their mixtures, are used to make the majority of latex binders(Sakthivel et al. 2020).

Water- born latex is mostly used as a chemical binder which is applied about 5–30% by weight(Das 2014).

3.7 Method of developing of cotton/polyester non-woven fabric

Polyester and cotton recycled waste fibers were used for the production of nonwovens. The raw materials which cotton and polyester wastes were collected for this study from post-consumers and garment scrap wastes from textile industries or from post-consumers for the preparation of adhesive bonded nonwovens. First it sorted and open by means of mechanical Process. Wastes woven fabric should be converted in to fiber mechanically by using grinding, opening and blending machine. The wastes from post -consumers should processed through the sequence of operational procedures. First, the wastes were cleaned, because they were containing many undesirable materials. After that the fibers were process in the mini laboratory carding machine for the preparation of nonwoven webs. During the production process of nonwovens from recycled cotton (R-cotton) and recycled polyester (R- polyester) fibers were blended with cotton and polyester with a proportion of 50/50, 70/30 and 30/70 cotton/polyester respectively by using an electronic balance in grams of fibers

3.8 Study Area

Non-woven fabric that is developed from recycled cotton fibre and recycled polyester fibre for interlining of clothing application is that propose in this research work. The research mainly focuses on the development of non-woven fabric from recycled cotton and polyester fibres in different ratios. Developed samples were subject to different tests to know the physical properties and different performances of the fabric.

3.9 Study Population

The study population would consist of sample such as non-woven fabric samples. The size of the samples would consist about 12 developed fabrics to test and make optimisation studies.

3.10 Research Approach

The research is an experimental work based on the developed non-woven fabric samples. The research mainly focuses on the preparation and development of non-woven fabric samples Minitab software, excel and origin lab software's were used for design the experiments and optimisation studies the response of the physical and mechanical properties of the developed non-woven sample. The effect of concentration of binder and fabric composition or blend ratio, on the final tensile strength values, bursting property, fabric weight and tear strength of the fabric is also studied in this work

3.11 Variables

Since the research work is based on experimental work, most of the variables that are proposed in this study are related to the experimental work. The variables in this study are technically defined and can be classified into two categories like the Dependent variable or the response variable and the independent variables like fibre composition and binder concentration. The response variable in this study is tensile strength and other performance characteristics of nonwoven fabric.

3.12 Sample size

The size of the fabric samples is 200 x 30 mm cut , 125mm by 125mm and 100x75mm developed nonwoven samples for different tests . The samples were further cut into convenient pieces to test its mechanical property.

3.13 Method of Analysis

- ✓ Garment scraps are collected ,sorted , grinded and converted to recycled fibres.

- ✓ Recycled fibre are then characterized based on their length, diameter, elongation and strength by standard test procedures.
- ✓ Recycled fibres are then opened well, cleaned and parallelized to create fibre web.
- ✓ Fibre webs are coated with brush roller to bind fibres together.
- ✓ Chemically bonded fibre webs are pressed with require pressure to increase fibre cohesion b/n fibres and for better fibre compactness.
- ✓ After nonwoven fabric sample is developed drying and finishing is carried out on it

Once the samples are developed, the developed samples are tested for its mechanical property test.

1. All the response variables and independent variables are experimentally determined after running the required experimental runs.
2. The experimental data is then analysed using Minitab software to optimise the results.
3. The developed fabric samples are tested for its prospective application as interlining for clothing
4. Suitable discussions and conclusions were draw.

3.14 Design of Experimental plan

Table 3-7 list of factors and levels

Factor	Factors Name	Level	
		Minimum	maximum
A	Rc/Rp blend ratio (%)	30:70	70:30
B	Binder concentration (%)	5	10
C	No of layer	1	3

3.14.1 Experimental observation

Binder Concentration (%): Low = 5%, High = 10% (2 levels)

Fiber Blend Ratio (Cotton: Polyester): Low = 30:70, Medium = 50:50, High = 70:30 (3 levels

Table 3-8 Experimental observations

Exp no	Cotton/polyester Blend ratio%	No of layer	Binder concentration%
1	70:30	1	5
2	50:50	1	5
3	30:70	1	5
4	70:30	3	5
5	50:50	3	5
6	30:70	3	5
7	70:30	1	10
8	50:50	1	10
9	30:70	1	10
10	70:30	3	10
11	50:50	3	10
12	30:70	3	10

3.15 Scanning electron microscope Analysis

SEM uses a focused electron beam to scan the surface of a sample. When the electron beam interacts with the material, secondary electrons are released and are then captured to create an image. The produced images provide in-depth information about the sample's composition, morphology, and geography. The surface properties of produced nonwoven samples can be revealed with the use of SEM. Researchers commonly utilize SEM to study the morphology of nonwoven fabric binding techniques and fiber arrangement, especially regarding morphological changes prior to and following strength testing. By photographing the particles, scientists can determine their size, shape, and dispersion.

3.16 FTIR Analysis

FTIR research was performed to look at the chemical and functional groups present in the recycled cotton and fibers. The fundamental idea behind FTIR spectroscopy is that distinct infrared wavelengths are absorbed by various functional groups and chemical bonds found in fiber materials. We can determine the presence and properties of different functional groups and chemical moieties in the fiber sample by examining the pattern of absorption peaks in the FTIR spectrum.

3.17 Physical and mechanical properties of developed nonwoven fabrics

The physical and mechanical properties of all the developed fabrics were tested. Tests were carried out to evaluate fabric weight (g/m^2), fabric thickness (mm), tensile strength (N/ m^2), elongation (%) etc., of the prepared non-woven samples, as per the standards.

The developed recycled cotton/polyester samples within different ratios such as 50:50 RC/P, 70:30 RC/P, and 30:70 RC/P and samples with different web layer and binder concentration on the principle of weight of recycled fibers by using electronic balance were prepared. The thickness of the preferred samples in this study ranges from 30cm wide and 200 cm long were developed to measure the tensile strength property as shown in figure 3.7 which shows the prepared samples of chemical bonded recycled nonwovens from garment scraps wastes.

The physical and mechanical properties of nonwovens which are the most essential properties such as fabric thickness, fabric weight, fabric tensile strength, fabric bursting strength and other properties are tested and analyzed. The entire chemical bonded samples were tested according to the ASTM and ISO. And physical properties of the nonwoven samples were also tested to understand the conformance of chemically bonded nonwoven samples.

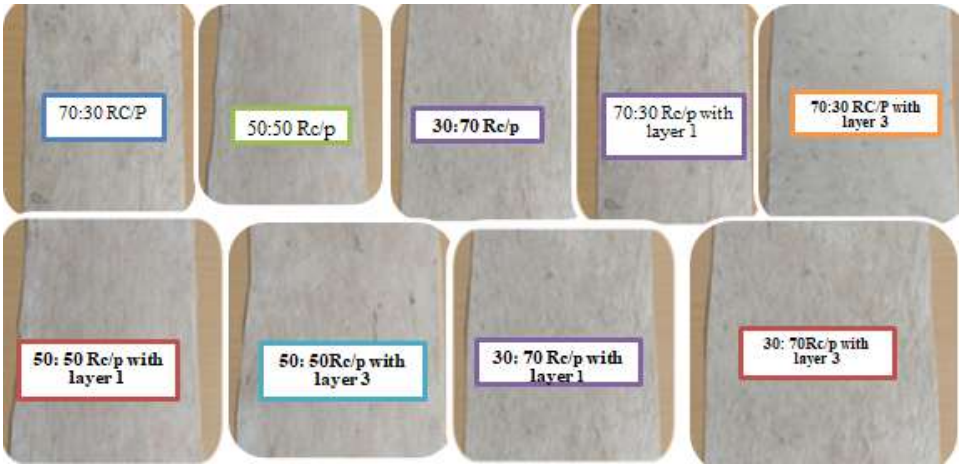


Figure 3-13 chemically bonded nonwoven samples with different blend ratios

3.18 Experimental frame work

Experimental frame work was summarized in the figure as follow:

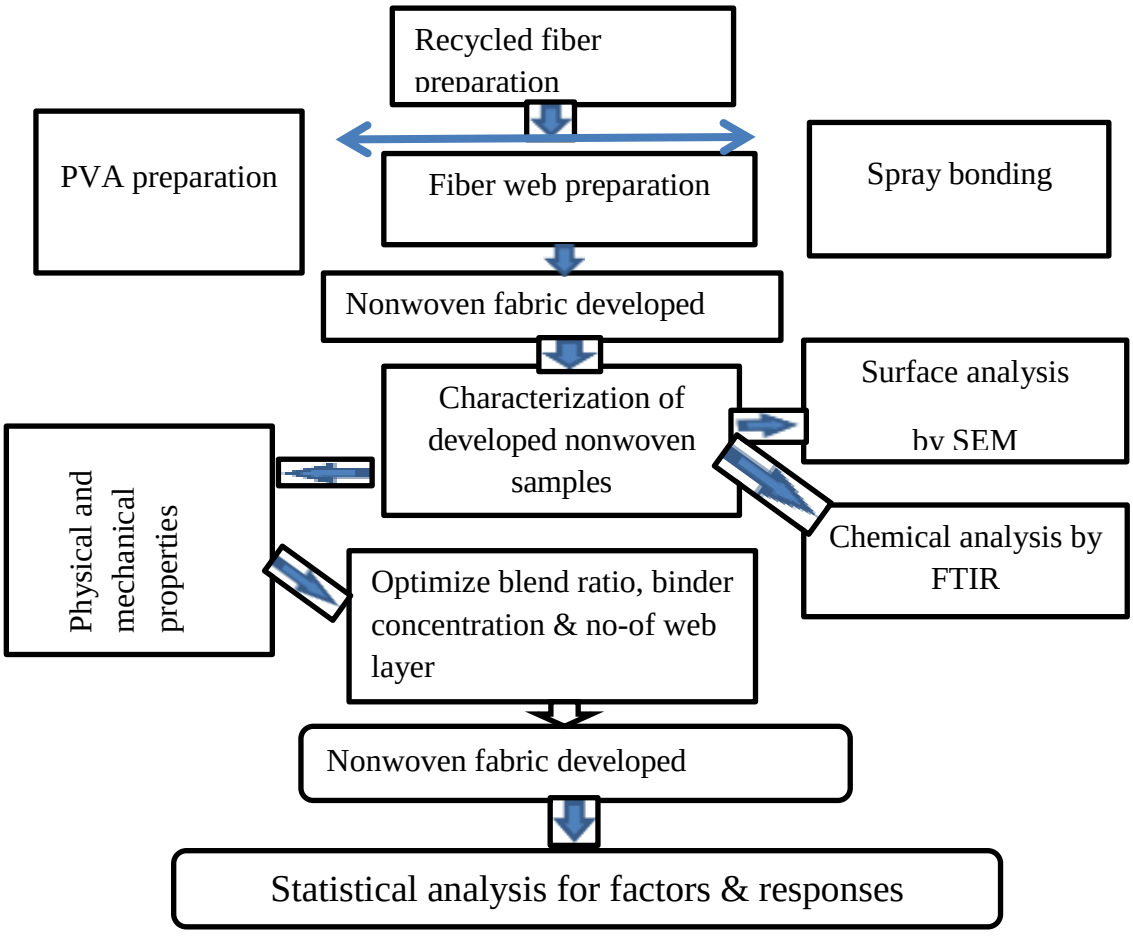


Figure: Experimental frame work

3.19 Testing of Physical Properties of Developed Nonwovens

3.19.1 Thickness Testing Measurement

The thickness tester machine was used to measure the thickness of non-woven fabric. The numerical display range starting from a thickness of 0.001~25mm, measuring with an accuracy of 0.00125mm, lowering speed of pressing-foot 1.72 mm/s, area of pressing foot 2500mm^2 and Load Weight 1000cN Pressing duration 10s. The sample size which was taken for thickness measurement was 15-cm width and 30-cm length. The mean value of all the five random readings of thickness has been taken. It was used to determine the nearest value in mm, and the calculated result is the average values of thickness of the samples under the test. The nonwovens thickness was determined in accordance with the digital thickness tester with ISO 9073 test methods.



