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Influence of moisture in recycled nonwoven materials and it´s impact during molding

Master Thesis

Study programme:	N3106 Textile Engineering
Study branch:	Nonwoven and Nanomaterials
Author:	**Arjunkumar Ramasubramania Raja, B.Tech.**
Thesis Supervisors:	Ing. Tomáš Kalous Department of Nonwovens and Nanofibrous materials

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Master Thesis Assignment Form

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Rules for Elaboration:

1. Prepare a literature review focused to heat transfer in textile materials, about it's testing methods, and about nonwoven materials applications in automotive industry.
2. Design and set materials and methods.
3. Materials collection (from industry), preparation of samples and selecting suitable tests to be done.
4. Study about the mechanical characterstics of the sample after the testing is done.
5. Discuss the results and draw a conclusion.

Scope of Graphic Work:
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1. Keey, R.B., *The Drying of Textiles*, Rev. Prog. Coloration 23, 57-72 (1993).
2. Woo, S.S., Shalev, I., and Barker, R.L., *Heat and Moisture Transfer Through Nonwoven Fabrics Part I: Heat Transfer,* Textile Res. J. 64, 149-162 (1994).
3. Parikh, D. V., Chen, Y. and Sun, L. (2006), Reducing automotive interior noise with natural fiber nonwoven floor covering systems, *Textile Research Journal*, **76**(11).

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Liberec,2021 Arjunkumar Ramasubramaniaraja

ANOTATION:

The recycled non-woven material which was brought from the Ideal company, had problems while molding and using it for the end use applications in automobile sector. The problems were the materials were wet, while receiving and had very weak mechanical properties. Firstly, the heat transfer of the material was studied in our lab with the help of thermal conductivity measuring instrument, this experiment is done to get a basic idea about the thermal conductivity of the material. And, with this material, we planned to make samples with four different moistures level 0%,10%,20%,30% respectively. The samples were prepared at the dimensions of (30*30) mm, so that it could be molded and studied in our lab in suitable conditions. Then, each samples were prepared individually based on their respective moisture levels, water percentage that should be added was also calculated based on their different moisture percentage level and added, then the sample was packed in the air tight covers and kept in the room temperature for 2 days in our lab. Then all the samples were pressed in hot pressing machine, and in cold press for molding. After the material is molded the samples were prepared from it in appropriate dimensions for 3-point bending test and tensile test to study about the mechanical behavior of this material. We also carried out the thermal analysis of the material to find out which samples with different moisture levels have faster rate of heat dissipation immediately after pressing is done.

Keywords: Automotive, Recycled nonwovens, Moisture, molding, thermal conductivity, mechanical properties, Stiffness

ANOTACE:

Netkaná textilie z druhotných surovin využívaná firmou Ideal vykazovala nedostatky při lisování a konečném aplikaci v automobilovém průmyslu. Problémy byly způsobeny lisováním vlhkých nebo dokonce mokrých materiálů po transportu mezi výrobcem a odběratelem. Z původních materiálů byly připraveny menší vzorky (30x30 mm). Nejprve byl zkoumán prostup tepla skrze netkanou textilii pomocí specializovaného zařízení poskytující základní údaje o tepelné vodivosti materiálu. Následně byla vysušená textilie stanovena jako referenční a došlo k navlhčení ostatních vzorků přidáním vody o 10, 20, 30% (hmot.). Připravené vzorky byly následně ohřívány pomocí hydraulického lisu a za studena lisovány v druhém lisovacím zařízení. Mechanické vlastnosti lisovaných materiálů byly následně testovaný pomocí trhací zkoušky a trojbodového ohybu. Posledním měřením bylo zaznamenání ohřáté netkané textilie a vliv vlhkosti na chladnutí netkané textilie.

Klíčová slova: automotive, recyklované netkané textilie, vlhkost, lisování, tepelná vodivost, mechanické vlastnosti, tuhost.

CONTENTS

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LIST OF SYMBOLS:

Q	Heat transfer
W	Watts
k	Thermal conductivity
ΔT	Temperature difference
A	Area of cross section
h_c	Coefficient of heat transfer
m	Meter
x	Unit material distance
K	Kelvin
q	Heat flow
L	Length / Thickness of the sample
dt/dx	Temperature gradient
λ	Effective heat conductivity
t	Time
U1	The voltage on the heat flux sensor in mv
U2	Voltage on differential thermocouple in mv
mv	Millivolt
R	Thermal Resistance

1 INTRODUCTION

Textile fabrics are plane structures that are processed in many ways, such as interlacing or by entangling yarns or fibers. In general, textile yarns are defined as the continuous strands of textile fibers used to make up textile items. Each individual fiber consists of millions of individual, long molecular chains with a distinct chemical structure in this process. Clothing also has different purposes, such as shielding people from their surroundings against toxic substances. [1]

In recent years, textile fabrics have been improved in different ways to provide assistance in the control of heat and moisture to and from the human body. These developments are made by designing fibers, yarns and various types of fabric constructions, and by creating various types of fabric finishes. The fabrics can be constructed in such a way that it can provide a particular rate of loss of insensitive perspiration, so that it allows the skin to maintain the body fluids at necessary levels to cool the body, And vice versa. Now, with the advent of new technology and the invention of smart textiles, textile products have become capable of sensing changes in environmental conditions or in the functioning of the body and are beginning to react to these changes. Textile fabrics are engineered and manufactured in such a way that they contain a chemical that senses and responds to the change in ambient temperature by releasing heat when needed. [1]

The dominant mode of heat transfer at temperatures higher than 400-500 K is found to be radiation heat transfer. In nonwovens, convection heat transfer is negligible; the sum of its conduction and radiation components gives efficient thermal conductivity. [2]

A significant factor affecting the radiation portion of effective thermal conductivity was found to be fabric density. As the fabric density increased, radiative thermal conductivity was found to decrease. It has also been found that the radiative thermal conductivity of a sample depends significantly on the size of the pores. It was found that an increase in the mean pore size caused an increase in the heat transfer mode of radiation. Over three distinct applied temperature ranges, identical patterns were seen. [3]

For future Army lightweight protective clothing systems, nanofiber technology (fiber diameter less than 1 micrometer) is under development. Ballistic and chemical / biological defense nanofiber applications are being actively studied, but research is being performed on the thermal properties of nanofibers and their possible protection against cold environments. [4]

In their use as thermally insulating fabrics, one of the main applications of nonwoven fiber systems is Examples of such applications include ski parkas, sleeping bags, and building insulation. Several mechanisms can produce heat transfer through a layer of fibers: free and forced convection, conduction through the solid fibers, conduction through the air in the interfiber spaces, and radiation. The relative contributions of this mechanism have been the subject of most of the research in this area. [5]

Textile products have also shown enormous growth and use in the automotive industry. For a number of purposes, such as improving comfort and providing the necessary thermal insulation, these materials are used in vehicles. And also for acoustic qualities and also for the safety of automobiles. Textiles account for just 3 percent of the raw materials used in automobiles (compared to 60 percent steel, 20 percent plastics, 15 percent aluminum, etc.), but now we can assume that the textile industry has a large potential market in the automotive sector, given the number of current vehicles worldwide. The worldwide development of the automotive industry shows that the use of nonwovens, woven structures and composite textile products in this sector will be in high demand. [6]

Nonwovens materials widely used in the automotive industry, it is because of the number of advantages that the material has, such as lightweight, sound efficiency, flexibility, versatility and easily customizable properties, moldability (easy to adapt to unusual shapes), recyclability, low cost of process and materials, as well as an attractive cost / performance ratio. The most popular technologies used to process nonwovens for automotive applications are the following (sqm) according to INDA (Association of the Nonwovens Fabrics Industry): spun bonded (66 percent), needle punching (27 percent), hydroentangled / resin (6 percent), and others (1 percent). [7]

Unique functions such as absorbency, liquid repellence, durability, elongation, softness, power, flame retardance, washability, cushioning, thermal insulation, sound insulation, filtration, use as a bacterial barrier and sterility are given by nonwoven fabrics. These characteristics are also combined to produce fabrics suitable for specific jobs, while at the same time maintaining a good balance between life-of-use and cost of the product. [8]

2 HEAT- INTRODUCTION

In solids, liquids and gases, thermal energy is the product of the movement of tiny particles called atoms, molecules or ions. It's possible to transfer heat energy from one object to another. The transition or flow is called heat because of the difference in temperature between the two objects. Heat is a measure of the internal energy from one body to another that has been absorbed or transferred. It is not conserved; it can be either created or destroyed. [9]

2.1 HEAT-DEFNITION

Heat is defined as the form of energy that is transferred between the two substances at different temperatures. The direction of flow of energy is from the substance that has higher temperature to that of the lower temperature. Heat is measured in terms of energy, usually denoted as calories or joules. [10]

2.2 HEAT TRANSFER- DEFINITION

Heat transfer in the field of thermal engineering, concerns about the generation, use, conversion and exchange of heat (thermal energy) between the physical systems. Heat transfer is classified in to various categories, such as Thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. [11]
The fundamental modes of heat transfer are classified as:

- Conduction
- Convection
- Radiation

2.2.1 Conduction heat transfer

Conduction is the molecular motion method of heat transfer, augmented by the flow of heat from a high temperature area through textile material. When they are at varying temperatures, heat transfer by conduction takes place through the interface between two bodies in contact. Heating textile fabric in a cylindrical dryer is a typical example of heat conduction. [12]

If the fluid can be held stationary, so there will be no convection. However, the transfer of heat by conduction is still possible. Conduction happens when there is a transfer of energy inside the heat medium from one molecule to another. On both solids and liquids, conduction may take place. The rate of heat transfer mostly depends on the physical characteristics of that particular solid or fluid, known as its thermal conductivity (k). The thermal conductivity is defined as the measure of the rate of heat transfer across a unit width of porous material, for a unit cross-sectional area and for a unit difference in temperature. [12]

The relationship between heat transfer and thermal conductivity is given as

$$Q = \frac{\mathrm{kA\Delta T}}{\mathrm{x}} \qquad (1)$$

From the equation (1), where ΔT is the temperature difference T_1 -T_2 , defined by the temperature on the either side of the fabric. The unit of the thermal conductivity is give as,

Where, W = (K) m^2 K /m

So the unit of K is given as the W/m^2 K/m and it is expressed as W/mK. [12]

2.2.2 Convection heat transfer

Heat convection is a mode of transfer of heat via the mass movement of a fluid such as air. Heat convection occurs on the surface of an object, where the object's surrounding fluid is heated and energy is transferred away from the heat source. When the surface temperature varies from that of the ambient fluid, convective heat transfer occurs. [13]

Two types of convective heat transfer may be distinguished:

- Free or normal convection: when fluid motion is caused by buoyancy forces due to thermal ± temperature differences in the fluid resulting from density variations. When the fluid is in contact with a hot surface in the absence of an internal source, the molecules detach and disperse, allowing the fluid to be less dense. As a result, while the hotter fluid becomes denser and the fluid sinks, the fluid is displaced. The hotter volume thus moves heat to the fluid's cooler volume. The upward movement of air due to a fire or hot object and the passage of water in a pot that is heated from underneath are familiar examples. [14]
- Forced convection: when a liquid is forced by an internal source such as fans, by stirring, and pumps to flow over the surface, producing an artificially induced convection current. [15]

Normal and forced convection occur at the same time in many real-life applications (e.g. heat losses at solar central receivers or cooling of photovoltaic panels) (mixed convection). [16]

So analyzing these conditions the temperature difference which induces the heat transfer can be defined as

$$\Delta T = surface\ \ temprature - mean\ \ fluid\ \ temprature$$

Using the above definition, the rate of heat transfer due to convection can be formulated with the help of newton's law of cooling

$$Q = h_c A \Delta T \qquad (2)$$

From the equation (2), where A is the heat transfer surface area and h_c is the coefficient of heat transfer from the surface to the fluid, referred to as the "convective heat transfer coefficient. The units for the heat transfer coefficient h_c can be determined with help of other variables .so the units of h_c are $W / m^2 K$.[1]

2.2.3 Radiation heat transfer

Radiation is a form of transmission of electromagnetic energy between all matter that is higher than the absolute zero temperature. During radiation, electrons that vibrate in the molecules found on the surface of the body emit energy. The total quantity of heat transfer depends on the two factors, the first being dependent on the body's absolute temperature and the second on the surface's radiant properties. [17]

If any radiant energy is absorbed by the surface of the body, it functions as an ideal radiator, which is called the black body. Not only does the black body absorb radiation at its maximum level, but it also releases radiation at its maximum level. Thus, emissivity is the concept that determines how much energy the surface absorbs or emits, and the term emissivity is defined by the symbol ε. In contrast to that of the black body, the term emissivity also similarly describes the radiant energy that can be absorbed. The emissivity value of the black body, by definition, is 1. [17]

Heat transfer by thermal radiation does not usually require a material medium for the energy transfer, unlike conduction and convection. In the case of thermal radiation from a solid surface, vacuum, gas or liquid could be the medium by which the radiation passes. Radiation energy may be absorbed, reflected or distributed by the molecules and atoms of the medium. If the medium is a vacuum, since no molecules or atoms exist, the energy of the radiation is not attenuated and thus completely transmitted. Therefore, in the case of gas (e.g. air), radiation heat transfer is more effective, energy may be slightly absorbed or reflected by air molecules, and equilibrium is transferred. For liquid medium, a thin layer near the solid surface is the bulk of the radiation absorbed and nothing is transmitted. [18]

Since World War II, microwaves have been used and developed extensively for heating applications. Generally, domestic and commercial microwave ovens run at a frequency of 2.45 Ghz and 12.2 cm is the corresponding wavelength. But microwaves do not easily heat all materials. Thus, the materials can be divided into three categories, i.e. insulators and absorbers for conductors. Dielectrics are called materials that absorb microwave radiation, so the heating of the microwave is often called dielectric heating. [19]

Dielectrics have two important properties:

1. The first property is that they have few charge carriers, and when the external electric field is applied, no adjustment can be made through the material matrix.

2. The second property explains that a dipole movement distance is demonstrated by the molecules or atoms comprising the dielectric. The stereochemistry of covalent bonds in a water molecule, giving a dipole motion to the water molecule, is an example of this. Dipoles can be formed in two forms that can be caused, one by natural or the other. A transient dipole movement may be caused by distortion of the electron cloud around non-polar molecules or atoms in the presence of an external electric field. The friction is produced within the dielectric because of this movement and the energy is released in the form of heat as a result. [19]

The interaction of dielectric materials with the microwave spectrum of electromagnetic radiation results in the absorption of energy. This depends directly on the time taken by the molecules in that substance to relax, which in turn depends on the molecule's volume and functional groups. And the dielectric property of a material is usually related to the geometry of temperature, density, moisture content, and material. [19]

2.3 HEAT TRANSFER IN TEXTILES

In any clothing situation, large quantities of heat are transmitted through the different layers of textile materials that constitute the clothing of the person. The exact quantity and direction of the heat transferred depends on several factors, such as the temperature and humidity of the environment, the person concerned physical and/or mental effort, the design and number of layers of clothing and their closeness to match, the thickness and bulk density of each layer of clothing, and the properties of each layer of clothing to absorb and transmit moisture In all cases, including regular day-to-day environments, layer wear, extreme cold or extreme heat conditions, the basic physical concepts of heat transfer by textile materials apply. It is obviously beneficial in severe cold conditions that the clothing of the person provides an effective shield against unnecessary heat transfer, thus minimizing the metabolic loss of heat from the human body. [20]

When heat is transmitted through a porous or cellular material such as a cloth, the heat may flow through the fibers through conduction, through conduction and convection through the air spaces trapped in the fabric between the fibers, or through radiation inside the fabric from one fiber surface to another. Perhaps the most convenient way to consider the complex heat flow problem through textile fabrics is first to analyze the much simpler heat flow problem through an air gap without fibers before investigating the heat flow through an actual fabric. This scenario in practice closely correlates to firefighting situations in which heat is first transmitted from the fire to the surface of the clothing of the firefighter until it can actually be transmitted via the clothing itself. [21]

The evaporation mechanism is affected by the process of liquid transport as well. It will only evaporate on the lower surface of the fabric if liquid water is not able to diffuse through the fabric. Evaporation may take place in the fabric as the liquid diffuses through the fabric due to capillary action. [22]

In addition, in cotton fabrics, but not in polyester fabrics, the heat transfer process has a major influence on the evaporation process. Water vapor diffusion and liquid water diffusion are primarily influenced by the moisture sorption process, but not by heat transfer. The moisture sorption of the fibers is primarily determined by the liquid transport process when there is liquid diffusion in the fabric, since the fiber surfaces are rapidly covered by liquid water. In the meantime, distributions of water content in the fibers are not strongly related to distributions of temperature. On the other hand, all moisture transport processes greatly influence heat transfer. Evaporation and sorption of moisture have a strong effect on heat transfer, which is in turn affected by the absorption of water vapor and liquid diffusion. [23]

As a whole in reacting to external humidity transients, a dry fabric exhibits three phases of transport action. Two rapid processes dominate the first stage: water vapor diffusion and liquid water diffusion in the air filling the void spaces of the interfiber, which can achieve new steady states within fractions of seconds. During this time, due to the concentration gradient between the two surfaces, water vapor diffuses into the fabric.