Figure 3-14 digital non-woven fabric thickness tester

GSM is the weight of nonwovens in one gram per square meter. And it is also the metric measurement of the weight of the nonwoven fabrics. Its unit is g/m^2. To measure the gram per meter square (g/m^2) of the nonwoven fabrics by g/m^2 cutter, fabric weight was one of the physical tests of the nonwoven fabrics. And by the following ways we can measure the weight of the nonwoven fabrics. Cut the nonwoven fabrics with GSM cutter in (g/cm^2), then after, weight the nonwoven fabric with an electrical balance, the cut sample is 100cm^2, the weight of the samples are multiplied by 100 or divided by 0.01 to change the centimeter in to meter. It was performed three random readings, and takes the average values from three reading. Then the result is the GSM of the particular non-woven fabric as illustrated in figure 3.15 . The nonwovens fabric weight

was determined in accordance with the GSM tester with ASTM D-3776 test methods.



Figure 3-15 Nonwoven fabric weight testing

3.19.2 Tensile strength **testing of nonwoven fabric**

Tensile testing was conducted at Ethiopian textile industry development institute using ISO 9073-3 Standard for nonwovens, determination of tensile strength and elongation. A 200mm x30mm piece of nonwoven fabric sample is stretched until it breaks using a Mesdan testing machine.

The test sample was fixed in the clamp and the upward button was pressed as the machine goes up automatically until the sample breaks.

The objective of this test was to test the tensile strength of the produced fabric samples in a controlled setting using the Mesdan Fabric Strength Testing Machine.

The nonwoven interlining samples were subjected to a breaking strength test and elongation according to ISO 9073-3 The test standard outlines a process for applying the grab method of determining the force at maximum, as well as elongation at maximum force of the samples. The developed samples had dimensions of 200x30mm. Samples were conditioned under standard temperature and humidity (for example, 21°C ± 1°C and 65% ± 2% RH) for 24 hours prior to testing.

Tensile Testing Machine: A Mesdan tensile strength tester machine that applies a controlled force to the fabric sample and measures the resulting elongation and breaking force.



Figure 3-16 Mesdan tensile strength tester machine

Table 3-9 Machine set up of Mesdan tensile strength tester

Machine set up of Mesdan tensile strength tester	
Load cell ID/FS (kg)	5/500
Sample length	200mm
Clamp speed	100mm/min
Pretension	2(N)
Observation method	dry sample

Tensile strength is measured in terms of some quantities and units depending upon the test method and standard. tensile strength is most often specified as force per unit width of fabric. Common Units: Newton's per meter (N/m) or pounds-force per inch (lbf/in).Tensile strength is also called force per unit area. Common Units: Pascal's (Pa), kilopascals (kPa), or mega Pascal's (MPa).

Maximum Force (Peak Load**)**: The highest force that the fabric can withstand without rupturing.

Calculating Tensile Strength

• Tensile Strength (Force per Unit Width)

Tensile Strength=Maximum Force (N)/ cross-sectional area of the nonwoven sample(m2)

Example: sample A1L1P5 having 30 mm wide and 200mm long has tested and piece of fabric breaks at 48.96 N , then its tensile strength is tensile Strength=Maximum Force (N)/Cross-Sectional Area of sample (m^2)=48.96/6000mm^2=48.96/6=8.16(N/m^2)

3.19.3 Elongation at Break

It measures the stretching ability of the fabric before failure, which is crucial for flexible and stretchable applications. The elongation at break of a nonwoven fabric is a measure of its elasticity and stiffness. It measures how much deformation a fabric can endure before breaking. Higher binder concentration improves mechanical properties but increases weight. Lower binder concentration reduces strength but improves flexibility. It is the percent increase in length of the fabric before breaking under tensile stress. It is expressed as a percentage of the original length.

$$\text{Elongation at Break}(\%) = (\text{Final Length} - \text{Initial Length}) \div \text{Initial Length} \times 100$$

3.19.4 Bursting Strength of nonwoven samples

Busting strength test was performed according to ASTM D3787 using a “Mullen” machine. Bursting strength the maximum hydrostatic pressure required to rupture the sample by constantly, increasing the pressure applied through a rubber diaphragm on nonwoven sample. The sample is initially held flat & rigid and allowed to bulge during the test. Burt strength is expressed in k/Pa or N. The procedure is laid out in Tappit403. Explains the hydraulic techniques used to calculate nonwoven bursting strength, which ranges from 70 k N/m^2 to 110 k N/m^2. The pneumatic technique, which is occasionally required for weak nonwoven samples, is explained. Description of burst test method, the nonwoven sample is held between two tiny circular clamps in the lab to determine the burst. A rubber diaphragm that has been expanded by hydraulic pressure is used to provide increasing pressure to the sample at a regulated rate until the paper bursts.



Figure 3-17 Bursting Strength of nonwoven samples

To calculate the bursting strength of the developed nonwoven samples, the ASTM D3787 standard is employed. When the 125mm by 125mm nonwoven sample is stretched, it begins swelling instantly in all directions that are possible. When pressure is applied gradually, the fabric ultimately reaches a pressure point and bursts.

3.19.5 Tear Strength of nonwoven sample

The falling-pendulum type (Elmendorf) apparatus is employed for measuring the ripping strength of nonwoven samples in accordance with ASTM D1424 The Elmendorf test apparatus's falling pendulum tears a specimen of interlining. The maximum follow-through angle of the pendulum after tearing is used to calculate the energy to propagate the tearing. The energy that has been expended in ripping the specimen is higher with a smaller follow-through angle. 100x75mm was the dimension of the samples. The forces needed to cause the fabric to tear samples were measured in Newton's (N). The tearing strength of the nonwoven samples was evaluated using an Elmendorf M008HE SDLATLAS Power Tear tester in compliance with the test procedure offered by D1424, ASTM.



Figure 3-18 Tear Strength of nonwoven sample

4 CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

The results and discussion section of this research presents a comprehensive analysis and interpretation of the data obtained from the experiments conducted on the nonwoven samples developed from the recycled cotton and recycled polyester fiber by combined with different characteristics. This section aims to explore and explain the outcomes of the experiments, focusing on the determination of physical and mechanical properties for performance characteristics like tensile strength, thickness, weight ,bursting strength, tear strength and elongation at break of the developed nonwoven sample. The data obtained from tensile strength, thickness, bursting strength, tear strength and elongation at break were analyzed to understand the effects fiber blend ratio, binder concentration and no-of web layer on the developed nonwoven fabric performance.

Twelve different types of chemically bonded nonwoven samples were developed from recycled cotton/polyester blended in different blending ratios. The physical properties of the chemical bonded nonwovens of recycled cotton and polyester fibers were measured and mean values with standard deviation of samples were given in Table 4.1. The physical properties of developed samples 50/50, recycled cotton/polyester, 70/30 recycled cotton/polyester and 30/70 recycled cotton/polyester wastes chemically bonded nonwovens were tested according to the ASTM and ISO standards to determine the properties of the nonwovens in accordance with their tensile strength and other conformance tests.

Table 4-1 Mechanical properties of chemically bonded nonwovens

Sample code	Fabric direction	Average force(N)	Tensile strength (N/m^2)	Average Elongation (%)	Average time(s) to breakage
A1L1P5	longitudinal	48.96	8.16	6	10.8
AIL1P10	longitudinal	75.96	12.66	5.5	12.8
A2L3P5	longitudinal	120	20	7.33	5.2
A2L3P10	longitudinal	156	26	6.433	7.2
B1L1P5	longitudinal	103.98	17.33	10	13.3
B1L1P10	longitudinal	118.86	19.81	8	13.4
B2L3P5	longitudinal	164.1	27.35	12.343	14.471
B2L3P10	longitudinal	177.12	29.52	9	12
C1L1P5	longitudinal	127.38	21.23	10.417	11
C1L1P10	longitudinal	136.31	22.71	9.261	10.459
C2L3P5	longitudinal	195.24	32.54	12.438	12.632
C2L3P10	longitudinal	201.6	33.66	10	14.529

4.2 Data Analysis

4.2.1 Analysis of variance (ANOVA)

The formation of chemical-bonded nonwovens, their binder concentration, number of fiber web , and fiber blend ratio variables influencing the manufactured of nonwovens' fabric (GSM), fabric strength, fabric thickness, fabric elongation at break and etc. were the main focus of the study. The purpose of the investigation was to examine the conformity properties of the fabric for interlining application of 12 chemically bonded nonwovens samples. Physical and mechanical characteristics were also examined. Properties like thickness, fabric weight, bursting strength, tensile strength, and elongation at break were all statistically analyzed. Minitab 19.2 for regression and correlation and one-way ANOVA and origin19 were utilized for the data analysis.

The ANOVA test provides a P-value that accounts for variance, mean difference, and data size. When the P-value and the critical value of the t-test are less than 0.05, it means that there are significant differences in the group expression data. A one-way analysis of variance, It was analyzed using an ANOVA with a 95% confidence level. A significant difference has been

Observed ($p<0.05$). The degrees of freedom associated with the F-statistic test and its significance limit (p-value) were disclosed by the analysis of variance (ANOVA) results. The ANOVA analysis of the F-statistic test in this instance is a ratio of variance within and between groups. A significant F-test value indicates confirmation against H0 (the null hypothesis) because it implies that there are more differences between groups than within groups. A one-way ANOVA with a 95% confidence level was used to analyze the test results. The mean ± standard deviation was used to display all experimental data. Origin, MINITAB 19.2 and excel software for data analysis and the Analysis of Variance (ANOVA) was used to analyze the results. Based on the p-value and alpha values, the one-way ANOVA was utilized to determine whether there were any statistically significant differences between the groups and within groups of the means of two or more independent groups. Additionally, the p-value from the ANOVA output is used to analyze the findings of the ANOVA in order to ascertain whether or not the mean differences are statistically significant. The 2018 version of the Origin software was used to plot the graph.

4.2.2 Physical properties of developed nonwoven samples

Table 4-2 physical properties of developed nonwoven sample

sample code	A1L1P5	A1L1P10	A2L3P5	A2L3P10	B1L1P5	B1L1P10	B2L3P5	B2L3P10	C1L1P5	C1L1P10	C2L31P5	C2L3P10
Thickness(mm)	0.31	0.33	0.92	0.93	0.28	0.29	0.85	0.86	0.27	0.29	0.82	0.83
Weight(GSM)	30	32	86	97	30	32.6	85.51	87.3	29	30.5	85.5	86

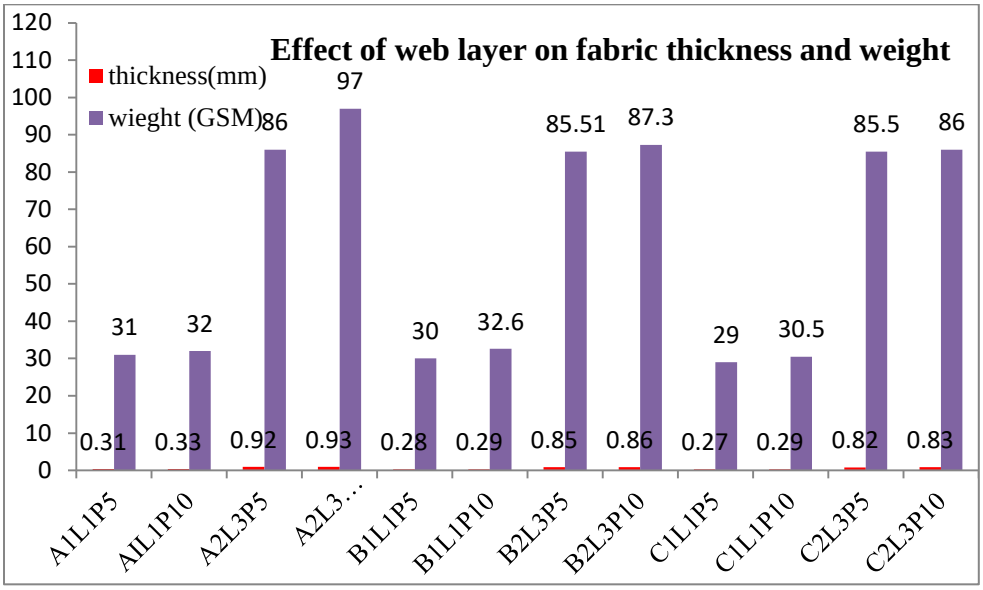


Figure 4-1 Effect of web layer on fabric thickness and weight

- The result from the graph shows that more fiber web layers (3 layers) increases thickness and weight (GSM), of the developed samples which enhances bursting strength, tensile strength, and tear strength due to the added material and dense structure. But fewer layers (1 layer) results in a thinner and lighter fabric with lower mechanical properties.
- Results from graph indicated that nonwoven samples' are measured physical and mechanical parameters were in agreement. Interlinings are available in a wide range of weight from 13.56 to 135.62 gram per square meter(Barnard 2018).
- Because cotton fiber contains more amorphous regions than polyester fiber, the cotton sample of the cotton/polyester composite fabric was found to have the maximum thickness(Akter et al. 2024).
- According to these findings, sample A2L3P10, which was composed of 70% recycled cotton and 30% recycled polyester, had the highest thickness value and fabric weight values, while sample C1L1P5, which was composed of 30% recycled cotton and 70% recycled polyester, had the lowest thickness and fabric weight values when compared to other samples.