The second stage requires the absorption of moisture from fibers, which is relatively slow and takes a few minutes to a few hours to complete. Water sorption into the fibers takes place in this time when the water vapor diffuses into the yarn, which increases the relative humidity of the fibers' surfaces. The surfaces of the fibers are saturated due to the film of water on them after liquid water diffuses into the fabric, which will increase the sorption process again. Finally, as a stable state, the third stage is reached, in which all four modes of moisture transport and the process of heat transfer become steady and the coupling effects between them become less important. Temperature distribution, water vapor concentration, fiber water content, and liquid volume fraction and evaporation rate are invariant over time. [24]

2.4 THERMAL CONDUCTIVITY

The capacity of the material that allows heat to pass through it is known as thermal conductivity. Materials with high thermal conductivity can transfer heat efficiently and can also absorb heat from the atmosphere. Materials with poor thermal conductivity can resist heat flow and slowly obtain heat from the atmosphere. The thermal conductivity SI unit is measured per degree kelvin (W / m*K) in watts per meter. [25]

2.4.1 Heat conduction and thermal conductivity

The rate of heat conduction through a material can be proportional to the difference in temperature between the material and the region perpendicular to the flow of heat and inversely proportional to the length of the heat flow path between the two levels of temperature. The French scientist J.B.J. Fourier, developed this dependency on his work published in the year 1822. It is a feature of the conducting material and of its condition. With the notation in Fourier's law suggested. [26]

$$q = \frac{KA}{L}(t_1 - t_2) \qquad (3)$$

from the equation (3),In which the conductance of the geometry is called kA / L. Heat can flow through the material as there is a temperature difference of (t1-t2) between the surfaces. We understand from the second law of thermodynamics that the direction of this flow is from the surface of the higher temperature to the lower one. Under the first law of thermodynamics, this flow of heat will be at a constant rate under steady conditions. [26]

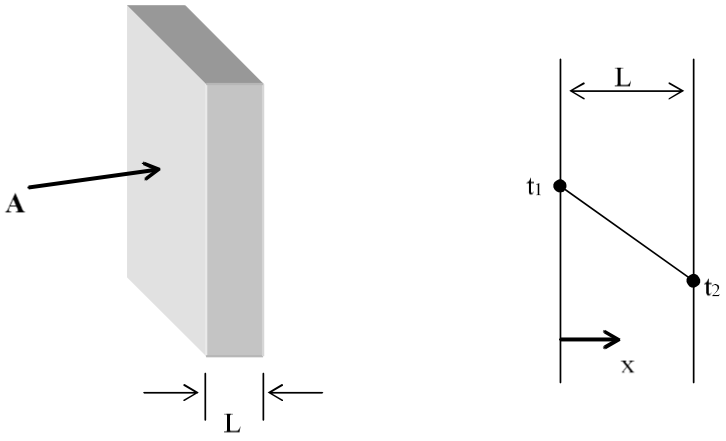

Figure 1: one dimensional steady- state heat conduction [19]

The thermal conductivity k, which is analogous to electrical conductivity, is a property of the thermal material. It is equivalent to the rate of heat transfer between opposite faces of a unit cube of the material which are maintained at temperatures differing by 1˚. In SI unit, k is expressed as W/mK. The conduction equation may also be written as the heat transfer rate per unit area normal to the direction of heat flow q, as

$$\frac{q}{A} = q'' = \frac{k}{L}(t_1 - t_2) = k\left[-\frac{(t_2 - t_1)}{L}\right] = -k\,\frac{dt}{dx} \qquad (4)$$

The quantity q" is very useful and is hereafter called the heat flux. Note that the quantity in the brackets is minus the temperature gradient through the material, that is, -dt/dx. Thermal conductivity is, however, a thermophysical property. A material's thermal conductivity depends on its chemical nature, physical structure, and state. It also varies according to the temperature and pressure at which the material is exposed. However, thermal conductivity is much less dependent on pressure than on temperature in most instances, so that pressure dependence can be ignored and thermal conductivity can be tabulated as a temperature function. The conduction of heat in gases and vapors depends primarily on the molecular transfer of the molecular movement's kinetic energy. That is to say, heat conduction is the transmission through successive collisions of kinetic energy from the more active molecules in high temperature regions to the molecules in low molecular kinetic energy regions. The temperature of a gas element is proportional to the mean kinetic energy of its constituent molecules, according to the kinetic theory of gases. Obviously, the faster the molecules travel, the quicker the energy can be transferred. Consequently, this means that a gas's thermal conductivity should be dependent on its temperature. [26]

2.5 HUMIDITY – DEFINITION

Humidity is the water vapor concentration that is present in the air. As a general rule, water vapor, the gaseous state of water, is invisible to the human eye. The possibility of snow, dew, or fog being present is indicated by humidity. As the temperature increases, the amount of water vapor necessary to achieve saturation increases. It will gradually reach the saturation point without adding or losing water mass as the temperature of a parcel of air rises. There can be major differences in the amount of water vapor present within a parcel of air. [27]

Three key humidity measures are used widely: absolute, relative and precise. The water content of the air is determined by absolute humidity and is expressed in grams per cubic meter. Relative humidity, expressed as a percentage, displays the actual absolute humidity condition relative to the maximum humidity given the same temperature. The ratio of water vapor mass to total moist air parcel mass is real moisture. [28]

2.5.1 Effect of humidity on the drying rate

In the below figure, a drying curve is shown for the moisture content versus time. This shows that the drying rate at which the moisture is extracted is the slope of this curve. The curve begins with the warm-up phase, where the material has begun to heat and the rate of drying is very low. The rate of drying also rises to its peak rate as the heat increases in the material and it is sustained for a period of time known as the constant rate period. When the material's moisture content decreases to a critical amount, which is known as the content of critical moisture. [29]

This is the stage where it is not possible to sustain the elevated evaporation rate. And this contributes to the falling rate era, the surface moisture flow in the falling rate period is inadequate to sustain surface saturation. So this period can be separated into first and second falling rate cycles. A transition between the constant rate period and the second falling rate period is usually the first falling rate. Usually, gas, steam, temperature, humidity and flow rate appear to dominate during this time. And internal factors such as moisture and energy transport in textile materials will dominate in the second falling rate era. [30]

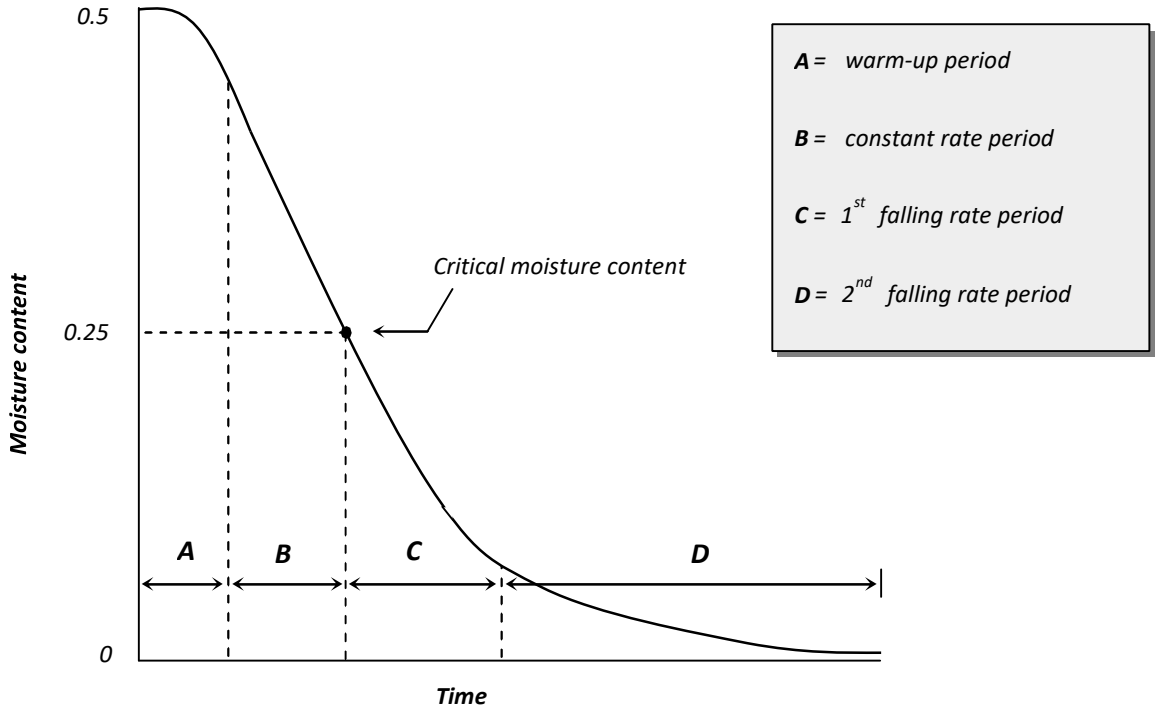

Figure 2: moisture content profile for the textile material [30]

A plot of the drying rate versus the moisture content may also reflect the drying phase. Time progresses from right to left in this story. On the far right is the warm-up era, and the constant rate period corresponds to the plateau zone. The segment between the plateau region and the origin is the falling rate time. [31,32]

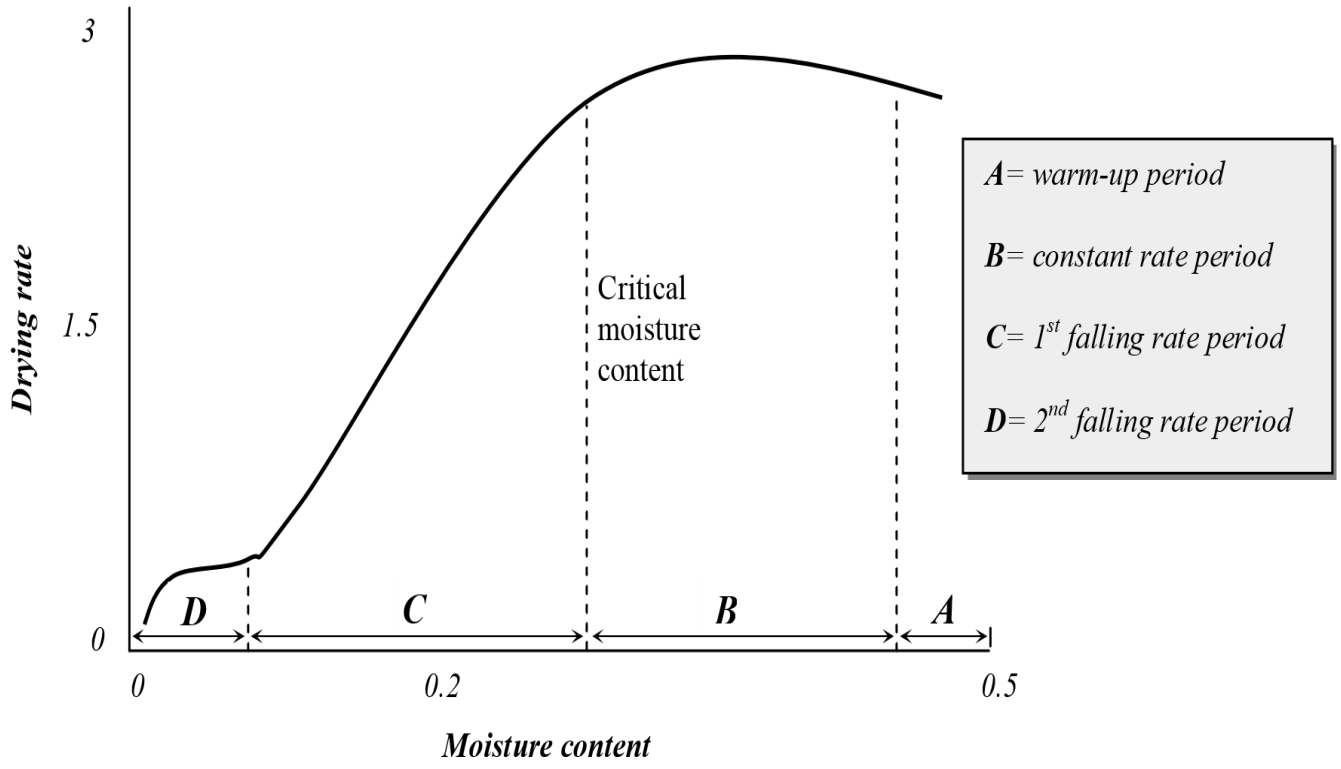

Figure 3: drying rate profile for the textile material [31]

2.6 MOISTURE IN FIBRES

For each fiber, the moisture that the fiber will pick up varies and it is shown in the table below. Water is monomolecularly absorbed by many natural fibers at low relative humidity, below 0.35. From a thermodynamic point of view, at a rate that depends on the fiber 's chemical potential gradient, we can expect the flow of water through a single fiber. [33]

There is a profound influence of moisture on the physical properties of certain fibers. When moisture is sorbed, hygroscopic fibers can swell and shrink as it is driven off. First, the wet fabrics lose the moisture trapped between the fibers, and then the threads dry out and shrinkage begins. It is generally assumed that the shift in volume on shrinkage is linear with moisture content. Moisture is used in hydrophilic materials to decrease stiffness and increase creep, possibly as a result of plasticization. Moisture content variations can increase creep. The principle of sorptive diffusion can be extended to explain movement of moisture at relative equilibrium humidities below unity. Only those molecules with kinetic energies larger than the moisture-fiber bond activation energy will migrate from one site to another. [33]

Table 1 : Smoothed values of dry-basis moisture content (kg/kg) for the adsorption of water vapour at 30˚C onto textile fibers. [33]

Fiber	Mc=0.2	Mc=0.5	Mc=1.0
Cotton	0.0305	0.0565	0.23
Cotton, mercerized	0.042	0.0775	0.335
Nylon 6.6, drawn	0.0127	0.0287	0.05
Orlon (50˚C)	0.0031	0.0088	0.05
Cupro	0.0515	0.0935	0.36
Polyester	0.0014	0.0037	0.03
Viscose	0.034	0.062	0.25
Wool	0.062	0.09	0.38

2.6.1 Porosity and pore size distribution in fabric

The porosity of a textile fabric refers to the total amount of void space within its limits, whereas permeability refers to the accessibility of void space to the flow of a gas or liquid. Porosity is commonly defined as the ratio between the void space and the total volume encompassed by the material boundaries. [34]

The overall porosity of the fabric can be visualized as having three components: (a) the porosity of the intrafiber, or the void space found within the walls of the fibers themselves; (b) the porosity of the interfiber, or the void space contained in the yarn between the fibers; and (c) the porosity of the inter-yarn, or the void volume of the yarn interstices. Effective porosity has been named the portion of the total porosity available to fluid flow and is primarily a function of the components of interyarn and interfiber. Of course, the total interfiber and interyarn porosity depends on such variable construction characteristics as fiber & fineness, form, weave type, number of yarns per inch and yarn twist. [35,36]

The amount of porosity in the fabric defines the water holding capacity of the fabric. If in a cloth the porosity is much higher, so it will retain more water. The porosity determination formula is obtained by dividing the total amount of water removed (extruded) from the fabric sample by the sample volume.