4.2.3 Mechanical properties of developed nonwoven and their testing result

Table 4-3 Mechanical properties of developed nonwoven and their testing result

Sample code	Tear strength(N)	Tensile strength (N)	Elongation at break (%)	Bursting strength (N)
A1L1P5	2.94	8.16	4.15	146
AIL1P10	2.98	12.66	5.5	146.5
A2L3P5	5.1	20	7.33	294
A2L3P10	5.64	26	6.433	318
B1L1P5	3.95	17.33	10	220
B1L1P10	4.1	19.81	8	244
B2L3P5	5.9	27.35	12.343	343
B2L3P10	6.2	29.52	9	392
C1L1P5	4.91	21.23	10.417	293
C1L1P10	5.40	22.71	9.261	321
C2L3P5	6.86	32.54	12.438	416
C2L3P10	7.35	33.66	10	465

4.3 Statistical analysis of developed nonwoven fabrics

Inferential statistics includes regression analysis. P-values and coefficients are used in regression analysis to display the relationships and determine whether the model's correlations are statistically significant. The coefficients show the mathematical relationship between the independent and dependent variables. The p-values of the coefficients demonstrate the statistical importance of these relationships. The regression F value is the outcome of testing the null hypothesis, which asserts that all regression coefficients are zero. In other words, the model is incapable of making any predictions. The F-test essentially determines if the inclusion of additional coefficients improves or detracts from the model when compared to an intercept-only model with no predictors.

4.3.1 Regression Equation for strength of developed nonwoven samples

An ANOVA is used to determine the components' relative importance in relation to their percentage contribution to the reaction. ANOVA is also required to determine confidence ranges for error predictions and error variances for special effects. Adjusted probability (P-value) and degree of freedom (DF) Approximate root mean square adjusted SS: Total Squares the F-values fitted with 95% confidence intervals are computed and presented as indicated in table 4.1.

General Linear Model: elongation versus blend ratio, binder concentration, no-of layer.

Table 4-4 Analysis of variance for the response of tensile strength

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**significance**
Blend ratio	2	45.938	22.9691	36.40	0.001	Significant
Binder concentration	1	7.161	7.1611	11.35	0.012	Significant
No-of layer	1	4.404	4.4044	6.98	0.033	significant
Error	7	4.417	0.6311	*	*	*
Total	11	61.92	*	*	*	*

As it is observed from the result of the regression analysis in Table 4.1, the fiber blend ratio, binder concentration and no- of web layer have a significant effect on the tensile strength of nonwoven samples. Because the p-value of the fiber blend ratio, binder concentration and no- of web layer is less than 0.05, therefore, this indicates that blend ratio has a significant effect on the tensile strength of nonwoven samples.

Model summary

Table 4-5 Model summary for Experimental Design

Standard error	R-square	Adjusted R-square	Predicted R-square
0.794390	92.87%	88.79%	79.04%

A statistic called R2 is used to evaluate how well the model and data fit together. The greater the R2 score, the better the model matches the data. R2 is consistently between 0% and 100%. When the number of data and predictors in the model is taken into consideration, the adjusted R2 is the percentage of response variance that the model can explain.

When calculating the mean squared error (MSE) to mean squared sum (MS Total) ratio, adjusted R2 is equal to one or less. Predictor inclusion always raises R2, even when the model does not truly improve. By taking into consideration the number of predictors in the model, the adjusted R2 value aids in the process of selecting a decent model. In table 4.2, the higher R2 values were displayed as 92.87% and 88.79%, respectively. This outcome suggests that the model and the data are more closely fitted.

4.3.2 Normal Probability Plot

To determine whether a set of data is roughly normally distributed, one can utilize the normal probability plot (fig. 4.2). The data points should nearly form a straight line since they are displayed against a fictitious normal distribution. Deviations from the norm are consistently indicated by this line. Values that are far from 'o' on the normal probability plot are statistically significant. Statistically significant and non-significant effects have different dot colors and shapes. The graphic shows that there is relatively little difference between the diagonal line and the nonwoven's real strength value. This implies that the response model is capable of accurately capturing the interactions between these two elements.

4.3.3 Histogram of the residuals

The residuals' histogram is an exploration tool for showing the general features of the residuals, such as typical values, distribution, and form. The imbalanced distribution may be seen by the longer tail on one side. The points can be distinguished if one or two bars are not joined to the others. Take advantage of the residuals' histogram (as illustrated in figure 4.2 below) to search for outliers or skewed data.

4.3.4 Residual plots in Minitab

One kind of graph used to assess the goodness-of-fit in regression or ANOVA is called a residual plot. We can ascertain whether the ordinary least squares assumptions are being fulfilled by looking at the residual plots. If the assumptions are correct, unbiased coefficient estimates with the lowest variance will be produced by ordinary least square regions.

Residuals against fits: The "residuals versus fit" graphic is the most widely used residual analysis technique. This scatter plot shows fitted values, or estimated responses, on the x-axis and residuals on the y-axis. To find outliers, nonlinearities, and uneven error variances, mapping is utilized. The residual against fits graphic can be used to demonstrate that the residuals have a constant variance. On both sides of zero, this graph ought to display a random distribution of residuals. If a certain point is far from the bulk of other points, it may serve as an outline. There should be no observable patterns in the residual graphic (see fig.4.2below)

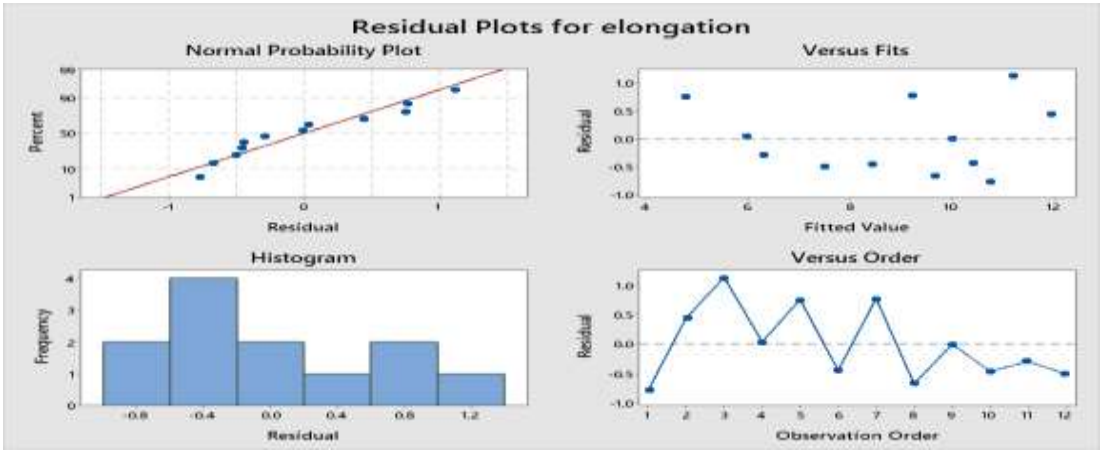


Figure 4-2 residual plots for elongation at break

Order of data versus residual: A residual analysis tool known as a "residuals vs. order plot" is used to identify serial correlation, a specific type of error term known as non-independence. When data are gathered in temporal (or spatial) sequences, a residual vs. order plot, as shown in figure 4.2 below, can be used to determine whether error terms adjacent to one another in a sequence are correlated.