It should be noticed, when we analyze the sample, that most of the water is deposited between the yarns and not inside them. The pores inside the yarns often tolerate the water within the fabric sample. And we can also note that in a fabric there are pores of different sizes in them (shown in the below figure). [37]

We can examine that it is a substance consisting of a solid matrix with an interconnected void by stating it as a porous medium. The pores' interconnectedness helps fluid to flow through the cloth. In a single step of flow, we can assume that a single fluid saturates the pores. We have both the liquid and the gas in two-phase flow that share the pore space. As is clearly seen in Figure 4, the distribution of pores with respect to shape and size is irregular in fabrics. The flow quantities (velocity, strain, etc.) would obviously be irregular on the pore scale (the microscopic scale). [37]

The usual way to derive the laws governing macroscopic variables is to start with the fluid-obedient standard equations and then obtain the macroscopic equations by averaging the volume or area containing several pores. We may presume that all the pore space is associated during the porosity measurement. We also have to work with a fabric in which some of the pore space is segregated from the others that remain. So we have to add "efficient porosity" to measure that, which is defined as the ratio of the attached pore to the total volume. [37]

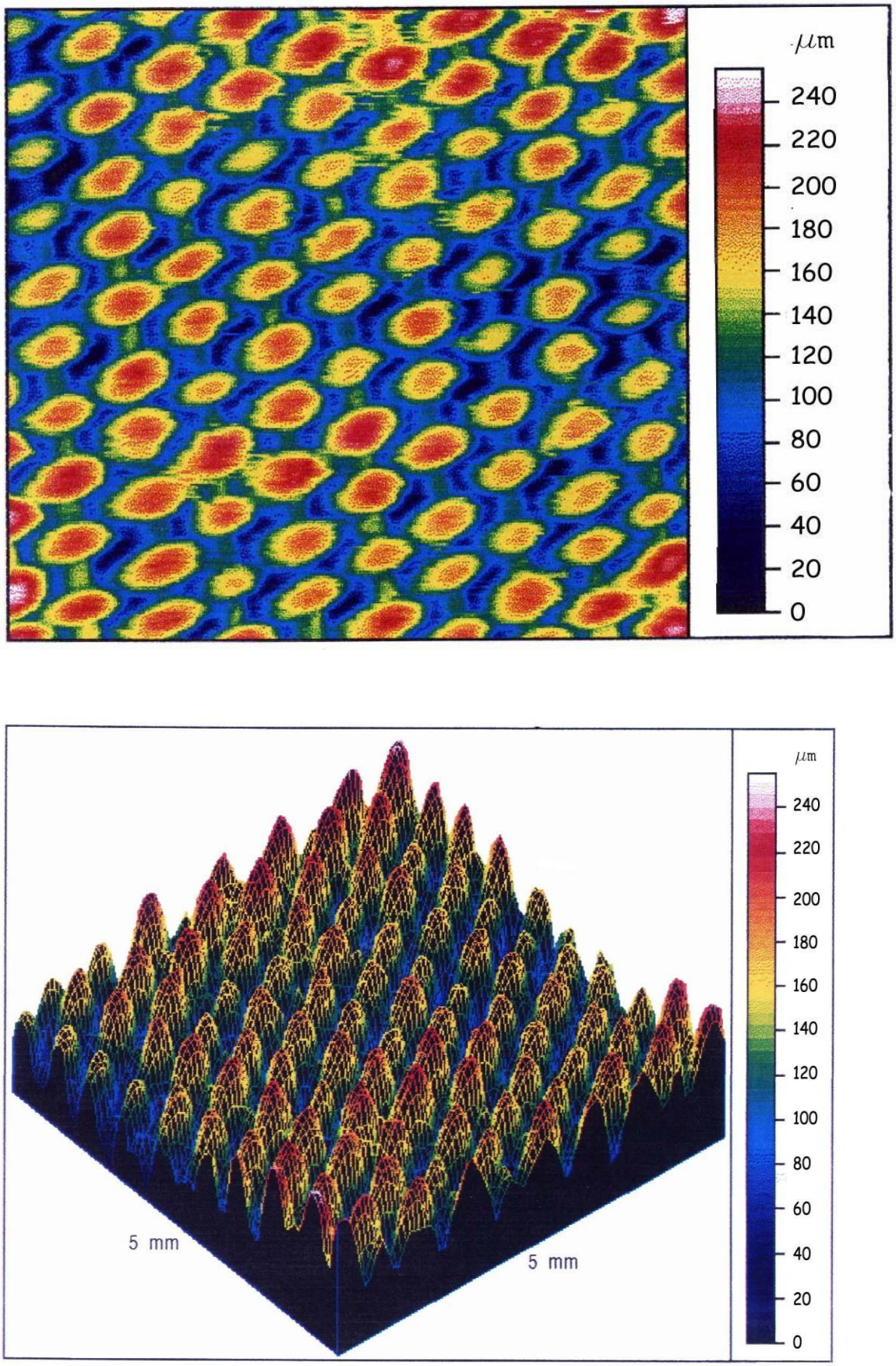

Figure 4: Pore size distribution within a fabric [37]

3 METHODS

This part explains about the various type of experiments that are successfully done to find the heat and moisture transfer through the non-woven fabrics. This experiments gives brief details about how the nonwoven fabrics are tested and explains the results obtained from this process. And also it gives necessary information about the properties of non-woven materials used in automotive textiles.

3.1 HEAT AND MOISTURE TRANSFER THROUGH NONWOVEN FABRICS

Heat and moisture transfer properties of nonwoven fabrics are of great practical importance because, when used in various applications such as surgical gowns and chemical protective garments, they play a major role in deciding the thermal comfort of those materials. [38]

When taking into account the efficiency of nonwovens for cold weather insulation, there are also areas of concern. There is a continuing need for realistic theoretical models that describe heat and moisture transfer processes across nonwoven structures in terms of basic principles, despite research conducted in these areas. In terms of the variables of nonwoven fabric construction, there is a special need for analytical models that can be used to accurately predict thermal insulation and moisture diffusion. [39]

The thermal conductivity of nonwoven fabrics has, therefore, been predicted directly from fiber and fabric variables in this model. This model is used to gain a deeper understanding of the role played by fiber size, orientation, and conductivity, as well as the web structure's anisotropy, strength, and thickness in heat transfer through nonwoven materials. [39]

3.1.1 Experimental method:

Using a specially adapted Kawabata Thermolabo, thermal conductance and conductivity were measured. As shown in the figure below, this system uses a small covered hot plate as a heat source and a water-cooled bath as a heat sink. The small guarded hot plate consists of a heated aluminum plate, thin printed heaters and a guard plate (1 mm thickness X 25 cm 2 area). [40]

The fabric sample is kept between the source of heat and the heat sink. The test takes place at a touch pressure of 588 Pa (6.0 g / cm 2) with a temperature difference of around 10O C between the heat source and the heat sink. For thick fabric samples, styrene foam spaces insulate the sample edge to exclude the edge effect. To minimize convection effects, most samples were tested with the hot plate above the cool plate, but we performed both up and down tests on selected objects to determine convection conductivity Kcv.

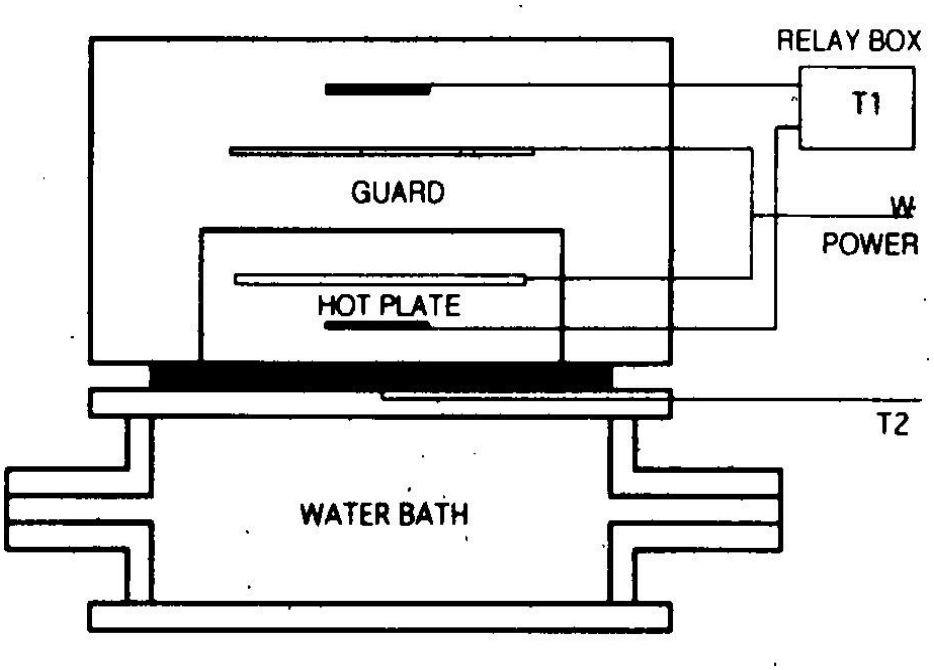

Figure 5 : thermal conductivity measuring system [40]

Gauge sensors were used to detect the temperature of the hot plate (Tl) and the guard. Using a micro thermocouple (0.001 in. diameter), the water bath temperature (T2) was measured. the required power (W) was measured at the steady state and the thermal conductance (k) was calculated as the heat flow per unit area per temperature difference. As the product of thermal conductance and fabric thickness, overall thermal conductivity (K) was measured. [40]

The inherent thermal resistance of the fabric excluding the boundary air layer was expressed by the reciprocal of thermal conductance. weight of the fabric, thickness, bulk density, fraction of fiber length, fiber denier, an anisotropic factor, and parameters of polar orientation are measured accordingly. These properties relate to the compactness of the fabric and the directionality of the fiber, considered to be the most important structural parameters influencing the properties of transfer. [40]

3.2 RADIATIVE HEAT TRANSFER THROUGH NON-WOVEN

Due to the considerable growth of such materials in thermal insulation applications, radiative heat transfer through fibrous media been the area of interest for many areas. Nonwovens are fibrous materials developed in various weights and structures, and their widespread use is due to their cost-effective manufacturing techniques. Their example covers a broad spectrum from low-cost fiber batting materials commonly used in residential buildings for insulation to the more costly composite materials used in aerospace. [41]

Many fibrous insulation materials operate on a concept that is based on reducing conduction and convection heat transfer, but are not as effective in suppressing radiative heat loss due to their large available surface area. Via high-porosity fiber thermal insulation, radiation can be a significant mode of heat transfer even at temperatures above a few hundred Kelvin. [41]

3.2.1 Experimental setup:

The figure below shows a diagram of the experimental setup. A radiative heat source was exposed to various nonwoven mats and photographs of the temperature profile were taken from the side of the material facing away from the heat source using a radiometric camera. Raytheon Inc.'s ExplorIR IR camera model has been fitted with a delta meter and electronic zoom to provide 2X and 4X magnification. The camera can record the temperature via the thermal image of the material along some arbitrary line and calculate an average temperature, as shown in the figure below. [42]

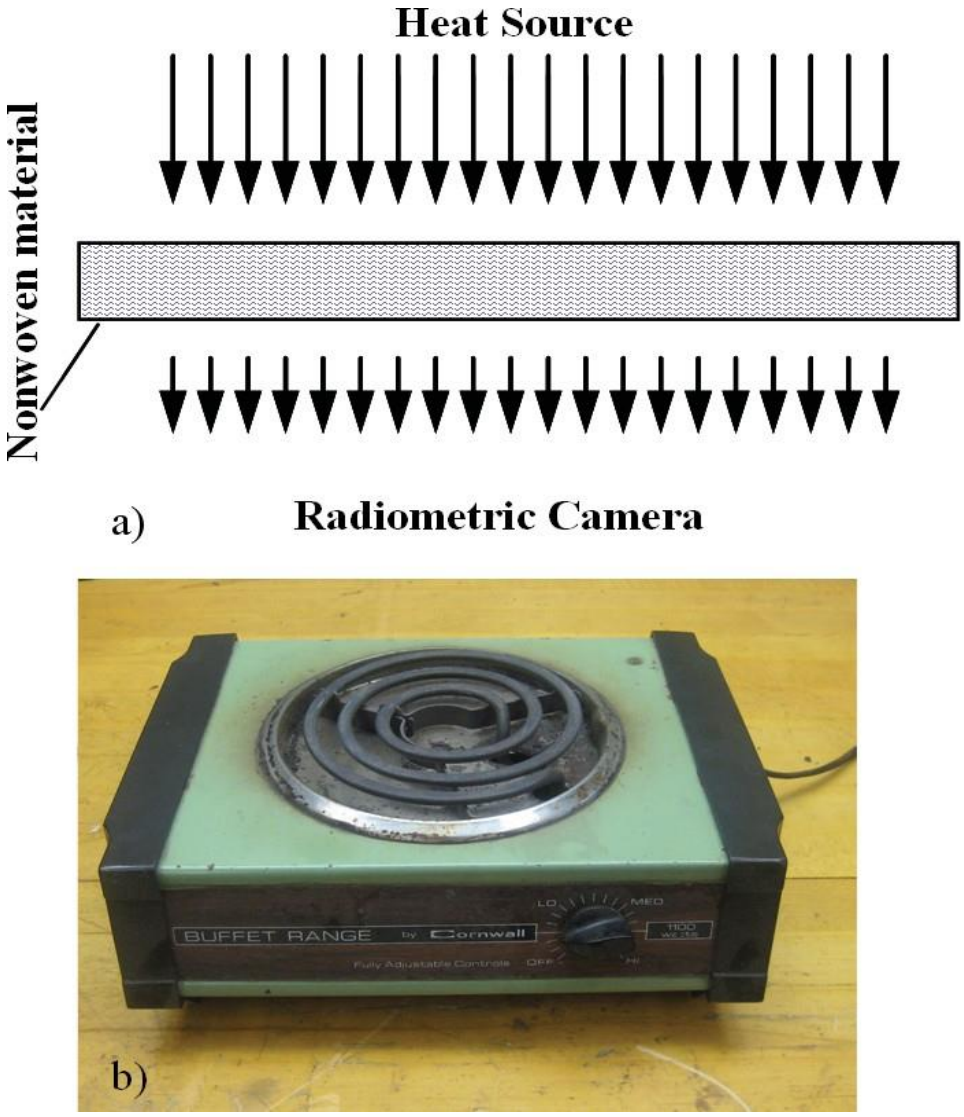

Figure 6 : The experimental setup (a) and the heat source (b) used in this investigation. [42]

To measure fiber diameters in the materials examined, optical microscopy and SEM images were used (30 readings for each average diameter). The base weight of the material (grams per square meter) according to the standard ASTM D-5261 was also measured. In accordance with the ASTM D-1777 standard, the thickness of the mats was also measured. The list of the samples considered in this research and their measured properties is given in the table below. [42]

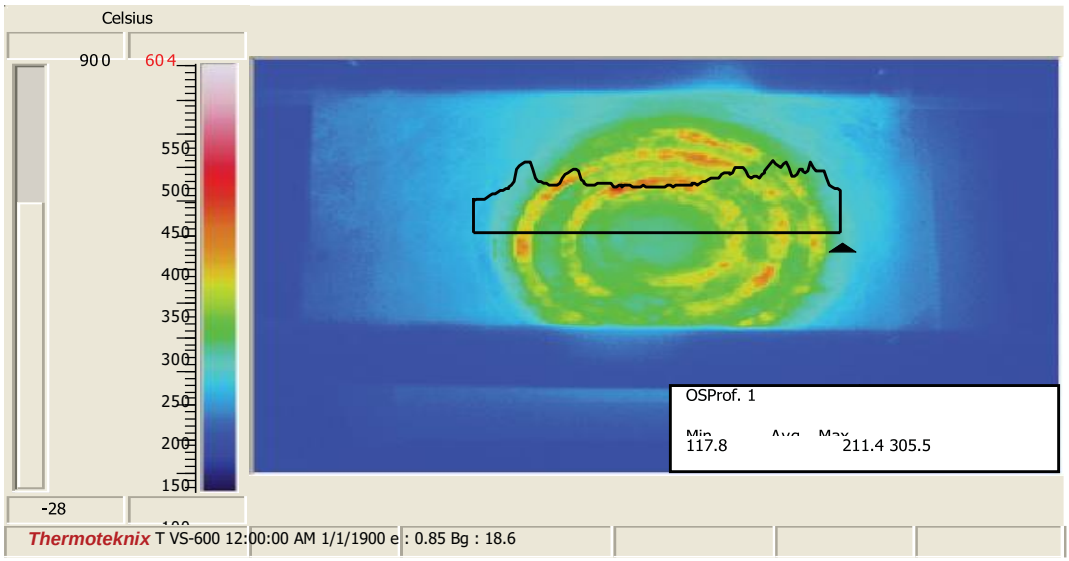

Figure 7: an example of thermal images obtained by our IR camera. An example of the line profiles used for recording the minimum, maximum and average temperature is also shown. [42]

Table 2 : Material properties [42]

sample	Material	Fibre diameter (μm)	Basis weight(gsm)	Thickness (mm)	Density (g/cc)	SVF(%)
R1	Polyester	20	20	0.19	1.36	8
R2	Polyester	20	34	0.24	1.36	10
R3	Polyester	20	102	0.42	1.36	18
T1	Polyproplyene	40	65	0.23	0.9	31
T2	Polypropylene	40	119	0.36	0.9	37
T3	Polypropylene	40	203	0.46	0.9	49
T4	Polypropylene	40	271	0.53	0.9	56

3.3 PROPERTIES REQUIRED FOR AUTOMOTIVE TEXTILES

The advances in fiber science and technology and fabric/web shaping innovations have spearheaded textile advances in the automotive industry. Such developments have led to the production of textiles and textile-based components for various automotive applications abroad that are capable of meeting the tough requirements of the industry in terms of high performance during use. Automotive textiles represent the most lucrative global market for technical textiles, with a wide range of products comprising innovative textile structures and high-quality designs within this category. Automotive textiles cover a wide variety of uses, including upholstery and seating, floor coverings, trunk liners, headliners, coverings for doors and side panels, pillar covers, thermal and sound insulators, filter fabrics, tyres and a range of flexible and hard composites reinforced with textiles. [43]

3.3.1 General considerations

Once manufacturers of textile roll products enter the automotive industry, they must ensure that their products comply with emission requirements and specifications of auto OEMs. In a particular interior material database system, they also need to enter product information. For the EU market, auto Tier 1 and Tier 2 suppliers are also expected to provide end-of - life vehicle recycling solutions for the product. These solutions include the isolation and recycling techniques of interior products, the identification of reuse zones, replication methods for the use of recycled materials, and the calculation of recycling costs. [44]

3.3.2 Property requirements

Usually, textile products used by vehicles fall into two categories: interior surface materials and materials for interior trimming. In visible areas in a vehicle passenger cabin, interior surface materials are applied as skin materials, primarily for interior decoration. In comparison, interior trim materials are also used as structural components or acoustical components of trim pieces in unseen areas in a car. Therefore, property specifications for these products differ depending on various end uses. However, trimability, emission, color variance (color match), colorfastness, abrasion, aging, odor, acoustical efficiency, and flammability are essential property specifications that are critically important to OEMs. [45]

3.3.3 Applications

Automotive interior pieces, from car to car and from material to material, are very diverse. A series of technologies integrated with process design, composite manufacturing, material engineering, and testing approaches are required to produce these parts. (1) passenger cabin, such as floor carpet, inner dash insulator, headliner, door trim, and seat; (2) trunk compartment, such as side trim, load floor and floor cover, and parcel shelf; (3) engine compartment, such as engine hood insulator and absorber. In general, application areas of automotive interior parts in a vehicle can be divided into three categories: Nonwoven fabrics can be used in all three application areas, as already stated. In automotive applications, a major reason why nonwoven fabrics are so flexible is that they can be manufactured either in a soft and bulky felt format, or in a rigid and thin panel format. In the manufacture of auto interior products, this unique material feature makes nonwoven fabrics very competitive. Typical engineering applications are discussed below for nonwoven fabrics in vehicle interiors. [46]

3.3.4 Trunk compartment- Trunk liners

Nonwoven fabrics are commonly used in the trunk compartment of the vehicle as trunk liners, including load floor cover and side trunk cover. The freight floor cover, consisting of a carpet layer and a padding layer, is very similar to the passenger floor cover. Sometimes, without back-coating, the carpet layer is made of flat felt. This helps to reduce the weight and cost of carpets. A bulky nonwoven form made using recycled fibers (shoddy fibers) is the padding layer. Often, the side trunk cover is made of uncoated flat felt and is shaped into a three-dimensional form in many instances. [46]

3.3.5 Trunk load floor

Under long-term static loading, the trunk load floor requires high deflection resistance. A wood composite that can be as heavy as 9 kg / m2 is mostly made up of conventional trunk load floor. The area of the trunk load floor is approximately 1 m2 in several instances. A weight reduction in the trunk load floor leads to improving the performance and cost-effectiveness of vehicle gasoline. Twin-wall trunk load floors have been implemented in several recent designs for this purpose. [47]

A typical twin-wall structure similar to the passenger floor mentioned in the previous section of the trunk load floor (Nick and Duval, 2005). The top panel and bottom panel are both made from a 50/50 natural fiber / PP blend or 50/50 glass fiber / PP blend of 2500 g / m2 nonwoven. The air gap thickness ranges between 0 and 30 mm. Light weight, excellent rigidity and noise barrier, ease of modularization, and the capacity for multifunctional integration are features of the twin-wall load floor. Low temperature stability (generally below 80℃) is an implementation limit for this structure. [47]

4 PRACTICAL PART

In this part, the experiments and tests that was done to find the mechanical strength, thermal conductivity, thermal behavior of the recycled non-woven material were explained in detail.

4.1 THERMAL CONDUCTIVICTY EXPERIMENT

As a first step of this project, the samples were collected from our laboratory. Then the samples were cut with the help of the scissors according to its accurate dimensions. Then to measure the thermal conductivity of the prepared material, thermal conductivity measuring instrument was used which was developed in our university. The schematic diagram of that machine and the procedure of measuring is explained in the context below.

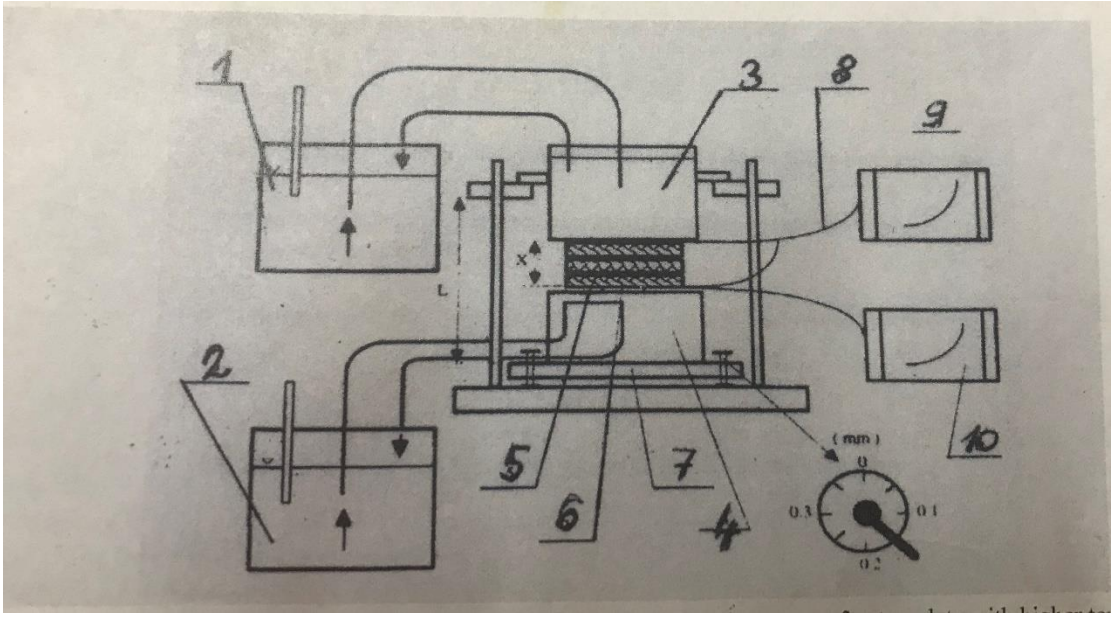

Figure 8: schematics of measuring device

1.Top plate thermostat 2. lower plate thermostat 3.top plate with high temperature 4. lower plate with lower temperature 5. measured sample 6. heat flux sensor 7.pad with elevation setting 8. differential thermocouple 9,10. Measuring or recording milivoltmeter

This is the device that is designated for Fast and accurate measurement of effective heat transfer for bulky(porous) materials with the range of thickness approximately 3-40mm.

Description of the device function

Effective heat conductivity of material is determined based on the equation of heat transfer

$$\frac{Q}{A.t} = \lambda . \frac{\Delta T}{L} \qquad (5)$$

From the equation (5),Where, $\frac{Q}{A.t}$ represents heat transfer ($W.m^{-2}$), Q is the amount of heat passed(J) , A area of heat flux transfer (m^2), t- time (s)

λ- (effective) heat conductivity ($W.m^{-1}.K^{-1}$)

ΔT – Temperature difference between top and bottom vessel (K)

L - thickness of the sample(m)

It is required to measure precise values of L, ΔT and heat flux during the determination of heat conductivity in following manner

L - set the distance between top and bottom plate (distance between bottom of the top plate and thermocouple on the top of the lower plate). This distance equals the thickness of the measured sample.

ΔT – from the calibration graph of differential thermocouple described by the following equation

$$\Delta T = 25.2 * U2 - 0.1504 \qquad (6)$$

From the equation (6), Where the U2 represents voltage on differential thermocouple in mv (channel.105 of the measuring device)

Heat transfer measured by thermocouple Hukseflux HFP 01-05 is calculated by following equation

$$Q/(A.t) = 15.94. U1 \qquad (7)$$

From the equation (7), Where U1 is the voltage on the heat flux sensor in mv (channel. 106 of the measuring device)

PROCEDURE TO BE FOLLOWED FOR MEASUREMENT:

1. Turn on the pumps on both thermostats and set the measuring temperatures – recommended 30 ℃ for the bottom of the plate and 37 ℃ for the top plate (needed time approximately 15 minutes)
2. Set the distance between the heat transferring plates according to the measured sample while using the distance setting components, set screws of the pads with the thread pitch of 1.25mm
3. Put the circular sample on the top of the heat transfer sensor. The sample must be similar in size (or larger) when compared to the surface of the hot plates. Set the top plate to the measuring position.
4. Track the progression of the voltage (heat transfer sensor – channel 106). After stabilization of the voltage (approx. 2-6 minutes) depending on the thickness of the sample) note down the voltage U1 and immediately switch to the channel 105(differential thermocouple) and note down the value U2.
5. Calculate the value of effective heat conductivity of measured sample using equation (8).

$$\lambda = 15.94 * U1(mv). \frac{L(m)}{\Delta T \ \ (C)} \qquad (8)$$

and the thermal resistance R($w^{-1}.m^2.K$) is given by the following equation(9)

$$R = \frac{L(m)}{\lambda} \qquad (9)$$

So, we have set some values while performing this experiment, the values are

Temp (T1) = 30℃

Temp (T2) = room temperature

Distance between two plates = 18mm

So in the table below, the necessary values for finding the effective heat conductivity was measured separately and their final average value is given.

Table 3: Average values for all the samples for finding the effective heat conductivity

	Thickness (in m)	U1 (mv)	U2 (mv)	ΔT=25.2* U2–.1504	Q/ (A.t)	ƛ	Thermal resistance – R
Sample (average value)	0.00718	1.5894	0.1472	39.90248	25.33504	0.004559	1.574985691

For your reference, the individual calculation part for each and every sample is presented in the supplementary part.

So, from all these values we got, the effective thermal conductivity for all the samples were found individually. The final equation for the thermal conductivity is given below.

$$\frac{Q}{A.t} = ƛ. \frac{\Delta T}{L}$$

Table 4: final values of effective thermal conductivity for all the samples

	Final Equation
Sample 1	24.8664
Sample 2	26.7792
Sample 3	25.77498
Sample 4	24.707
Sample 5	24.54760
Average	25.335036

The below picture gives a clear idea about how the process is done.

Figure 9: shows the exact experimental setup as described in the figure above and how the sample testing is done to find effective thermal conductivity.

4.2 PREPARATION OF THE SAMPLE:

For the preparation process, the samples were first collected from the ideal factory, which was founded in the year 2006 in Czech Republic as IDEAL automotive. This company has nearly four major branches in the Czech Republic and many branches across the world. IDEAL automotive mainly focus on the products that are used in automotive textiles. Their products are mainly consisting of Textile lining components for the interior and exterior of vehicles and Manufacturing and coating of semi-finished products in the field of non-woven fabric and tuft.

The samples which was collected from the factory consists of four big sheets made up of reused fibers that is bonded mechanically using the needle punching machine.

Then the samples were cut in to the standard size in both machine and the cross direction. The size dimensions for the sample is (30*28) cm in one direction and in other as (28*30) cm respectively.

So, by this way 4 sets of sample were prepared in both the machine and cross direction from the samples we got from the ideal factory, and it was named as A, B, C, D respectively.

Totally 10 samples were prepared of the same size for each and every sets A, B, C, D in both the machine and cross direction and was named in the numerical order for the testing and other process.

4.2.1 Thickness Measurement:

First from the prepared samples which was brought from the ideal factory is grouped in four categories A, B, C, D respectively. Now using the thickness measuring device, the thickness values all the samples in both the machine and cross directions were measured. For each and every sample 3 readings were taken with the help of the thickness measuring device and average of that 3 values are taken as the final thickness value of the sample. All the values that was obtained from the device was in millimeters respectively.