Regression Analysis: elongation at break (%) versus binder concentration

The regression equation is

elongation at break (%) = 11.48 - 0.3445 binder concentration

4.3.5 Factorial Plots for strength

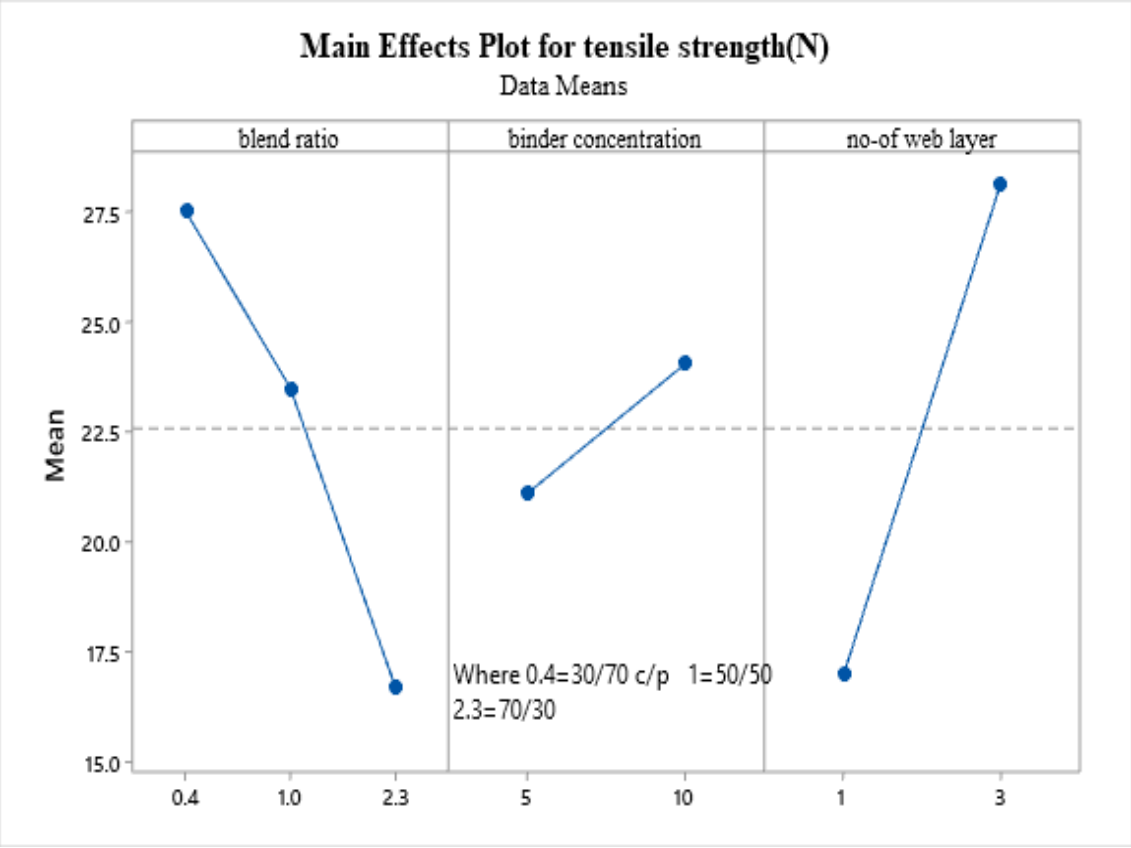


Figure 4-3 Factorial Plots for tensile strength

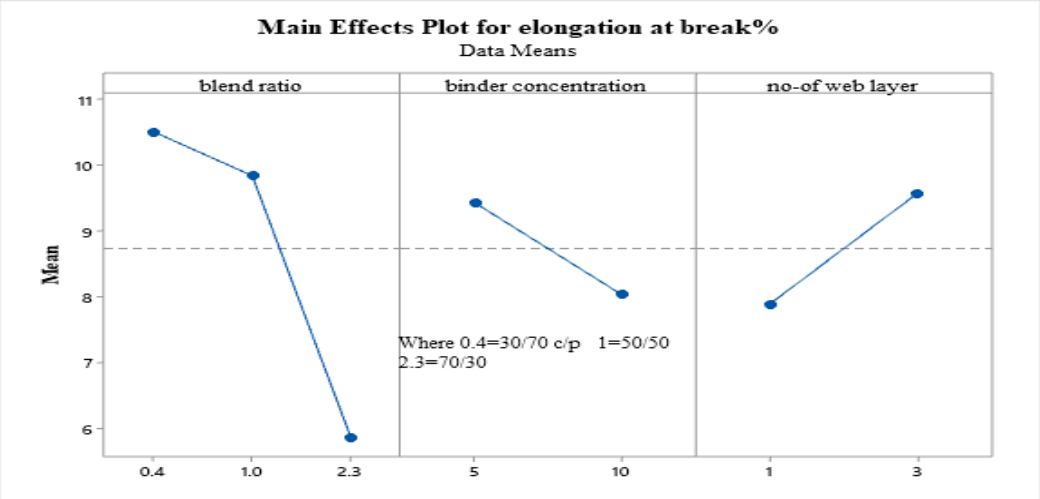


Figure 4-4 Factorial Plots for elongation at break

4.3.5.1 General Linear Model: bursting strength versus blend ratio, binder concentration, no-of web layer

Factor Information

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
blend ratio	2	43586	21793.2	121.20	0.000
binder concentration	1	61276	61275.5	340.79	0.000
no-of web layer	1	2538	2537.5	14.11	0.007
Error	7	1259	179.8		
Total	11	108658			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.4092	98.84%	98.18%	96.60%

Coefficients

4.3.6 Fits and Diagnostics for Unusual Observations

Obs	bursting strength	Fit	Resid	Std Resid	
5	146.50	169.21	-22.71	-2.22	R

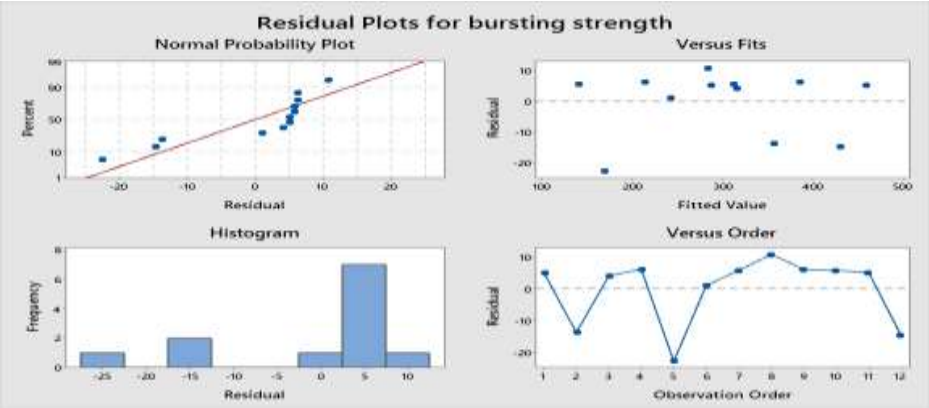


Figure 4-5 residual plots for bursting strength

Regression Analysis: tear strength versus binder concentration

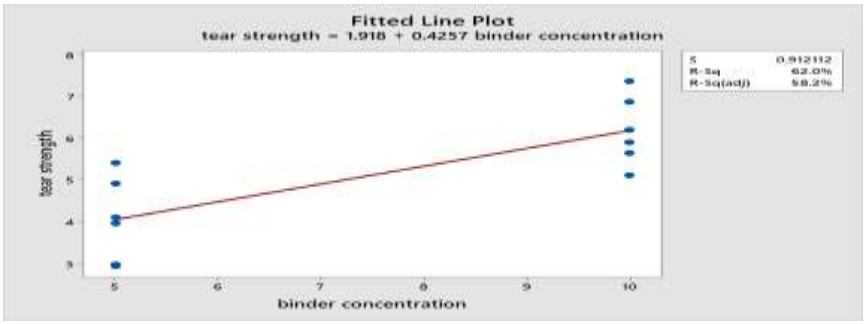
The regression equation is

tear strength = 1.918 + 0.4257 binder concentration

Model Summary

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	13.5894	13.5894	16.33	0.002
Error	10	8.3195	0.8319		
Total	11	21.9089			



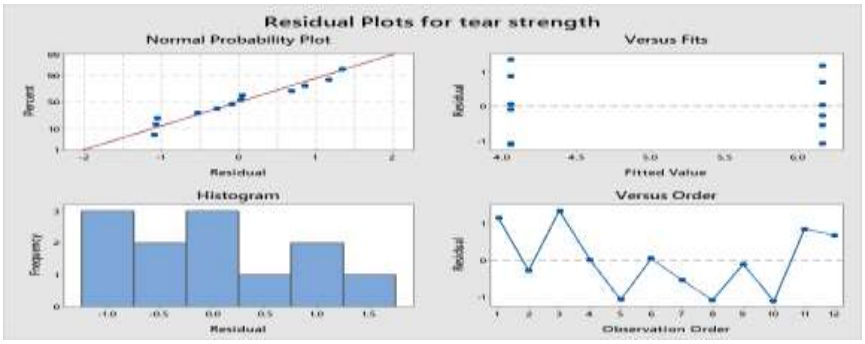


Figure 4-6 residual plots for tear strength

4.3.6.1 Regression Analysis: bursting strength versus binder concentration

The regression equation is

bursting strength = 85.50 + 28.58 binder concentration

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	61276	61275.5	12.93	0.005
Error	10	47383	4738.3		
Total	11	108658			

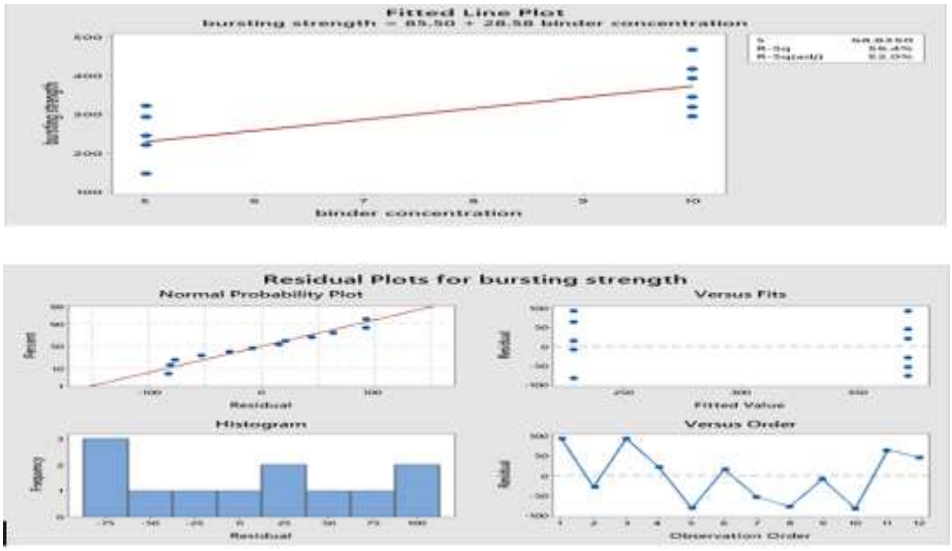


Figure 4-7 fitted line and residual plots for bursting strength

4.3.7 Interaction plots for mechanical properties of developed samples

Interaction plots for tear strength

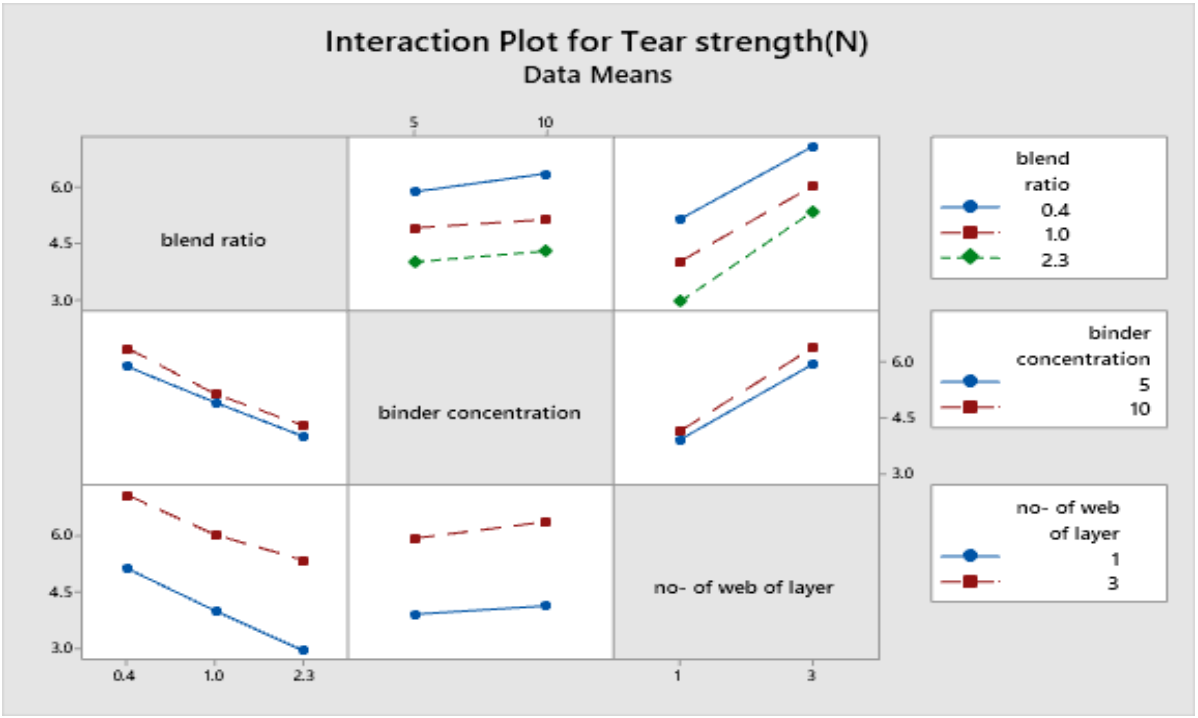


Figure 4-8 Interaction plots for tear strength

Where 0.4=30/70 c/p 1=50/50 2.3=70/30

Interaction plots for tear strength

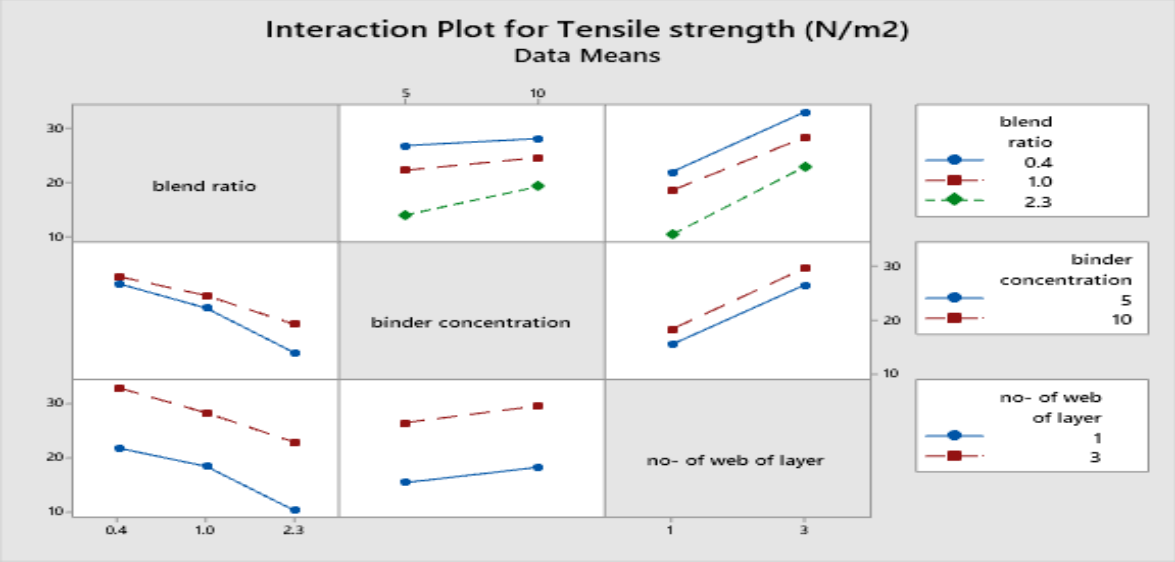


Figure 4-9 Interaction plots for tensile strength

Main effects of plot for elongation at break (%)

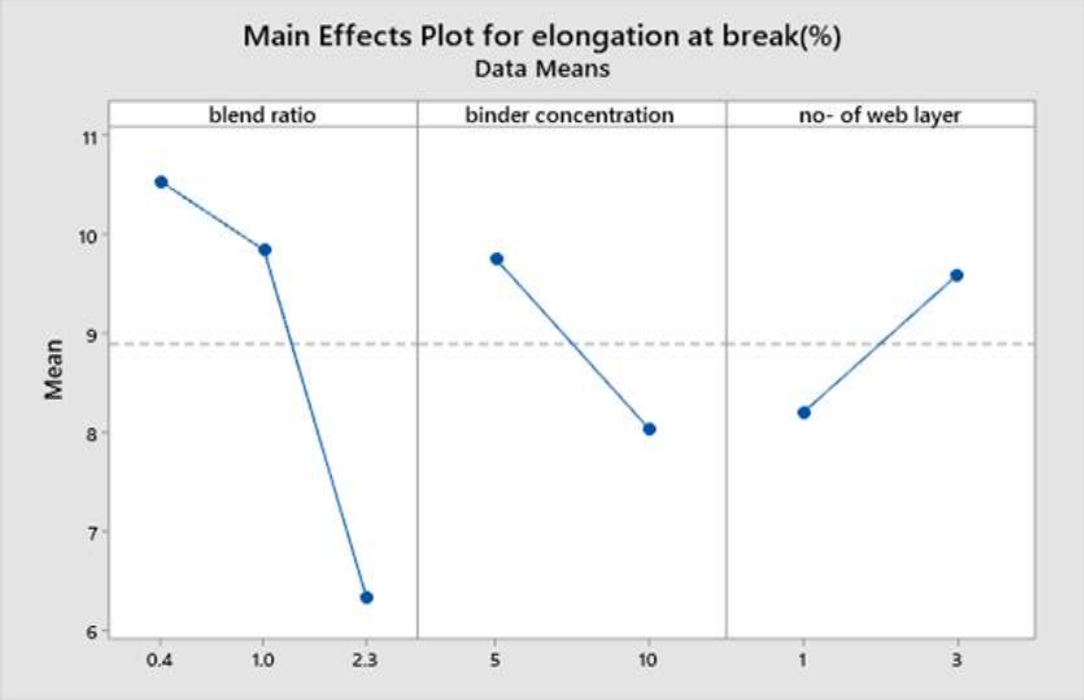


Figure 4-10 Main effects of plot for elongation at break (%)

Interaction plot for bursting strength

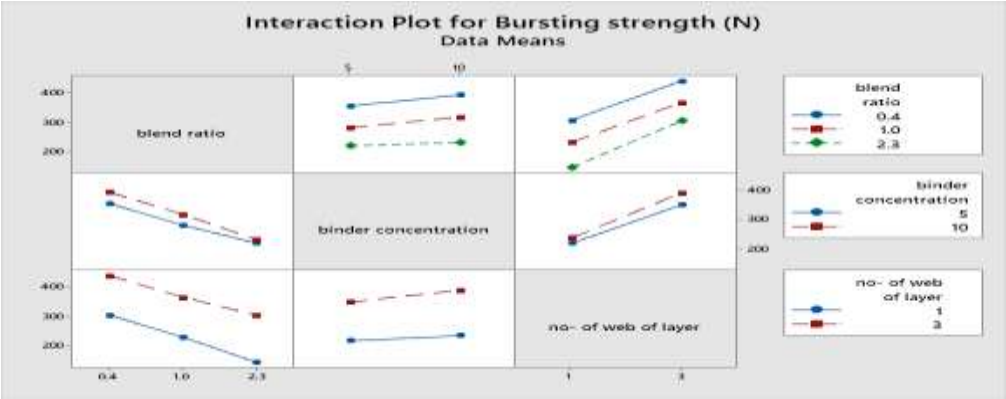


Figure 4-11 Interaction plot for bursting strength

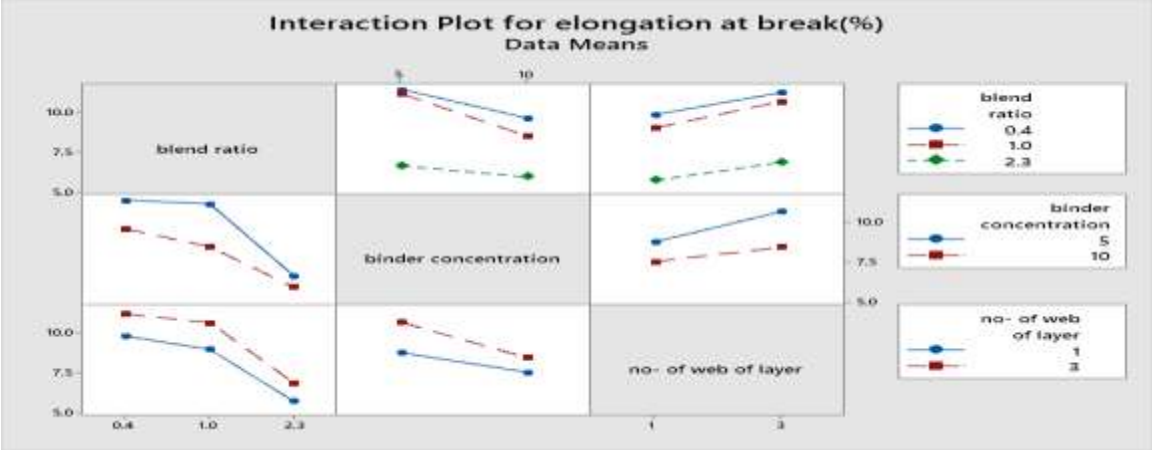


Figure 4-12 Interaction plot for elongation at break

4.3.8 Mechanical properties of developed nonwoven

Mechanical properties of developed nonwoven samples

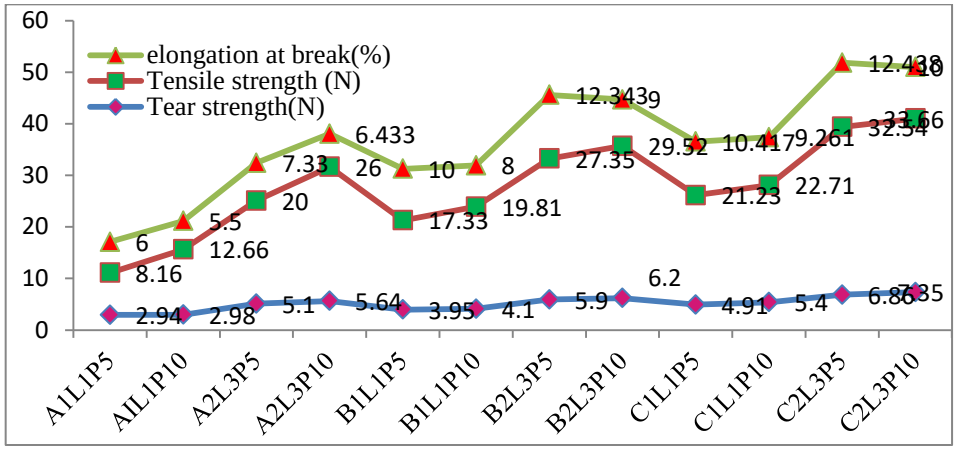


Figure 4-13 Mechanical properties of developed nonwoven samples

4.4 Discussion Based on the Results

- Results from Tables 4.1, 4.2 and 4.3 indicated that all 12 measured values of physical and mechanical properties of nonwoven samples. The mechanical and physical parameters of developed non-woven fabric samples were tested based on ASTM and ISO standards. The samples were developed with varying fiber blend ratios (70:30, 50:50, 30:70 cotton/polyester), binder percentage (5% and 10%), and web layer counts (1 and 3) to study their influence on bursting strength, tensile strength, tear strength, thickness, and weight (GSM) of the fabric . The samples were analyzed for bursting strength, tensile strength, tear strength, thickness, and weight to determine the most appropriate composition for garment interlining applications.
- Test results indicated that 30:70 cotton/polyester proportion, 10% binder content, and 3 layers of web were shows highest value for mechanical properties, where bursting strength is 465 N, tensile strength 33.6 N/m^2, and tearing strength 7.33 N(Eryılmaz et al. 2013). Thickness and weight of this sample were 0.83 mm and 86 GSM, respectively. On the other hand, the lowest performance was exhibited by the 70:30 blend, 5% binder, and 1 layer, with bursting strength of 146N, tensile strength of 8.16 N/m2, tear strength of 2.95N, thickness of 0.31 mm, and weight of 30 GSM. These result shows that increased polyester ratio, increased binder level, and increased web layers significantly enhance non-woven products mechanical and physical performance.

- More fiber web layer i.e.3 layers on the other hand changed fabrics properties by creating thick and dense non-woven samples. Maximum material, leading to high strength and high thickness samples development. Its impact on mechanical properties like maximum bursting strength 465N (for 30:70 blend, 10% binder) maximum tensile strength 33.66N/m^2 (for 30:70 blend, 10% binder) maximum tear strength 7.35N (for 30:70 blend, 10% binder(C2L3P10)).

- At high binder levels the nonwoven becomes non-porous and dense(Santos, Maloney, and Jose 2021). Higher binder concentration increases fiber cohesion and bonding. Developed samples are stiffer but stronger. It have an impact on mechanical properties include enhanced bursting strength 465N (for 30:70 blend, 3 layers) enhanced tensile strength 33.66 N/m^2 (for 30:70 blend, 3 layers) enhanced tear strength 7.35N (for 30:70 blend, 3 layers(C2L3P10)).