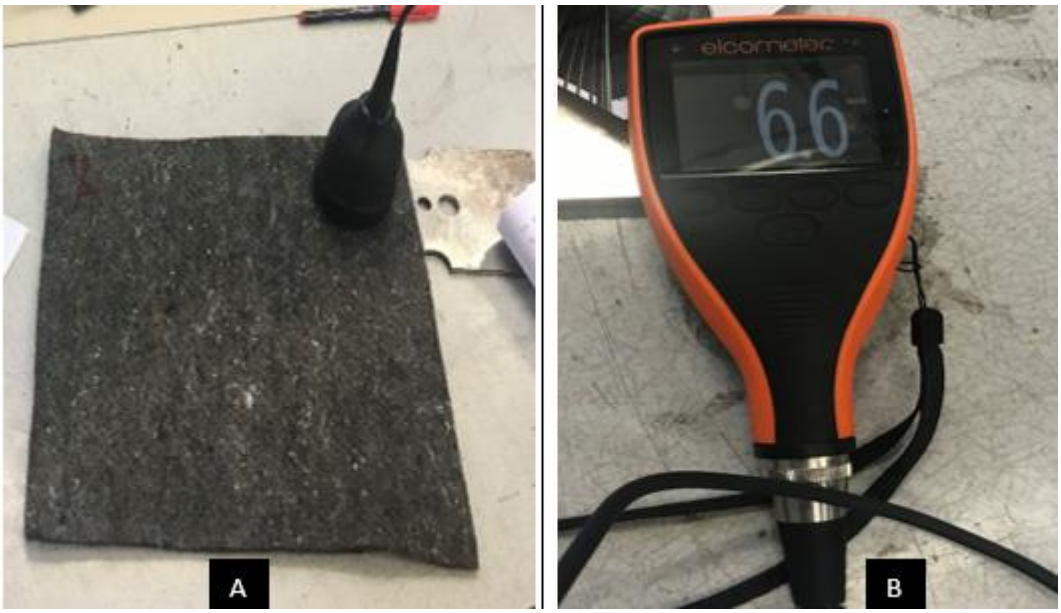

Figure 10: (a) shows how the thickness of the sample measured using the thickness measuring device. (b) represents the picture of thickness measuring device with the value on it.

4.3 PROCESS METHODS:

Now from that four sets, it was planned to separate the sample in to four categories, for that four categories 10 samples were taken randomly from the A, B. C, D and it was collected separately.

The four categories are as follows

1. Fully dried sample (0% moisture)
2. Sample with 10% moisture
3. Sample with 20% moisture
4. Sample with 30% moisture

For, making the sample wet in different moisture levels, the water sprayer was used. All the samples were weighed individually and it was taken as the initial weight (in grams). And then the samples were made kept in the pressing machine covered with help of the lightweight sheets to avoid the direct contact while drying and the temperature in pressing machine is set at 225℃ .

Figure 11: represents the picture of hot pressing machine in our laboratory which is used for the drying of the samples at high temperatures.

4.3.1 Sample Fully Dried (0%) Moisture

For each set of samples, the procedure is varied slightly. Firstly, for 0% moisture level The initial weight of the sample was measured and then it was dried in the pressing machine for the time around 1 minute and then the sample was taken out from the machine and it was transferred to the other manual small press machine. There small amount of pressure was applied sample, for about 30seconds. As the top and bottom plate of the manual press machine remains in the normal room temperature, the sample gets cools down little bit from its initial temperature. After taking from the press again the weight of sample (which will be decreased compared to the initial weight) should be noted by keeping it in the weighing balance. Then the sample is packed with air tight cover and for maintaining it on 0% moisture the samples were packed with the silica gel beads, as it helps in absorbing the remaining moisture from the sample. The whole process is explained from the flowchart below.

Table 5: provides the values of weight measured before and after pressing of the samples with 0% moisture.

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
A6	72.0	71.4
A7	69.0	68.4
B5	74.2	73.4
B6	74.8	74.0
C2	84.2	83.4
C8	86.2	85.6
C9	94.8	94.6
D3	80.4	79.8
D9	81.6	80.8

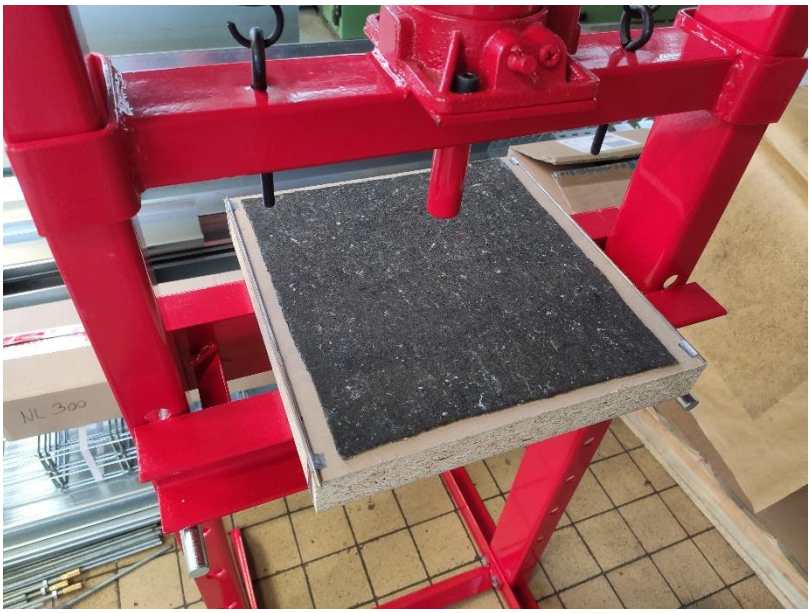

Figure 12: represents the cold pressing machine with the sample on it

4.3.2 Sample with 10% Moisture

Then, for the next set of sample (moisture level 10%) water sprayer was used for spraying water droplets in the sample to make it wet by 10%. First the initial weight of the sample was measured before spraying water droplets and values were noted respectively. Then after spraying the water droplets in the sample, the sample should be weighed again to calculate the percentage of water to be added in the sample. And for the calculation the formula given below.

$$\text{increase in weight (10\%)} = \frac{\text{initial weight} \times 10}{100} \qquad (10)$$

Suppose we have the initial weight of the sample as 68.2g now by using the above formula we got the final value as 6.82. so now to get total weight increased by the sample by 10% we have to add the initial value and the value we got from the above formula. So it will be 68.2+ 6.82 = 75.02g

Total increase in the weight of the sample = initial weight + increase in weight (10%)

Then the other process is explained as in the flowchart below.

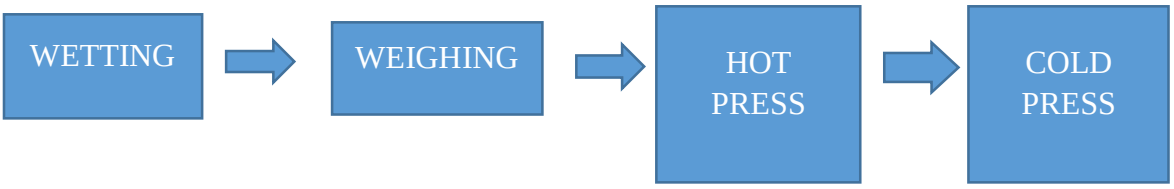

Table 6: provides the values of weight measured before and after pressing of the samples with 10% moisture

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
A1	74.8	67.8
A4	72.4	64.8
B3	82.6	74.0
B4	78.4	69.8
C3	95.8	85.8
C6	90.2	80.0
D1	85.6	76.4
D2	89.2	79.6
D10	90.6	81.6

4.3.3 Sample with 20% Moisture

Then for the 20% sample, the initial weight of the sample was measured and using the water sprayer water droplets were sprayed in the sample. And the required increase in weight was calculated using the formula below. and finally we check that by using the weighing balance and it is taken as the final weight (20%) of the sample.

So to find the increase in weight and final weight of the sample we use the below formula.

$$\text{increase in weight (20\%)} = \frac{\text{initial weight} \times 20}{100} \qquad (11)$$

total increase in the weight of the sample = initial weight + increase in weight (20%)

Then as explained in the flowchart above, the same procedure follows for 20%moisture also.

Table 7: provides the values of weight measured before and after pressing of the samples with 20% moisture.

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
A2	82.2	67.6
A3	84.2	70.4
B1	87.2	71.2
B2	90.6	74.2
C4	100.2	81.6
C5	101.6	83.6
C7	106.8	87.8
D6	99.4	81.4
D7	99.0	81.2

4.3.4 Sample with 30% Moisture

And at last for the 30% moisture level, firstly the initial weight of the sample was measured. Then by using the water sprayer, water droplets were sprayed in the sample. Then the required weight was calculated by using the formula below. Then the final weight of the sample is measured using the weighing balance.

Thus, for calculating we use the below formula.

$$\text{increase in weight (30\%)} = \frac{\text{initial weight} \times 30}{100} \quad (12)$$

total increase in the weight of the sample = initial weight + increase in weight (30%)

Then the same procedure as given in the flowchart above follows for the 30% moisture also.

Table 8: provides the values of weight measured before and after pressing of the samples with 30% moisture.

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
A8	89.6	67.8
A10	87.8	66.8
B8	97.6	73.8
B9	89.6	67.8
C1	110.6	84.2
C10	112.8	85.6
D4	103.2	78.6
D5	109.4	83.0
D8	104.4	78.8

Figure 13: (a) shows the sample with the moisture level 0%. (b) shows the sample with moisture level 10%. (c) shows the sample with moisture level 20%. (d) shows the sample with moisture level 30%.

4.4 BENDING TEST

The international standard followed for doing the bending tests is EN ISO 178:2003. This standard specifies the method for determining the flexural properties of rigid and semi-rigid plastics under defined conditions. A standard test specimen is defined, but parameters are included for alternative specimen sizes for use where it is appropriate. A range of test speeds is included.

This method is useful in investigating the flexural behavior of the test specimens and also for determining the flexural strength, flexural modulus and other aspects of the flexural stress/strain relationship under the conditions defined.

The principle of working is that the test specimen, supported as a beam, is deflected at a constant rate at the mid span until the specimen fractures or until the deformation reaches some predetermined value. During the process, the force applied to the test specimen is measured.

For doing bending test, we have machine in our laboratory which is used for finding the bending rigidity of the given samples. In the bending test we have one stationary clamp at the bottom and another clamp which is moving that is situated at the top of the sample. Once the machine is switched on, the top clamp will move perpendicular to that of the sample and continue to bend down the sample until the maximum value is reached. The speed of the top clamp is 10mm/min.

A bend test produces tensile stress in the convex side of the specimen and compression stress in the concave side. This creates an area of shear stress along the midline. Results are plotted on a stress-strain diagram

For doing the bending test, the samples were prepared according to the specified dimensions (10*2 cm). After the sample is prepared, it was kept in room temperature for 2 days covered with air tight covers. Totally 6 samples were prepared in both machine and cross direction separately for different moisture levels. And the testing was done in our laboratory.

So below are the figures, which illustrates how the bending test is done in our laboratory.

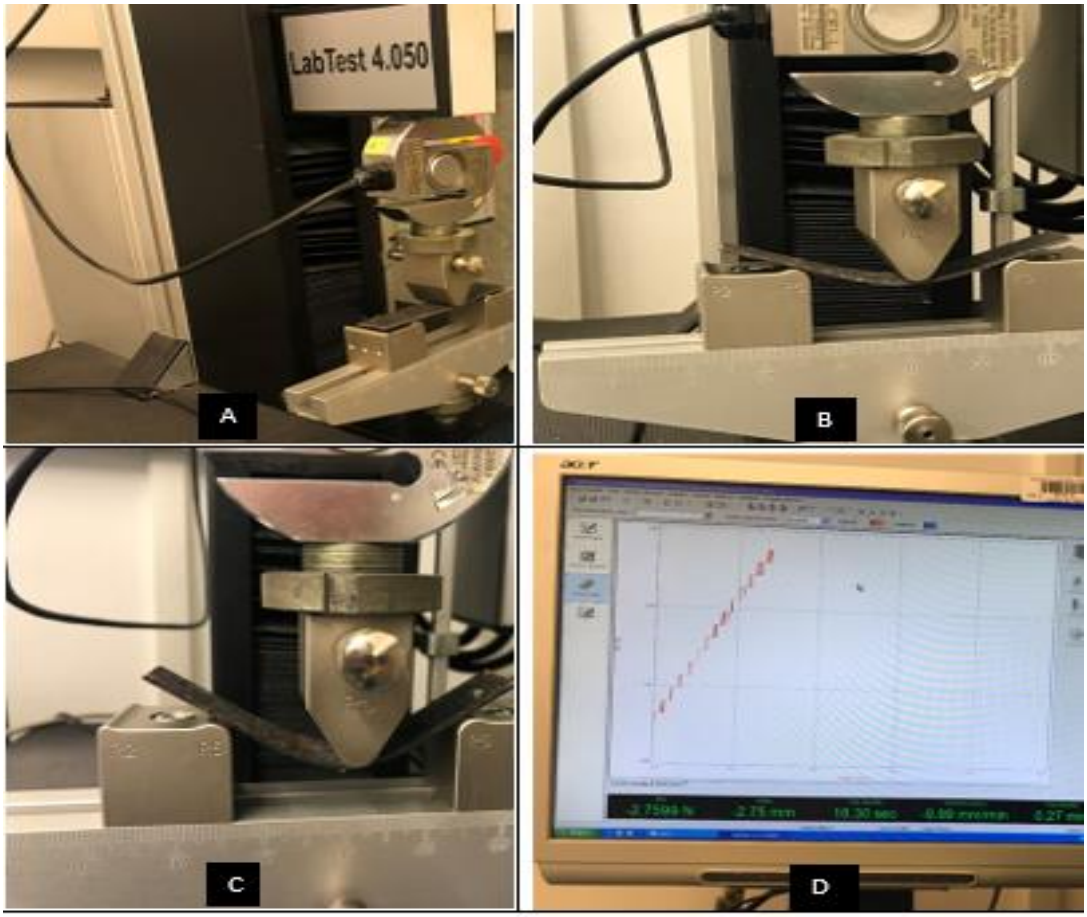

Figure 14:(a) shows the actual set up of the bending test machine. (b) represents the initial stage where the sample is bend slightly. (c) represents final stage at which the sample is bended to its maximum. (d) shows the values that are recorded simultaneously in the system in order to find the maximum bending resistance. Then with those samples thickness in mm, and width in mm was measured for each and every samples individually before doing the bending test.

4.4.1 Bending Test Calculations

In this part, the thickness and the width values for each and every sample in machine and cross direction were calculated and their averages were found out separately for different moisture levels. The thickness and width values varied for different moisture level samples and it was found increasing with increase in moisture level, because of the natural fibers present in the sample material. The values are as follows.

CROSS DIRECTION (0%)

Table 9: values measured for finding thickness for 0% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.81	1.82	1.84	1.82
Sample 2	1.93	1.96	1.98	1.95
Sample 3	2.21	2.19	2.32	2.24
Sample 4	2.08	2.11	2.16	2.12
Sample 5	1.93	1.97	1.90	1.93
Sample 6	2.09	2.06	2.11	2.08
Sample 7	2.11	2.14	2.13	2.12
Sample 8	2.13	2.16	2.17	2.15
Sample 9	2.14	2.12	2.11	2.12
Sample 10	2.09	2.13	2.16	2.12

Table 10: values measured for finding width for 0% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	19.65	19.73	19.75	19.71
Sample 2	20.58	20.60	20.73	20.63
Sample 3	21.74	21.92	22.22	21.96
Sample 4	22.66	22.75	22.83	22.74
Sample 5	20.42	20.47	20.54	20.48
Sample 6	19.62	20.02	19.86	19.83
Sample 7	21.20	21.32	21.47	21.33
Sample 8	20.32	20.44	20.57	20.44
Sample 9	20.12	20.20	20.32	20.21
Sample 10	19.01	19.23	19.32	19.18

MACHINE DIRECTION (0%)

Table 11: values measured for finding thickness for 0% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.00	1.99	1.98	1.99
Sample 2	2.03	2.00	2.05	2.02
Sample 3	1.95	1.98	2.00	1.97
Sample 4	1.99	2.01	2.02	2.00
Sample 5	1.97	2.00	2.02	1.99
Sample 6	1.95	1.99	2.01	1.98
Sample 7	2.02	2.04	2.07	2.04
Sample 8	1.92	1.93	1.97	1.94

Table 12: Values measured for finding width for 0% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	19.01	19.10	18.95	19.02
Sample 2	20.16	20.12	20.24	20.17
Sample 3	21.13	21.23	21.42	21.26
Sample 4	19.98	20.03	20.19	20.06
Sample 5	20.98	21.24	21.32	21.18
Sample 6	19.84	19.96	20.01	19.93
Sample 7	20.59	20.65	20.83	20.69
Sample 8	20.65	20.72	20.69	20.67

So, from the above table the average values in both cross and machine direction were calculated for (0%). And for all other moisture levels (10%,20%,30%) only average values were calculated and shown below. For reference the values for all the samples is present in the supplementary part.