4.4.1 Effect of fiber blend ratio, binder concentration and no-of web layer on tensile strength and Eb%

Mechanical properties of developed nonwoven and their testing result

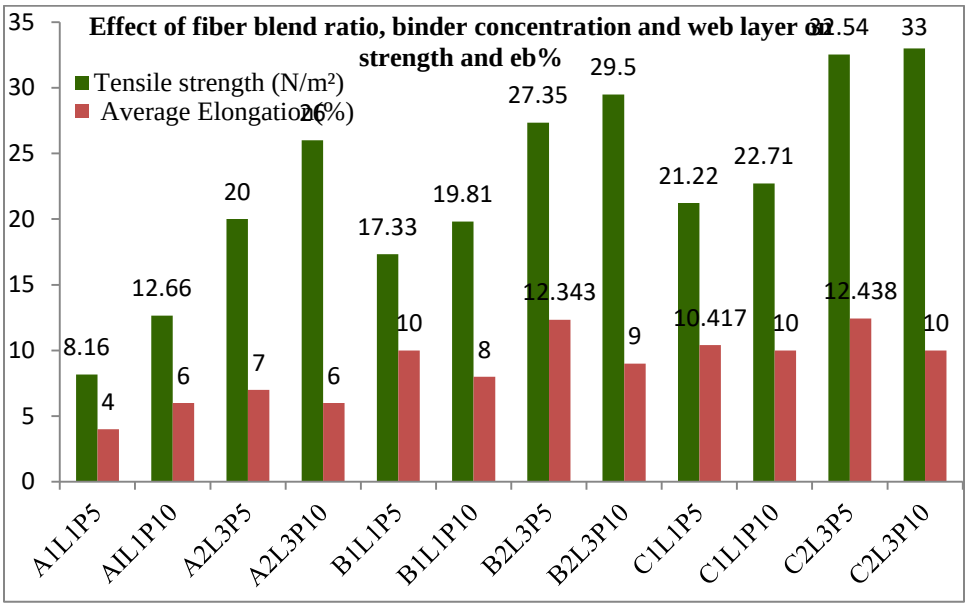


Figure 4-14 Effect of fiber blend ratio, binder concentration and web layer on strength and eb%

- In 70:30 Cotton/Polyester fibers (A1L1P5) blend ratio higher content of cotton fibers lowers tensile strength to (8.16N) due to weak fiber-to-fiber cohesion and elongation at break lesser (4.15%) due to short fiber length and non - plastic nature of cotton fibers.
- In 50:50 cotton/polyester blend both recycled cotton and polyester fibers are blended equally. Well balanced composition with a combination of softness and strength average fiber density and adhesion. This combination has an effect on mechanical properties like average bursting strength (343N), average tensile strength (27.35N/m^2), and moderate tear strength (5.9N).
- It also has an impact on physical properties like Moderate thickness (0.85mm) and moderate weight (85.51GSM).
- From the graph on the effect of blend ratio, binder concentration and web layer on strength and Eb% sample C2L3P10 (30:70 Cotton/Polyester ,10% binder concentration, web layer 3) has the highest strength value due to blend ratio increased content of polyester improves strength.
- Elongation at break percentage also increases as recycled polyester fiber content of the developed samples increases from A1L1P5(4.15%) to the highest value C2L3P5(12.435%) due to the plastic nature of polyester fiber.

4.4.2 Effect of binder concentration and blend ratio on tensile strength and elongation at break

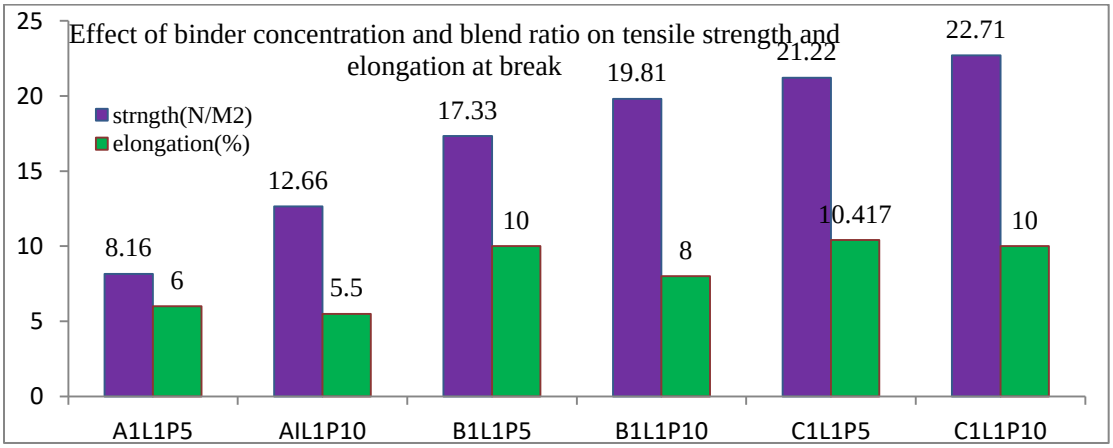


Figure 4-15 Effect of binder concentration and blend ratio on tensile strength and elongation at break

- From the graph on the effect of binder concentration and blend ratio on tensile strength and Eb% sample C1L1P10 (10% binder concentration) has the highest tensile strength value 22.71N/m^2 due to due the larger number of points of bonding between the fibers. At high binder levels the nonwoven becomes non-porous and dense this leads increases strength(Santos, Maloney, and Jose 2021).
- The additional binder creates a more consolidated and stronger nonwoven fabric structure that can withstand greater force before it ruptures.
- On the other hand the tensile strength of lower binder concentration of the samples are lower A1L11P5 (5% binder concentration) 8.16N/m^2 than that of the 10% binder concentration. This is because lower binder concentration result in fewer bonding points between the fibers and a weaker resultant structure.
- From the graph it indicated that the breaking elongation is higher at C1L1P5 (5% binder concentration)10.41%. This is because there are fewer points of bonding so the fibers can move more freely and stretch farther before the fabric ultimately fails. This results in a more elastic fabric with more elongation.
- But sample A1L1P10(10% binder concentration) break elongation percentage is lower 5.5%. This is because the higher binder concentration gives a stiffer and harder structure that inhibits the fibers mobility and reduces the extensibility of the fabric before breaking.

4.4.3 Effect of blend ratio, fiber web layer and binder concentration on bursting strength

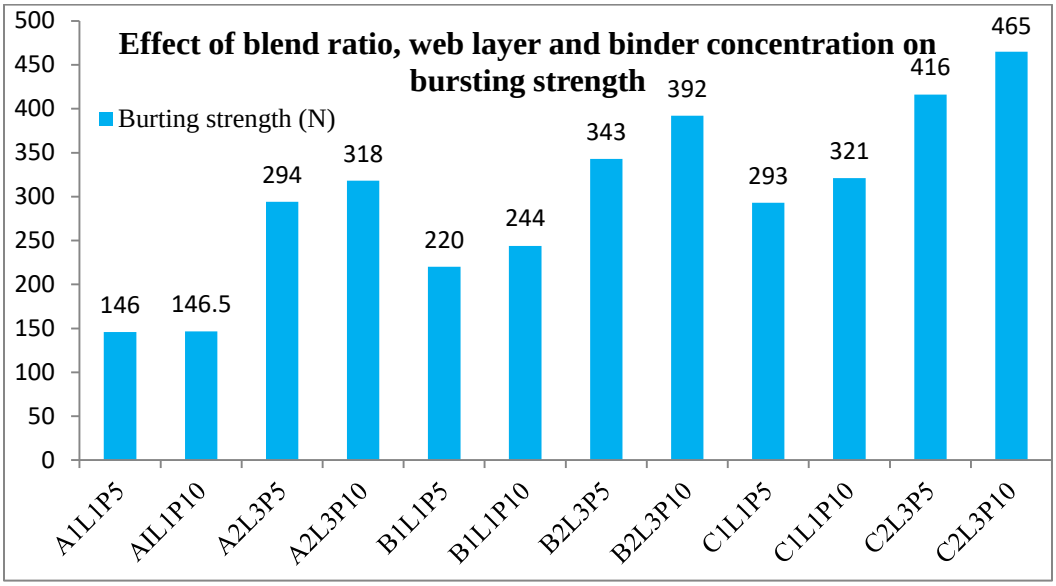


Figure 4-16 Effect of blend ratio, web layer and binder concentration on bursting strength

From the graph it indicated that the bursting strength is higher at sample C2L3P10. Its bursting strength 465N (for 30:70 blend, 10% binder and no-of layer 3).

30:70 Cotton/Polyester blend ratio increased content of polyester improves strength, endurance, and tightness. Polyester fibers are less bulky and smoother, thus possess lesser thickness but greater mechanical strength.

More no-of layers **(**3 layers**)** increases mass of the developed samples these enhances bursting strength values due to the added material and dense structure.

On the other hand the bursting strength of lower binder concentration of the samples are lower A1L11P5 (5% binder concentration) 146N than that of the 10% binder concentration.. This is because lower binder concentration result in fewer bonding points between the fibers and a weaker resultant structure.

4.4.4 Effect of blend ratio, web layer and binder concentration on tear strength of nonwoven samples

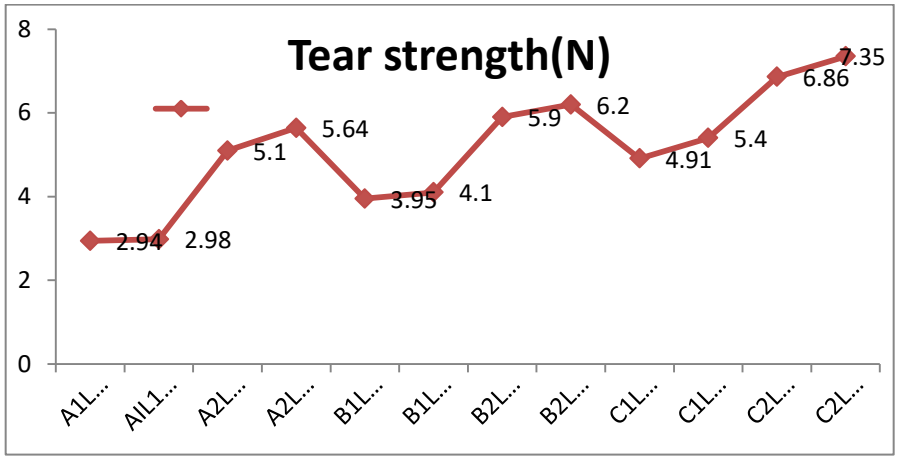


Figure 4-17 Effect of blend ratio, web layer and binder concentration on tear strength

From the graph above it indicated that the tear strength is higher at sample C2L3P10. Its tear strength is 7.35N (for 30:70 blend, 10% binder and no-of layer is 3)

30:70 Cotton/Polyester blend ratio increased content of polyester improves tear strength, endurance, and tightness. Polyester fibers are less bulky and smoother, thus possess lesser thickness but greater mechanical strength.

More no-of layers **(**3 layers**)** increases mass of the developed samples these enhances tear strength values due to the added material and dense structure.

On the other hand the tear strength of lower binder concentration of the samples are lower A1L11P5 (5% binder concentration) 2.94N than that of the 10% binder concentration. This is because lower binder concentration result in fewer bonding points between the fibers and a weaker resultant structure.

4.4.5 Effect of fiber blend ratio on mechanical properties of nonwoven samples

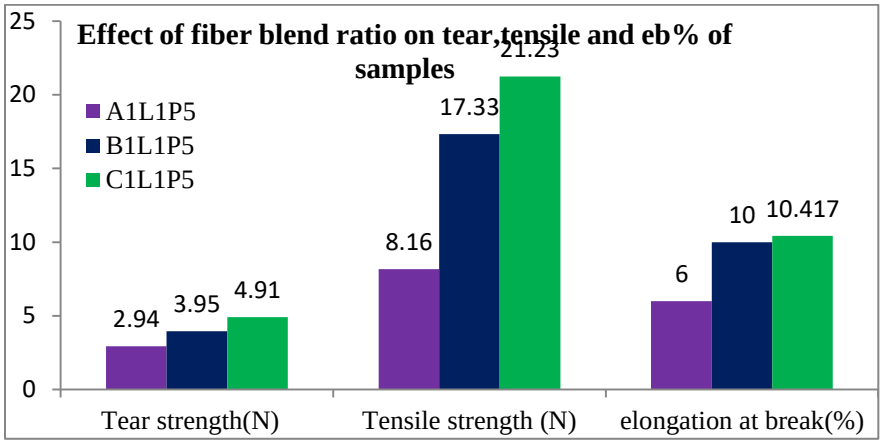


Figure 4-18 Effect of fiber blend ratio on tear, tensile and eb% of samples

The graph indicated that fiber blend ratio has an impact on mechanical properties of the developed nonwoven samples. Three nonwoven samples that having the same no-of web layer and the same binder concentration were analyzed. Recycled cotton with recycled polyester fiber sample were tested for tensile strength and maximum tensile strength was observed in blended nonwoven fabric prepared with 30:70 ratio of cotton and polyester(R and A 2017).

- ✓ Sample C1L1P5 has the highest values in all mechanical properties i.e., tear strength 4.91N, tensile strength 21.23N/m^2 and elongation at break 4.417%.
- ✓ This is because 30:70 cotton/polyester blend ratio increased content of polyester improves strength, endurance, and tightness. Polyester fibers are less bulky and smoother, thus possess lesser thickness but greater mechanical strength.
- ✓ On the other hand sample A1L1P5 has the lowest value in tear strength 2.94N,tensile strength 8.16N/m^2 and elongation at break 6%. This because in 70:30 Cotton/Polyester fibers blend ratio higher content of cotton softens and breathes the nonwoven fabric. Cotton fibers are more compact and thicker, resulting in greater thickness but reduced mechanical strength.
- ✓ But sample three B1L1P5 has moderate mechanical properties on average tear strength 3.95, average tensile strength 17.33 and average elongation at break 10%. because 50:50 cotton/polyester blend both recycled cotton and polyester fibers are blended equally. Well balanced composition with a combination of softness and strength average fiber density and adhesion.

4.4.6 Effect of fiber blend ratio and binder concentration on drape coefficient of samples

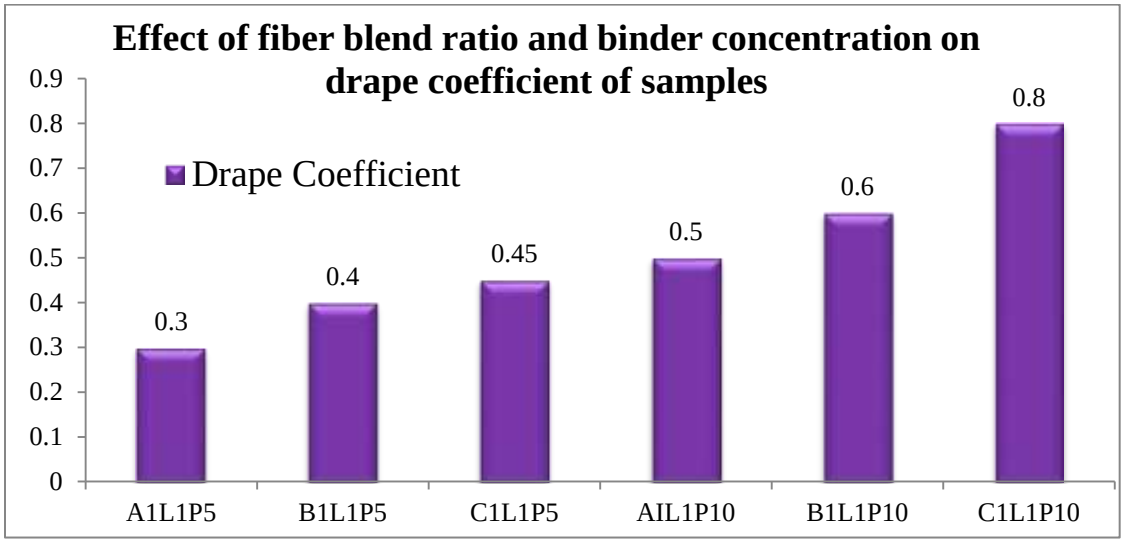


Figure 4-19 Effect of fiber blend ratio and binder concentration on drape coefficient of samples

- The graph indicated that the fabric becomes stiffer as the drape coefficient rises with an increase in binder percentage (from 5% to 10%).
- Stiffness (greater drape coefficient) is also increased by a larger polyester content.
- A1L1P5 (70/30 cotton/polyester, 5% binder) has the best drape ability (softest) with a drape coefficient of 0.30.
- C1L1P10 (30/70 cotton/polyester, 10% binder) has the least drape ability (stiffest) with a drape coefficient of 0.80.
- A1L1P5 (70/30 blend, 5% binder) has the best drape ability, with a drape coefficient of 0.30.
- C1L1P10 (30/70 blend, 10% binder) has the worst drape ability, with a drape coefficient of 0.80.

4.5 FTIR analysis of recycled cotton fiber and recycled polyester

To examine the chemical groups and functional group found in the recycled cotton and recycled fibers, FTIR analysis was done. The underlying principle of FTIR spectroscopy is that different chemical bonds and functional groups within a fiber material absorb specific wavelengths of infrared radiation. By analyzing the pattern of absorption peaks in the FTIR

spectrum, we can identify the presence and characteristics of various functional groups and chemical moieties in the fibers sample.

Fourier Transform Infrared (FTIR) was used to characterize the recycled cotton and recycled polyester fiber at (4000 – 500) cm−1and shown in Figure

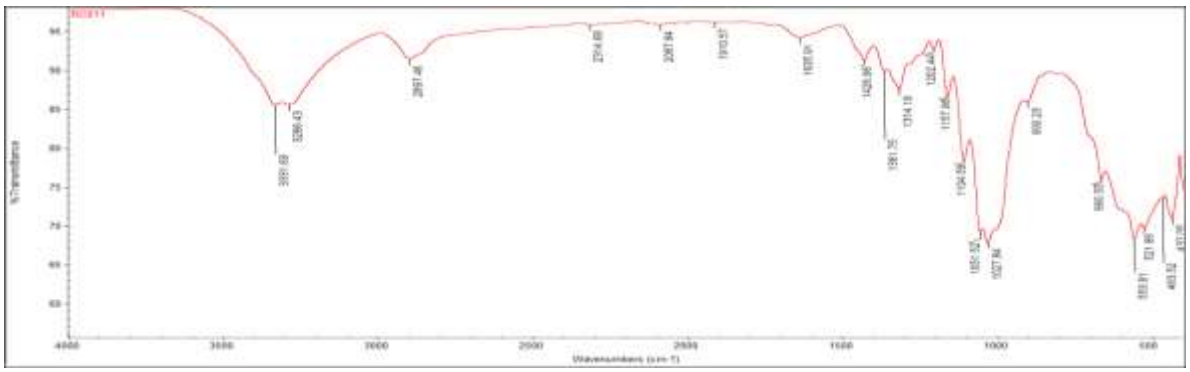


Figure 4-20 FTIR analysis of recycled cotton fiber

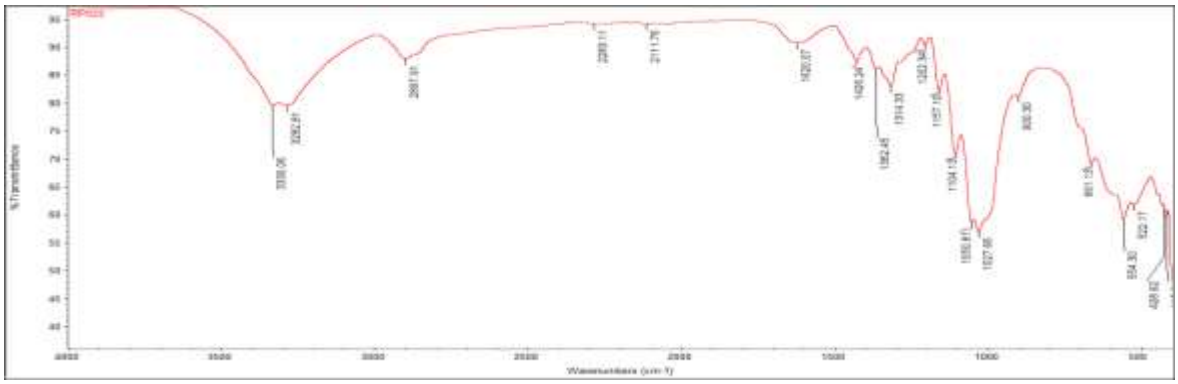


Figure 4-21 FTIR analysis of recycled polyester fiber

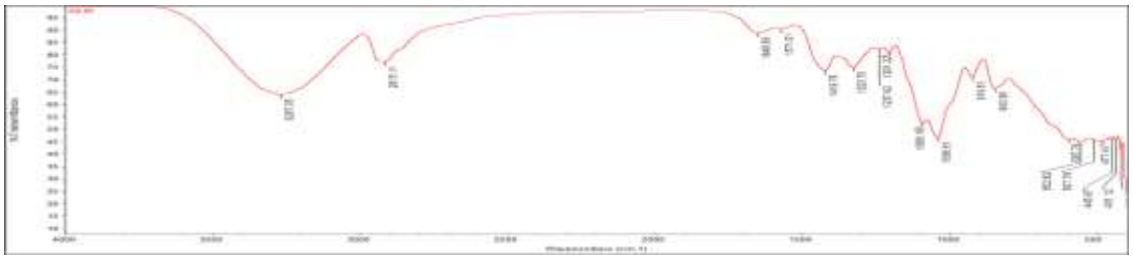


Figure 4-22 FTIR analysis of cotton /polyester nonwoven fabric

Aliphatic Amide Groups: Chemical Properties: Because of their potent intermolecular interactions, amides have comparatively high boiling temperatures. A combination of ammonia and acid chlorides or acid anhydrides produces amides in a laboratory setting. They are frequently made in an industrial setting by heating the carboxylic acid ammonium salts. Comprehending Spectra: NH increases major from 3350 to 3180 cm1 and trans and cis from 3320 to 3070 cm1. CO (amide I): primary: approximately 1650 cm1, secondary: 1680–1630 cm1, and tertiary: 1670–1630 cm1. ADH2 def. (Amide II): primary: 1650–1620 cm1, secondary: 1570–1515 cm1. It is the secondary amide III, around 1270 cm1.

Alcohol Functional Groups: - Alcohol's Chemical Characteristics: Alcohols are compounds that contain the hydroxyl (-OH) group. Depending on how many more carbon atoms are linked to the carbon coupled to oxygen, these compounds are classified as primary, secondary, or tertiary. Alcohols contain the extremely polar -OH group. This allows molecules to form hydrogen bonds with one another in the condensed phase. Because of this hydrogen bonding, alcohols have far higher boiling temperatures than similar alkanes with an equivalent number of carbon atoms. Free -OH forms include phenols (3612–3593 cm–1), secondary alcohols (3635–3620 cm-1), tertiary alcohols (3620–3600 cm–1), and -(3643–3630 cm–1).- Primary alcohols (1050 cm-1), phenols (1200 cm-1), tertiary alcohols (1150 cm-1), and secondary alcohols (1100 cm-1) all exhibit OH deformation vibrations and C-O stretching vibrations. frequency of stretching in -OH Free -OH forms are found in main alcohols (3643–3630 cm-1), secondary alcohols (3635–3620 cm-1), tertiary alcohols (3620–3600 cm–1), and phenols (3612–3593 cm–1). Phenols' Chemical Properties: The benzene ring in the family of aromatic compounds called phenols contains one or more hydroxyl groups instantly attached to it. There are many additional important phenol families than phenol, including xylenols and cresols.

4.6 Discussions Based on the Findings

This study analyzes the mechanical and physical properties of recycled (Cotton/Polyester) developed nonwoven samples combined with different variables such as fiber blend ratio number of web layer and binder concentration. The fiber blend ratio of polyester and cotton fibers is crucial in defining the nonwoven fabrics properties. This is how it affects the samples properties

- In 70:30 Cotton/Polyester fibers blend ratio higher content of cotton softens and breathes the fabric. Cotton fibers are more compact and thicker this resulting in greater thickness but reduced mechanical strength.
- In 70:30 Cotton/Polyester fibers blend ratio higher content of cotton lowers bursting strength (146N) due to less strong cotton fibers. Tensile strength lower (8.16N) due to weak fiber-to-fiber cohesion and tear strength also lesser (2.94N) due to short fiber length and inadequate bonding.
- Higher content of cotton fiber also has an effect on physical properties such as fabric thickness and weight of the developed nonwoven samples. The Thickness of the sample is Highest (0.93 mm) due to dense cotton fibers and its weight also better (97GSM) due to better fiber density.
- In 50:50 cotton/polyester blend both recycled cotton and polyester fibers are blended equally. Well balanced composition with a combination of softness and strength, average fiber density and adhesion. This combination has an effect on mechanical properties like average bursting strength(343N) average tensile strength (27.35N/m^2), and moderate tear strength (5.9N).
- It also has an impact on physical properties like Moderate thickness (0.85mm) and moderate weight (85.51GSM).
- On the other hand in 30:70 Cotton/Polyester blend ratio increased content of polyester improves strength, endurance, and tightness. Polyester fibers are less bulky and smoother, thus possess lesser thickness but greater mechanical strength. This fiber blend impacts on mechanical properties like maximum bursting strength(465N) owing to compact structure and robust polyester fibers, maximum tensile strength (33.66N/m^2) owing to enhanced fiber cohesion and maximum tear strength (7.35N) because of inter-fiber hooking.