CROSS DIRECTION

Table 13: Average values for thickness for all 0% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)_	Thickness(mm) (average)
Sample (average)	2.05	2.06	2.08	2.06

Table 14: Average values for width for all 0% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)_	Width (mm) (average)
Sample (average)	20.53	20.66	20.76	20.65

MACHINE DIRECTION

Table 15: Average values for thickness for all 0% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)_	Thickness(mm) (average)
Sample (average)	1.97	1.99	2.0	1.99

Table 16: Average values for width for all 0% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)_	Width (mm) (average)
Sample (average)	20.29	20.38	20.45	20.37

CROSS DIRECTION (10%)

Table 17: Average values for thickness for all 10% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.48	1.50	1.51	1.49

Table 18: Average values for width for all 10% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	20.11	20.20	20.29	20.20

MACHINE DIRECTION (10%)

Table 19: Average values for thickness for all 10% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.87	1.90	1.92	1.89

Table 20: Average values for width for all 10% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	20.06	20.15	20.21	20.14

CROSS DIRECTION (20%)

Table 21: Average values for thickness for all 20% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.92	1.94	1.94	1.93

Table 22: Average values for width for all 10% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	20.2	20.28	20.30	20.26

MACHINE DIRECTION (20%)

Table 23: Average values for thickness for all 20% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.03	2.05	2.07	2.05

Table 24: Average values for width for all 20% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	20.41	20.50	20.58	20.50

CROSS DIRECTION (30%)

Table 25: Average values for thickness for all 30% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.00	2.03	2.07	2.03

Table 26: Average values for width for all 30% moisture samples in cross direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width (mm) (average)
Sample (average)	20.13	20.25	20.26	20.21

MACHINE DIRECTION (30%)

Table 27: Average values for thickness for all 30% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.04	2.06	2.06	2.06

Table 28: Average values for width for all 30% moisture samples in machine direction.

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	20.23	20.36	20.44	20.34

4.4.2 Bending Test Results

In this part, the results obtained from the bending test machine for each and every sample in machine and cross direction for different moisture levels along with their graph were shown as follows.

MACHINE DIRECTION (0%)

Table 29: Bending test results obtained for the sample with 0% moisture in machine direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	9.95	6.73	6.36	214.17
2	11.42	7.48	7.47	207.4
3	10.12	8.36	7.47	266.55
4	10.29	7.97	6.33	269.46
5	10.45	8.54	6.98	281.38
6	10.56	9.93	6.75	347.00

Table 30: Average results of the above table for bending test with 0% moisture samples in machine direction

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	10.47	8.17	6.89	264.33
S	0.52	1.08	0.51	50.82

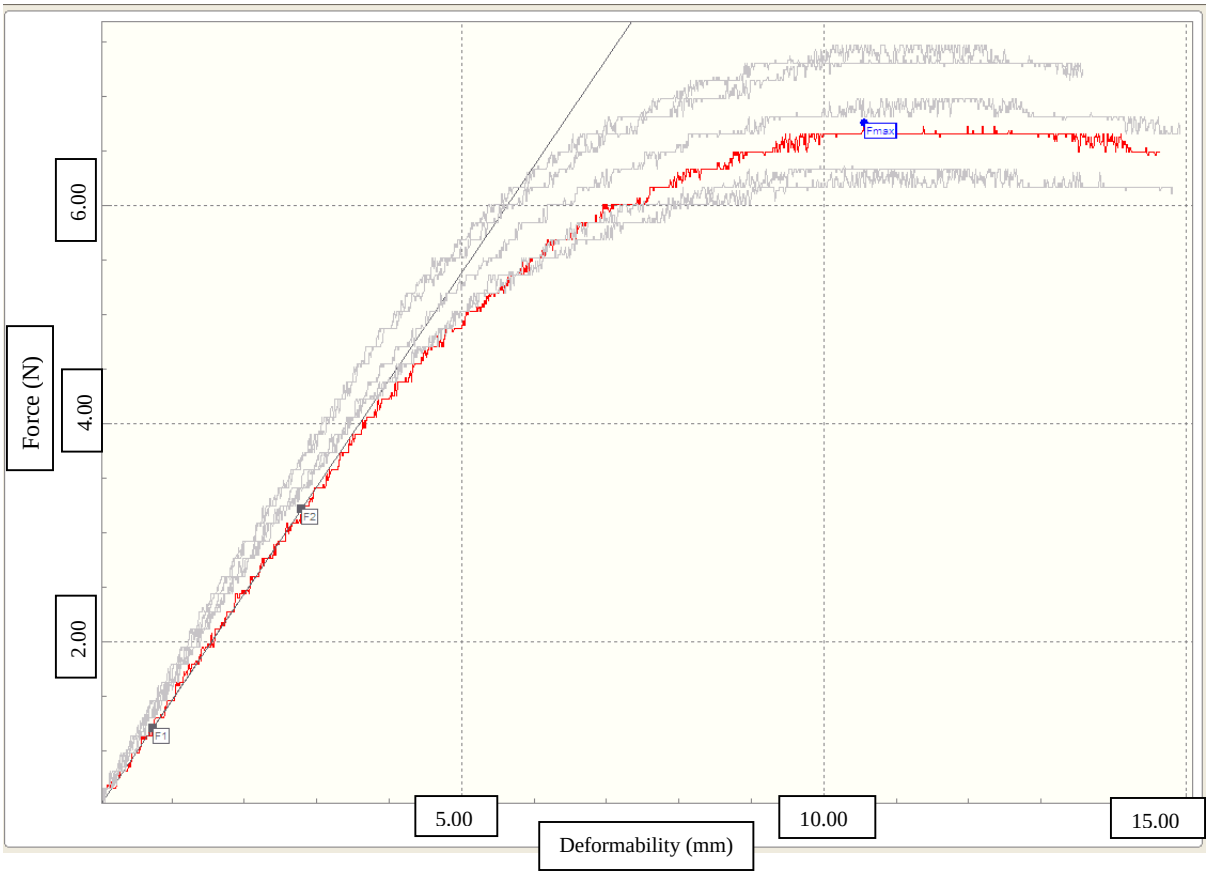

Figure 15: Graph shows the relation between the values of Force(N)and deformability (mm) for 0% moisture level in machine direction

CROSS DIRECTION (0%)

Table 31: Bending test results obtained for the sample with 0% moisture in cross direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	9.73	8.21	6.66	292.28
2	9.89	7.24	6.49	241.04
3	11.35	5.87	5.13	174.58
4	10.04	6.84	5.71	228.62
5	10.94	7.06	6.07	220.2
6	9.99	9.1	7.14	307.47

Table 32: Average results of the above table for bending test with 0% moisture samples in cross direction.

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	10.32	7.39	6.2	244.03
S	0.66	1.13	0.72	48.97

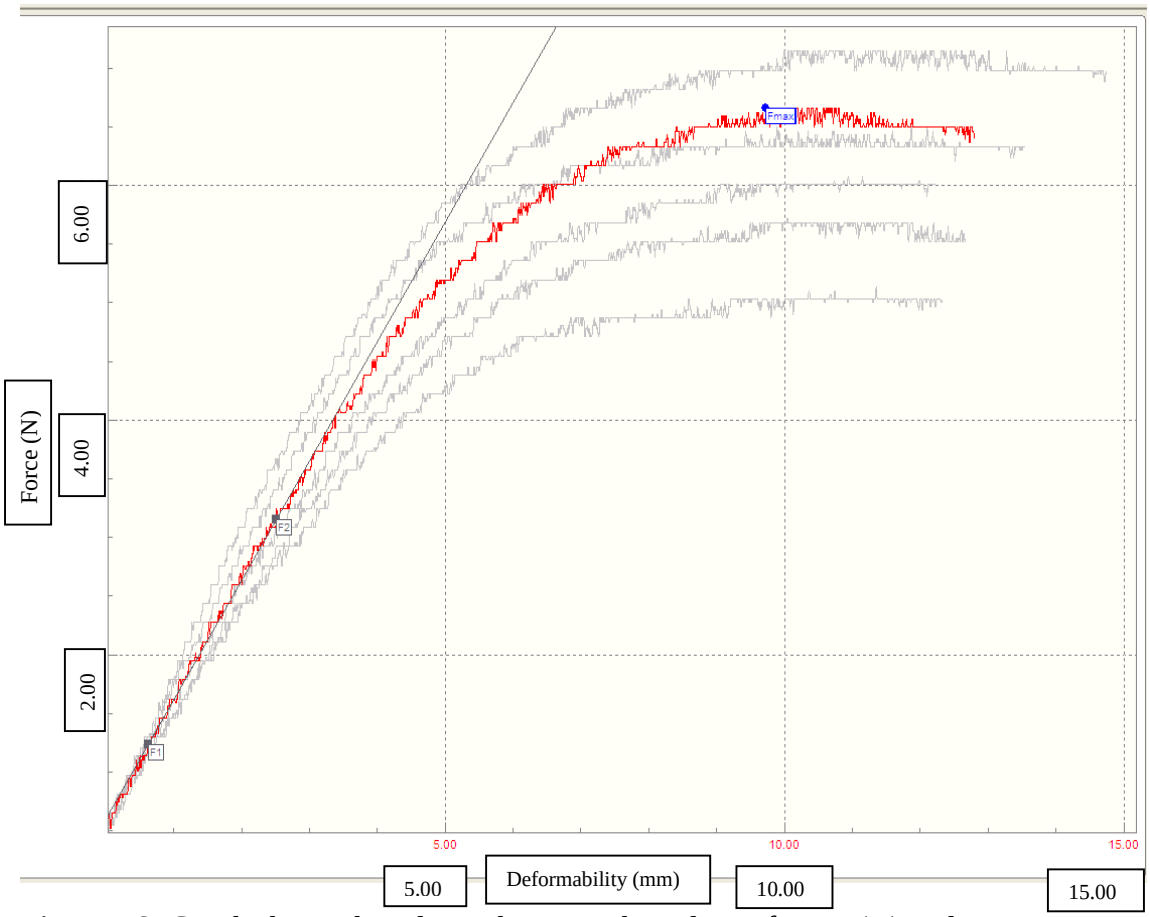

Figure 16: Graph shows the relation between the values of Force(N) and Deformability (mm) for 0% moisture level in cross direction

MACHINE DIRECTION (10%)

Table 33: Bending test results obtained for the sample with 10% moisture in machine direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	9.45	7.77	5.52	299.96
2	10.6	7.62	6.01	251.47
3	10.39	6.6	5.03	223.28
4	10.83	7.28	6.2	237.74
5	8.93	7.08	5.84	277.39
6	11.45	5.83	4.22	177.28

Table 34: Average results of the above table for bending test with 10% moisture samples in machine direction.

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	10.27	7.03	5.47	244.52
S	0.93	0.72	0.74	42.94

CROSS DIRECTION (10%)

Table 35: Bending test results obtained for the sample with 10% moisture in cross direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	14.61	11.58	4.94	380.1
2	13.2	12.97	4.74	488.92
3	13.03	13.61	5.03	523.42
4	14.61	15.13	6.07	522.73
5	13.81	15.72	6.1	562.09
6	13.45	14.07	5.45	501.58

Table 36: Average results of the above table for bending test with 10% moisture samples in cross direction

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	13.79	13.85	5.39	496.47
S	0.69	1.5	0.59	62.21

MACHINE DIRECTION (20%)

Table 37: Bending test results obtained for the sample with 20% moisture in machine direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	9.54	7.22	6.66	246.78
2	8.56	5.33	5.03	202.83
3	9.41	5.44	5.07	188.29
4	9.95	6.82	6.17	225.49
5	8.83	4.89	4.35	178.64
6	12.31	5.6	5.1	149.02

Table 38: Average results of the above table for bending test with 20% moisture samples in machine direction

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	9.77	5.88	5.4	198.51
S	1.34	0.92	0.85	34.71

CROSS DIRECTION (20%)

Table 39: Bending test results obtained for the sample with 20% moisture in cross direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	8.61	5.32	4.38	210.66
2	10.4	7.34	6.01	241.83
3	11.14	8.04	6.14	247.25
4	11.09	8.02	5.88	250.35
5	10.31	6.53	4.84	226.16
6	10.25	7.74	5.68	275.72

Table 40: Average results of the above table for bending test with 20% moisture samples in cross direction

STAT	Amax	Rmo	Fmax	E
	Mm	MPa	N	N/mm2
N	6	6	6	6
X	10.3	7.17	5.49	241.99
S	0.92	1.06	0.71	22.21

MACHINE DIRECTION (30%)

Table 41: Bending test results obtained for the sample with 30% moisture in machine direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm2
1	13.9	10.17	7.47	260
2	11.85	9.95	7.47	298.17
3	11.69	11.73	9.09	354.35
4	11.84	10.16	8.12	306.4
5	11.66	12.29	9.42	368.59
6	12.76	11.22	8.34	314.1

Table 42: Average results of the above table for bending test with 30% moisture samples in machine direction

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
n	6	6	6	6
x	12.28	10.92	8.32	316.93
s	0.89	0.97	0.81	39.45

CROSS DIRECTION (30%)

Table 43: Bending test results obtained for the sample with 30% moisture in cross direction

S.NO	Amax Mm	Rmo MPa	Fmax N	E N/mm^2
1	8.16	4.14	3.41	170.38
2	8.31	3.59	3.31	140.8
3	9.5	2.31	2.34	77.41
4	8.13	3.37	3.41	131.92
5	10.02	3.63	3.28	115.24
6	6.36	3.72	3.41	187.1

Table 44: Average results of the above table for bending test with 30% moisture samples in cross direction

STAT	Amax Mm	Rmo MPa	Fmax N	E N/mm2
N	6	6	6	6
X	8.41	3.46	3.19	137.14
S	1.28	0.62	0.42	39.21

4.4.3 Bending Test Analysis

In this part, from the values we got from the machine, mechanical strength of the material was calculated and it was compared with the different moisture level samples in both machine and cross direction.

MACHINE DIRECTION

Table 45: Average values and standard deviation calculated for Force max corresponding to their moisture levels in machine direction

S.NO	Moisture level (%)	Average	Standard Deviation
1	0%	6.89	0.51
2	10%	5.47	0.74
3	20%	5.4	0.85
4	30%	8.32	0.81

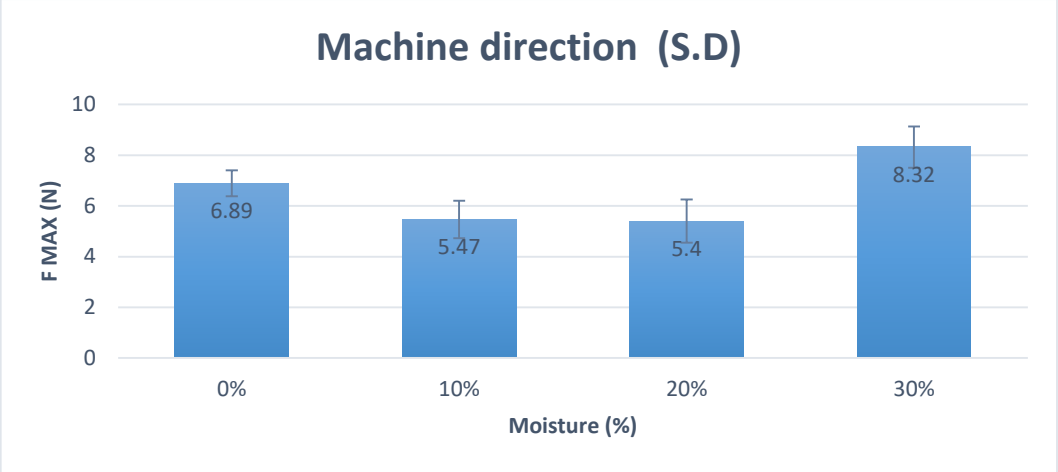

Figure 17: Graph shows the calculated average values of Force max and their standard deviation with respect to the different moisture levels in machine direction

From the above graph fig (16), the Force max values are varied with small differences for each and every samples with different moisture levels. The highest force max value is obtained for the sample with 30% moisture level in the machine direction. This shows that sample with 30% moisture level requires a lot of force to bend and relatively strong compared to the other samples in the machine direction. And it is followed by sample with 0% moisture which is the second highest compared with the other two samples. And the samples with 10% and 20% nearly have same force values and requires less force for bending.

CROSS DIRECTION

Table 46: Average values and standard deviation calculated for Force max corresponding to their moisture levels in cross direction

S.NO	Moisture level (%)	Average	Standard Deviation
1	0%	6.2	0.72
2	10%	5.39	0.59
3	20%	5.49	0.71
4	30%	3.19	0.42

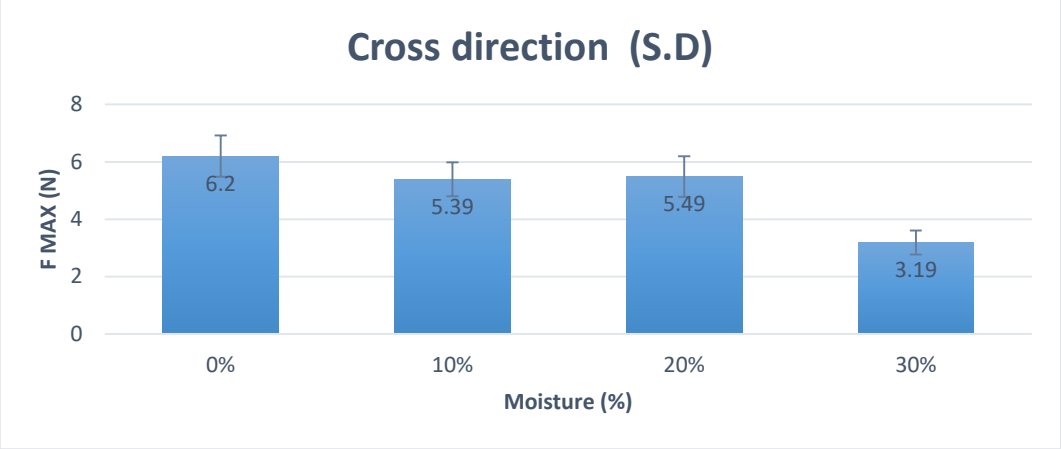

Figure 18: Graph shows the calculated average values of Force max and their standard deviation with respect to the different moisture levels in cross direction

From the above graph fig (17), in cross direction the force max values are higher in sample with 0% moisture level followed by 20%then by 10% and lastly by 30%. So it clearly shows that the force values also depend upon the fiber orientation in both directions. Sample with 0% moisture level behaves well in both cross and machine direction and requires high strength for bending. 10% and 20% samples do not show much difference and remains little bit same in both directions. But sample with 30% moisture level is relatively weak in cross direction.

MACHINE DIRECTION

Table 47: Average values and standard deviation calculated for Flexural modulus corresponding to their moisture levels in machine direction

S.NO	Moisture level (%)	Average	Standard Deviation
1	0%	264.33	50.82
2	10%	244.52	42.94
3	20%	198.51	34.71
4	30%	316.93	39.45

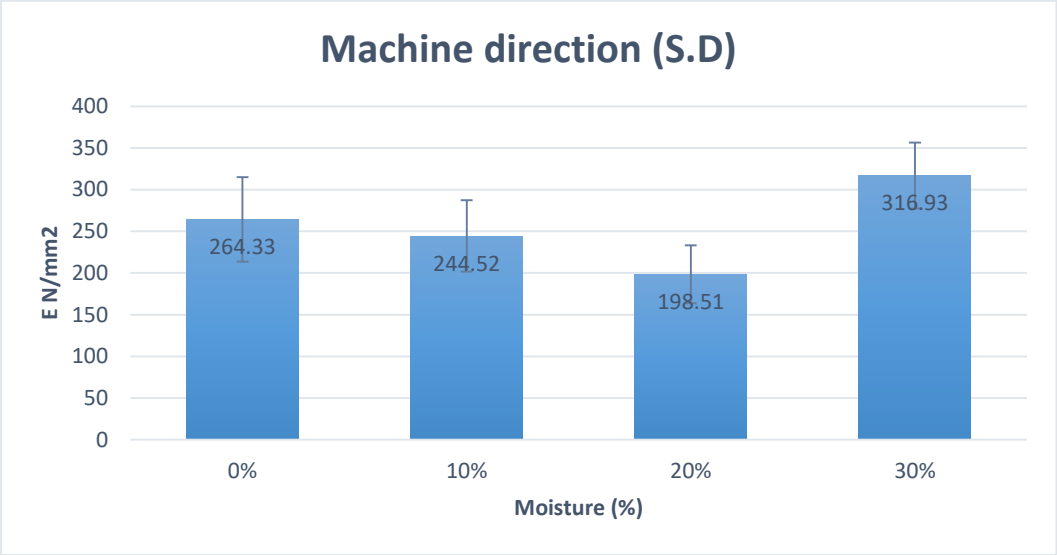

Figure 19: Graph shows the calculated average values of flexural modulus and their standard deviation with respect to the different moisture levels in machine direction

From the above graph fig (18), the flexural modulus values varies for each and every sample with different moisture levels. The flexural modulus is relatively high for the sample with 30% moisture level. And in machine direction the bending resistance is high for sample with 30% moisture compared to the other samples. Sample with 0% moisture levels shows the second highest value and sample with 10% is little bit low to that. Finally, the sample with 20% moisture have very low flexural modulus in machine direction.

CROSS DIRECTION

Table 48: Average values and standard deviation calculated for Flexural modulus corresponding to their moisture levels in cross direction

S.NO	Moisture level (%)	Average	Standard Deviation
1	0%	244.03	48.97
2	10%	496.97	62.21
3	20%	241.99	22.21
4	30%	137.14	39.21

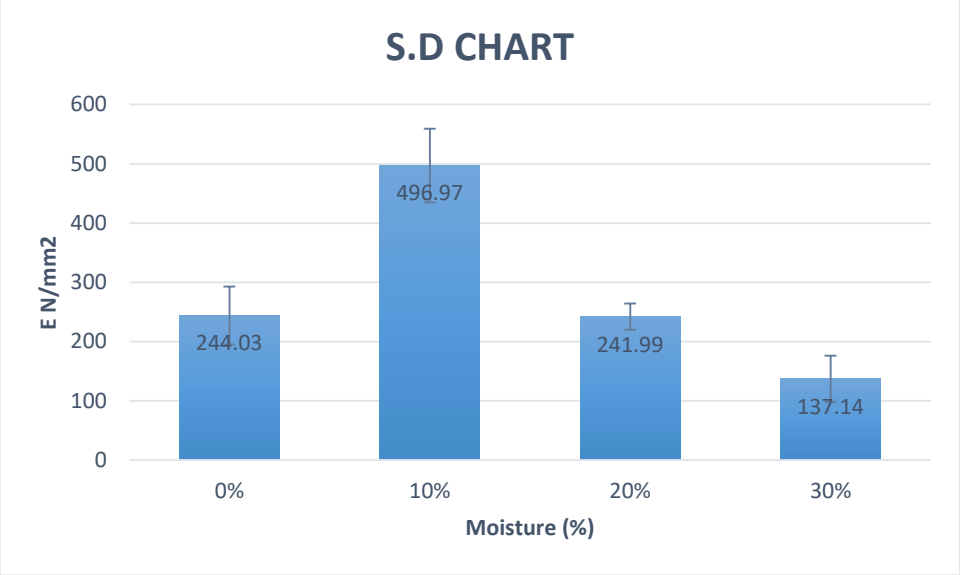

Figure 20: Graph shows the calculated average values of flexural modulus and their standard deviation with respect to the different moisture levels in cross direction

from the above graph (fig.19)**,** In cross direction the flexural modulus value is very high for the sample with 10% moisture level, and it shows high bending resistance in the cross direction. Next the sample with 0% moisture have the second highest flexural modulus value followed by 20%, and in cross direction the sample with 30% moisture level is relatively weak.

4.5 TENSILE TEST:

The standard procedure followed for testing the material is NWSP 110.1.R0 (grab strength test). This method is mainly used for determining the breaking strength and elongation of most of the non-woven materials. With this procedure it is applicable to test the nonwoven materials in both dry or wet conditions.

The principle of working is that a 100 mm wide specimen is mounted centrally in clamps of a tensile testing machine and force applied until the specimen breaks. Values for the breaking force and the elongation of the test specimen are obtained from the test instrument, scales, dials, autographic recording charts, or a computer interfaced.

This test method describes the procedures for carrying out nonwoven material grab tensile test. And it is mainly applicable for the determination of the effective strength of the nonwoven material.

The tensile test was carried out in our laboratory, with the samples prepared according to the specified dimensions (15*5 cm). totally 5 samples were prepared from each set of moisture levels and they were tested accordingly. The test is done in both machine and cross direction for all the samples with different moisture levels.

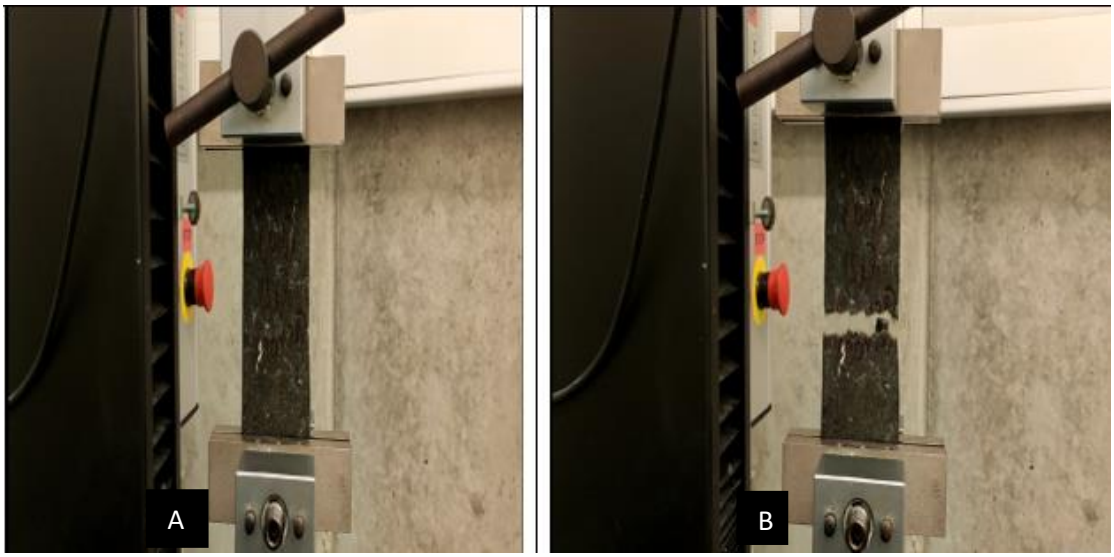

Figure 21: (a) represents the sample in the tensile testing machine before stretching. (b) represents the sample after fully stretched to the maximum point in the tensile testing machine.

4.5.1 Tensile Test Calculations

In this part, the thickness and the width values for each and every sample in machine and cross direction were calculated and their averages were found out separately for different moisture levels. because of the natural fibers present in the sample material, the thickness and width values were increasing with increase in moisture level. The values are as follows.

2C MACHINE DIRECTION (0%)

Table 49: Values measured for thickness in 0% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness(mm)
Sample 1	1.9	1.89	1.86	1.88
Sample 2	1.85	1.9	1.91	1.88
Sample 3	1.9	2.08	1.86	1.94

Table 50: Values measured for width in 0% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.4	5.3	5.4	5.36
Sample 2	4.9	5.0	5.1	5.0
Sample 3	5.1	5.1	5.0	5.06

9D MACHINE DIRECTION (0%)

Table 51: Values measured for thickness in 0% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.91	1.96	2.13	2.0
Sample 2	1.88	1.88	1.84	1.86
Sample 3	1.94	1.8	1.76	1.83

Table 52: Values measured for width in 0% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.17	5.21	5.28	5.22
Sample 2	4.88	4.79	4.89	4.85
Sample 3	5.0	5.07	5.04	5.03

3D CROSS DIRECTION (0%)

Table 53: Values measured for thickness in 0% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.96	2.01	1.98	1.98
Sample 2	2.08	2.07	1.96	2.03
Sample 3	2.06	2.04	2.08	2.06

Table 54: Values measured for width in 0% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	4.89	4.85	4.9	4.88
Sample 2	4.82	4.87	4.95	4.88
Sample 3	5.05	5.01	5.02	5.02

7A CROSS DIRECTION (0%)

Table 55: Values measured for thickness in 0% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.04	1.98	1.96	1.99
Sample 2	1.99	1.99	1.97	1.98
Sample 3	2.13	2.10	1.99	2.07
Sample 4	2.09	2.06	1.98	2.04

Table 56: Values measured for width in 0% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.27	5.21	5.11	5.19
Sample 2	4.78	4.79	4.85	4.80
Sample 3	4.83	4.96	4.99	4.92
Sample 4	4.99	5	4.97	4.98

So, from the above table the average values in both cross and machine direction were calculated for (0%). And for all other moisture levels (10%,20%,30%) only average values were calculated and shown below. For reference the values for all the samples is present in the supplementary part.

MACHINE DIRECTION

Table 57: Average values of thickness for all sample in 0% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.89	1.91	1.89	1.90

Table 58: Average values of width for all sample in 0% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	5.07	5.07	5.11	5.08

CROSS DIRECTION

Table 59: Average values of thickness for all sample in 0% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.04	2.03	1.98	2.02

Table 60: Average values of width for all sample in 0% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	4.94	4.95	4.96	4.95

MACHINE DIRECTION (10%)

Table 61: Average values of thickness for all sample in 10% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.91	1.92	1.91	1.91

Table 62: Average values of width for all sample in 10% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	5.0	4.99	4.98	4.99

CROSS DIRECTION (10%)

Table 63: Average values of thickness for all sample in 10% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.11	2.07	2.04	2.08

Table 64: Average values of width for all sample in 10% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width(mm) (average)
Sample (average)	5.08	5.06	5.05	5.06

MACHINE DIRECTION (20%)

Table 65: Average values of thickness for all sample in 20% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.94	1.96	1.93	1.94

Table 66: Average values of width for all sample in 20% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width (mm) (average)
Sample (average)	5.03	5.04	5.07	5.04

CROSS DIRECTION (20%)

Table 67: Average values of thickness for all sample in 20% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	2.03	2.02	2.03	2.02

Table 68: Average values of width for all sample in 20% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width (mm) (average)
Sample (average)	4.98	4.96	5.0	4.98

MACHINE DIRECTION (30%)

Table 69: Average values of thickness for all sample in 30% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.97	1.98	1.98	1.98

Table 70: Average values of width for all sample in 30% moisture in machine direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width (mm) (average)
Sample (average)	5.02	5.06	5.07	5.05

CROSS DIRECTION (30%)

Table 71: Average values of thickness for all sample in 30% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Thickness(mm) (average)
Sample (average)	1.98	2.00	1.99	1.99

Table 72: Average values of width for all sample in 30% moisture in cross direction

	Value 1 (average)	Value 2 (average)	Value 3 (average)	Width (mm) (average)
Sample (average)	5.09	5.08	5.06	5.08

4.5.2 Tensile Test Results

In this part, the results obtained from the tensile testing machine for each and every sample in machine and cross direction for different moisture levels along with their graph were shown as follows.