- Polyester fiber dominated non-woven sample also have an effect on physical properties of developed samples such as thickness of sample and weight of fabric. Higher polyester fiber lowers fiber thickness (0.83mm) because of compact fiber packing and its weight also less (86 GSM) because of less fiber density.
- Binder concentration influences fiber bonding, with implications for cohesion in the fabric. The effect of 5% binder concentration on the physical and mechanical properties of the developed samples leads to poor fiber bonding and fabric is flexible but not durable.
- Lower binder concentration have an impact on mechanical properties like decreased bursting strength 146 N (for 70:30 blend, 1 layer), decreased tensile strength 8.16N/m^2 (for 70:30 blend, 1 layer) and decreased tear strength 2.94N (for 70:30 blend, 1 layer).
- Lower binder concentration also have an impact on physical property of the developed samples by lowering thickness of the fabric due to more open fiber packing and decreases its Weight (GSM) due to lower amount of binder material.
- An increase in binder concentration results in an increase in the tensile strength of the nonwoven fabric(Hussain, Ullah, and Umar 2015). Higher binder concentration increases fiber cohesion and bonding. Developed samples are stiffer but stronger. It have an impact on mechanical properties include enhanced bursting strength 465N (for 30:70 blend, 3 layers) enhanced tensile strength (33.66 N/m2 for 30:70 blend, 3 layers) enhanced tear strength 7.35N (for 30:70 blend, 3 layers)
- At higher binder concentration, a thicker film is formed(Hussain, Ullah, and Umar 2015). Higher binder concentration also have an impact on physical properties like thickness by slightly increase from 0.31 to 0.33 due the binder fills more of the void spaces between the fibers, creating a denser and thicker structure and Weight of the developed samples slightly increases from 85.5 to 86 GSM due to extra binder material.
- Number of layers has a direct impact on the thickness, density, and mechanical properties of the fabric. Lower web layer of fiber has thin and light in weight of developed samples.it has less material and less strength. Produces a thinner and lighter weight fabric with lower mechanical properties.
- Its effect on mechanical properties include minimum bursting strength 146N (for 70:30 blend, 5% binder) minimum tensile strength 8.16 N/m2 (for 70:30 blends and 5% binder), minimum tear strength 2.94N (for 70:30 blend and 5% binder concentration) and impact

on physical properties like minimum thickness (0.31 mm) and minimum weight (30 GSM).

- More fiber web layer on the other hand changed fabrics properties creating thick and dense non-woven samples. Maximum material, leading to high strength and high thickness samples development. Its impact on mechanical properties like maximum bursting strength 465N (for 30:70 blend, 10% binder) maximum tensile strength 33.66N/m2 (for 30:70 blend, 10% binder) maximum tear strength (7.35N for 30:70 blend, 10% binder). The impact on physical properties maximum thickness (0.93) and weight maximum 86 (GSM). More layers (3 layers) Increases thickness and weight (GSM) of the developed samples these enhances bursting strength, tensile strength, and tear strength due to the added material and dense structure.

5 CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From this research work, the physical and mechanical characteristics of chemically bonded nonwovens developed from recycled cotton and recycled polyester garment waste fibers and with different blending ratios as 50/50 RC/P, 70/30 RC/P, and 30/70 RC/P nonwoven samples were examined.

The physical and mechanical properties of 12 non-woven fabric samples that were produced from recycling polyester and cotton fibers, taking into consideration the effect of blend ratio (70:30, 50:50, 30:70 cotton/polyester), binder concentration (5% and 10%), and web layer numbers (1 ,3) were developed. The samples were analyzed for bursting strength, tensile strength, tear strength, thickness, and weight (GSM). 30:70 cotton/polyester blend, 10% binder concentration, and 3 web layers showed the maximum mechanical performance with bursting strength of 465 N, tensile strength of 33.66 N/m^2, tear strength of 7.35N, thickness of 0.83 mm, and weight of 86 GSM.

On the other hand, A1L1P5 the lowest performance was shown by 70:30 mixtures, 5% binder, and 1 layer with bursting strength of 146 N, tensile strength of 8.16 N/m^2, tear strength of 2.94N, thickness of 0.31 mm, and weight of 30 GSM. The results confirm that increased polyester content, increased binder concentration, and additional web layers significantly influence the mechanical and physical characteristics of non-woven fabrics. The study provides valuable information towards the optimization of sustainable non-woven fabric production .

This study analyzes the mechanical and physical properties of recycled (Cotton/Polyester) developed nonwoven samples combined with different variables such as fiber blend ratio number of web layer and binder concentration. The fiber blend ratio of polyester and cotton fibers is crucial in defining the fabric's properties. This is how it affects the samples properties

- In 70:30 Cotton/Polyester fibers blend ratio higher content of cotton softens and breathes the fabric. Cotton fibers are more compact and thicker, resulting in greater thickness but reduced mechanical strength.
- In 70:30 Cotton/Polyester fibers blend ratio higher content of cotton lowers bursting strength (146N) due to less strong cotton fibers. Tensile strength lower (8.16N) due to weak fiber-to-fiber cohesion and tear strength also lesser (2.94N) due to short fiber length and inadequate bonding.
- Higher content of cotton fiber also has an effect on physical properties such as fabric thickness and weight of the developed nonwoven samples. The thickness of the sample is Highest (0.93 mm) due to dense cotton fibers and its weight also better (97 GSM) due to better fiber density.
- In 50:50 cotton/polyester blend both recycled cotton and polyester fibers are blended equally. Well balanced composition with a combination of softness and strength. Average fiber density and adhesion. This combination has an effect on mechanical properties like average bursting strength 343N, average tensile strength 27.35N/m^2 and moderate tear strength 5.9N.
- It also has an impact on physical properties like moderate thickness (0.85mm) and moderate weight (86.1GSM).
- On the other hand in 30:70 Cotton/Polyester blend ratio increased content of polyester improves strength, endurance, and tightness. Polyester fibers are less bulky and smoother, thus possess lesser thickness but greater mechanical strength. This fiber blend impacts on mechanical properties like maximum bursting strength 465N owing to compact structure and robust polyester fibers, maximum tensile strength: (33.66N/m^2) owing to enhanced fiber cohesion and maximum tear strength 7.35N because of inter-fiber hooking.
- Polyester fiber dominated non-woven sample also have an effect on physical properties of developed samples such as thickness of sample and weight of fabric. Higher polyester fiber lowers fiber thickness (0.83mm) because of compact fiber packing and its weight also less (86 GSM) because of less fiber density.
- Binder concentration influences fiber bonding, with implications for cohesion in the fabric. The effect of 5% binder concentration on the physical and mechanical properties of the developed samples leads to poor fiber bonding and fabric is flexible but not durable.

- Lower binder concentration have an impact on mechanical properties like decreased bursting strength 146N (for 70:30 blend, 1 layer) decreased tensile strength 8.16N/m^2 (for 70:30 blend, 1 layer) and decreased tear strength 2.94N (for 70:30 blend, 1 layer).
- Lower binder concentration also have an impact on physical property of the developed samples by lowering thickness of the fabric due to more open fiber packing and decreases its Weight (GSM) due to lower amount of binder material.
- Higher binder concentration increases fiber cohesion and bonding. Developed samples are stiffer but stronger. It have an impact on mechanical properties include enhanced bursting strength (465N for 30:70 blend, 3 layers) enhanced tensile strength 33.66 N/m2 (for 30:70 blend, 3 layers) enhanced tear strength 7.35N (for 30:70 blend, 3 layers)
- Higher binder concentration also have an impact on physical properties like thickness by slightly increase from 0.31 to 0.33 due the binder fills more of the void spaces between the fibers, creating a denser and potentially thicker structure and Weight of the developed samples Slightly increases from 85.5 to 86 GSM due to extra binder material.
- Number of layers has a direct impact on the thickness, density and mechanical properties of the fabric. Lower web layer of fiber has Thin and light in weight of developed samples.it has less material, less strength. Produces a thinner and lighter weight fabric with lower mechanical properties.
- Its effect on mechanical properties minimum bursting strength 146N (for 70:30 mixture, 5% binder) minimum tensile strength (8.16 N/cm for 70:30 blends 5% binder) minimum tear strength 2.94N (for 70:30 mixture, 5% binder) and impact on physical properties like minimum thickness (0.31 mm) and minimum weight (30 GSM).
- More fiber web layer on the other hand changed fabrics properties creating thick and dense non-woven samples. Maximum material leading to high strength and high thickness samples development. Its impact on mechanical properties like maximum bursting strength 465N (for 30:70 blend, 10% binder) maximum tensile strength 33.66N/m2 (for 30:70 blend, 10% binder) maximum tear strength 7.35N (for 30:70 blend, 10% binder).

5.2 Recommendation for future works

- In this research work, the recycled fibers from cotton and polyester of waste fabrics have been used. Similarly, the recycled fibers may be produced using other types of fabrics like viscose rayon, poly propylene, jute, flux and wool etc…

- The present work focuses on chemical bonded nonwoven material developed from recycled cotton and polyester for interlining application. Similarly, developed nonwoven fabrics of different fibers can be studied further for other application such as water and air filtration purposes.

- Based on the test results obtained, different chemical bonded nonwoven material can be recommended for acoustic and thermal insulation application .

- For the future I recommend that further study on the effects of binder concentration on nonwoven fabric performance for insulation application.

- Optimization research on interlining performance with low fabric thickness and fabric weight producing of higher performance of interlining materials.

- And also producing chemically bonded nonwoven material from recycled cotton and polyester waste for different applications such as blankets, jackets and pillows.

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5.4 APPENDICES

In this appendix, all the data has been collecting during the laboratory testing were provided.



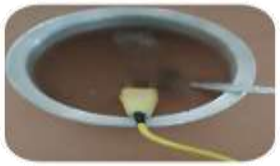
grinding



grinded textile waste



fiber blending and web preparation



binder preparation



web bonding by roller coating



web pressing



drying



fabric development



finished fabric

Tensile strength testing of nonwoven samples

Machine set up of Mesdan tensile strength tester	
Load cell ID/FS (kg)	5/500
Sample length	200mm
Clamp speed	100mm/min
Pretension	2(N)
Observation method	dry sample



Figure 3 16 Mesdan tensile strength tester machine

Sample code	Tear strength(N)	Tensile strength (N)	Elongation at break (%)	Bursting strength (N)
A1L1P5	2.94	8.16	4.15	146
AIL1P10	2.98	12.66	5.5	146.5
A2L3P5	5.1	20	7.33	294
A2L3P10	5.64	26	6.433	318
B1L1P5	3.95	17.33	10	220
B1L1P10	4.1	19.81	8	244
B2L3P5	5.9	27.35	12.343	343
B2L3P10	6.2	29.52	9	392
C1L1P5	4.91	21.23	10.417	293
C1L1P10	5.40	22.71	9.261	321
C2L3P5	6.86	32.54	12.438	416
C2L3P10	7.35	33.66	10	465

Physical properties of developed samples

Mechanical properties of developed nonwoven samples

4.3.5.1 General Linear Model: bursting strength versus blend ratio, binder concentration, no-of web layer

Factor Information

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
blend ratio	2	43586	21793.2	121.20	0.000
binder concentration	1	61276	61275.5	340.79	0.000
no-of web layer	1	2538	2537.5	14.11	0.007
Error	7	1259	179.8		
Total	11	108658			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.4092	98.84%	98.18%	96.60%