MACHINE DIRECTION (0%)

Table 73: Results obtained from the tensile test for the sample with 0% moisture in machine direction

S.NO	Amax (mm)	Fmax N	W J
1	14.73	894.22	11.1
2	17.36	917.83	13.78
3	18.61	1002.51	16.17
4	18.31	849.9	14.03
5	17.05	955.69	13.97
Average	17.212	924.03	13.81

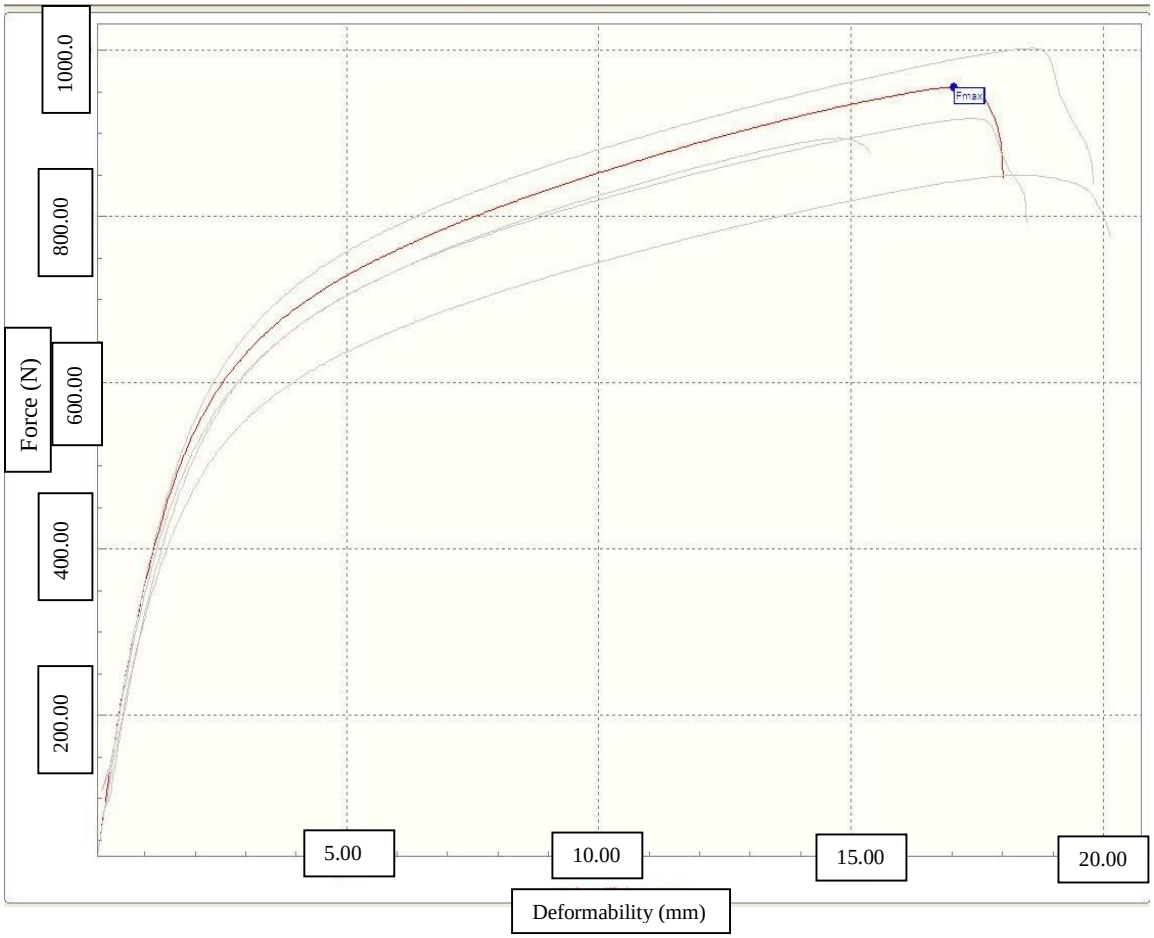

Figure 22: graph shows the relation between Force max(N) and deformability(mm) in tensile test for the sample with 0% moisture in machine direction.

CROSS DIRECTION (0%)

Table 74: Results obtained from the tensile test for the sample with 0% moisture in cross direction

Index	Amax (mm)	Fmax N	W J
1	23.58	744.44	14.51
2	23.77	714.27	14.47
3	22.68	708.36	14.62
4	20.08	846.85	13.84
5	22.48	944.55	17.74
Average	22.518	791.694	15.036

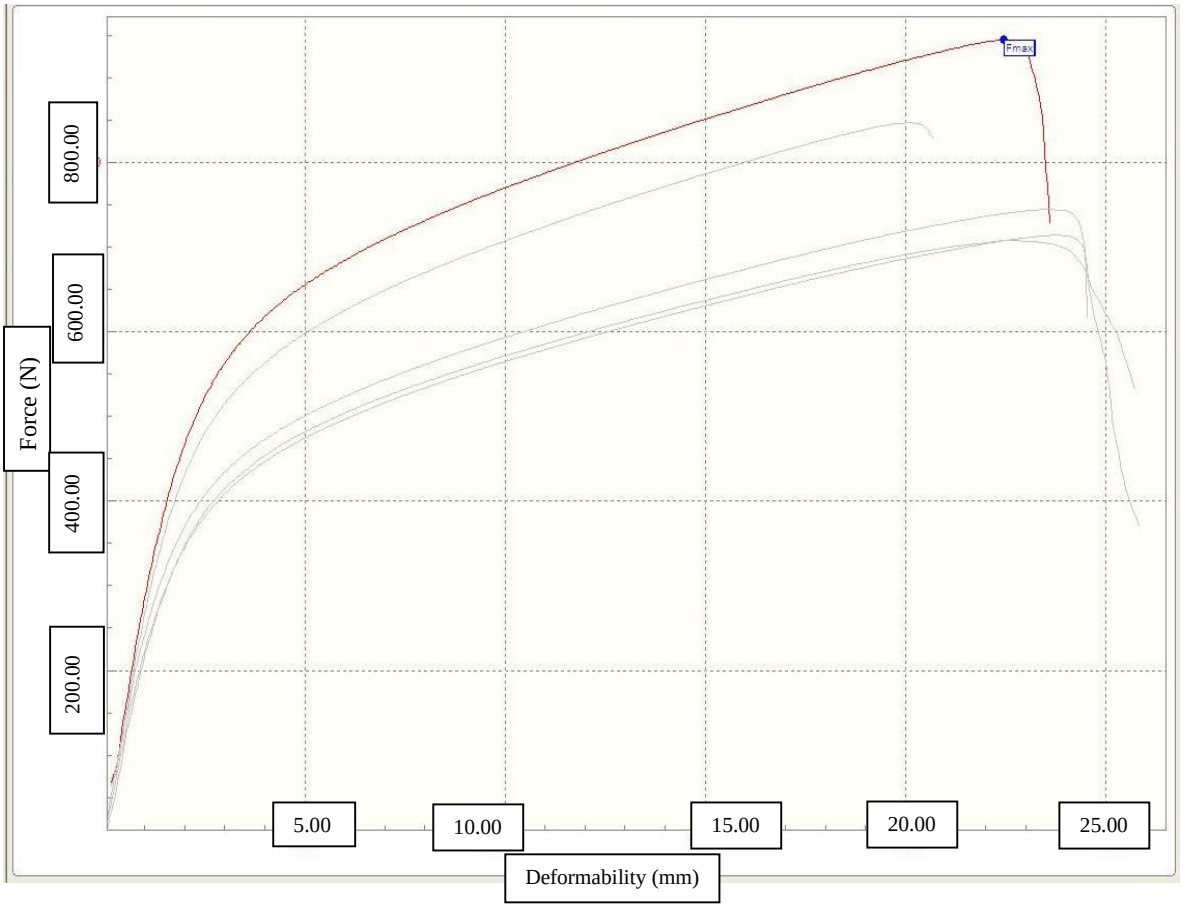

Figure 23: graph shows the relation between Force max(N) and deformability(mm) in tensile test for the sample with 0% moisture in cross direction

MACHINE DIRECTION (10%)

Table 75: Results obtained from the tensile test for the sample with 10% moisture in machine direction

Index	Amax (mm)	Fmax N	W J
1	18.98	842.92	13.96
2	13.87	852.17	9.9
3	15.59	1026.38	13.36
4	18.83	1030.89	16.37
5	13.63	842.24	11.54
Average	16.18	919.12	13.026

CROSS DIRECTION (10%)

Table 76: Results obtained from the tensile test for the sample with 10% moisture in cross direction

Index	Amax (mm)	Fmax N	W J
1	25.2	708.43	14.52
2	16.33	661.71	8.98
3	18.65	817.2	12.56
4	18.52	763.14	11.76
5	23.17	812.07	15.95
Average	20.374	752.51	12.754

MACHINE DIRECTION (20%)

Table 77: Results obtained from the tensile test for the sample with 20% moisture in machine direction

Index	Amax (mm)	Fmax N	W J
1	17.12	1083.1	15.56
2	16.98	839.12	12.51
3	14.58	1052.29	12.92
4	16.14	1015.6	14.66
5	16.97	1130.87	16.45
Average	16.358	1024.196	14.42

CROSS DIRECTION (20%)

Table 78: Results obtained from the tensile test for the sample with 20% moisture in cross direction

Index	Amax (mm)	Fmax N	W J
1	20.03	931.89	15.4
2	24.93	1084.01	21.68
3	22.44	985.79	18.89
4	20.1	700.15	12.15
5	19.96	755.06	12.67
Average	21.492	891.38	16.158

MACHINE DIRECTION (30%)

Table 79: Results obtained from the tensile test for the sample with 30% moisture in machine direction

Index	Amax (mm)	Fmax N	W J
1	15.09	757.04	10.1
2	14.76	695.21	10.28
3	19.92	731.87	13.0
4	17.72	1033.39	15.25
5	16.93	922.67	13.32
Average	16.884	828.036	12.39

CROSS DIRECTION (30%)

Table 80: Results obtained from the tensile test for the sample with 30% moisture in cross direction

Index	Amax (mm)	Fmax N	W J
1	23.32	831.55	16.31
2	18.81	744.76	12.26
3	17.09	707.13	10.34
4	23.22	891.75	17.08
5	24.81	890.65	18.04
Average	21.45	813.168	14.806

4.5.3 Tensile Test Analysis

So, to analyze the tensile strength results, the average for the force maximum (newton) for each and every sample in both the cross (30*28) and machine (28*30) direction were calculated. And for the different moisture levels (0%, 10%, 20%, 30%) the average and standard deviations is calculated and compared in the graph below.

Machine direction (28*30)

Table 81: Average and standard deviation values calculated for force max(N) according to their corresponding moisture levels in machine direction for tensile test

S.NO	Moisture level	Average	Standard deviation
1	0%	924.03	58.27
2	10%	918.92	100.24
3	20%	1024.19	111.76
4	30%	828.036	144.09

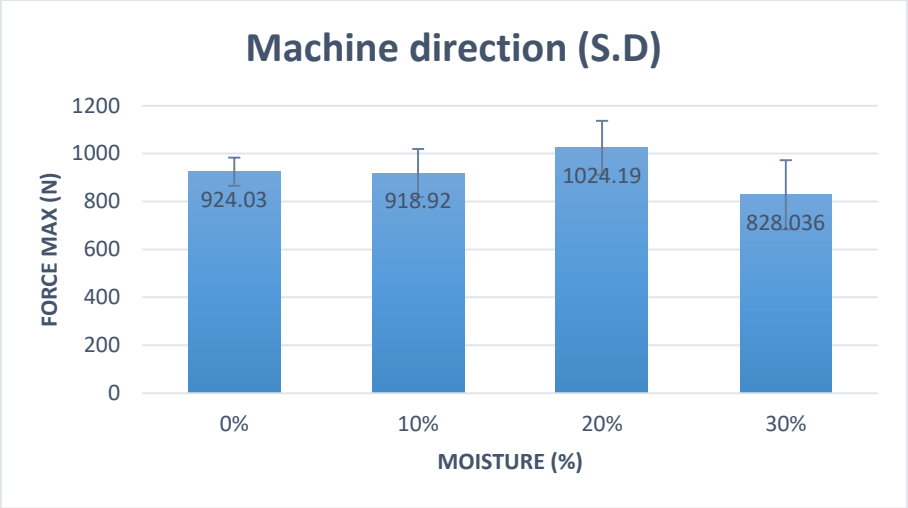

Figure 24: Graph shows the calculated average values of force max (N) and their standard deviation with respect to the different moisture levels in machine direction for tensile test.

From the above graph (fig 22), the force max value needed to stretch before the material breaks is relatively high in the sample with 20% moisture level. It shows the sample with 20% moisture level have higher strength and elasticity compared to other samples with different moisture levels. And sample with 0% and 10% is followed by that with little differences in their force max values. And sample with 30% have relatively weak elasticity in machine direction compared with other samples.

Cross direction (30*28)

Table 82: Average and standard deviation values calculated for force max(N) according to their corresponding moisture levels in cross direction for tensile test.

S.NO	Moisture level	Average	Standard deviation
1	0%	791.61	101.95
2	10%	752.51	67.14
3	20%	891.38	160.32
4	30%	813.16	84.32

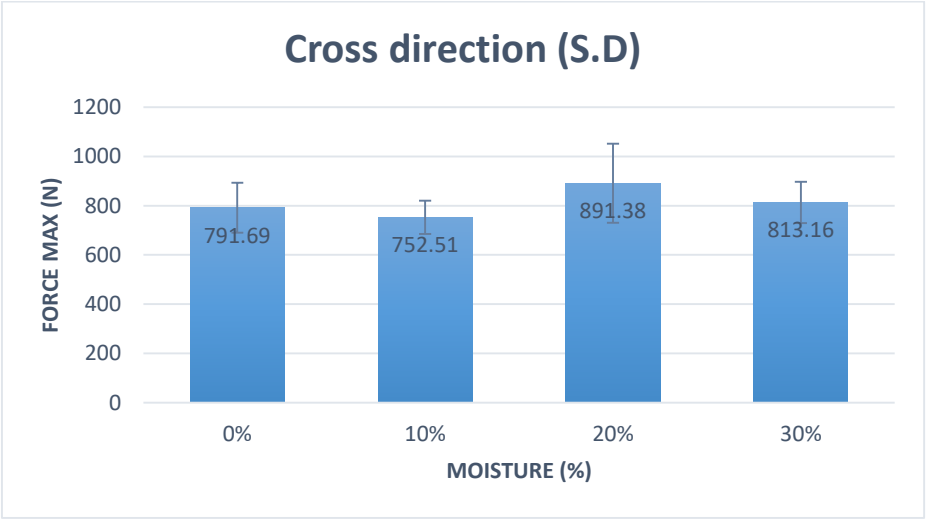

Figure 25: Graph shows the calculated average values of force max (N) and their standard deviation with respect to the different moisture levels in cross direction for tensile test.

From the above graph (fig 23), in cross direction also, the sample with 20% moisture have high force max values. It shows that this material can withstand high load and have high elongation compared to all other samples. But in cross direction, sample with 30%moisture level have good force max values and possess higher elongation compared with machine direction. Then it is followed by sample with 0% and 10% moisture levels respectively. And these two have relatively less strength and elongation in cross direction compared to other two samples.

MACHINE DIRECTION (28*30)

Table 83: Average and standard deviation values calculated for Amax (mm) according to their corresponding moisture levels in machine direction for tensile test.

S.NO	Moisture level	Average	Standard deviation
1	0%	17.21	1.53
2	10%	16.18	2.60
3	20%	16.35	1.06
4	30%	16.88	2.10

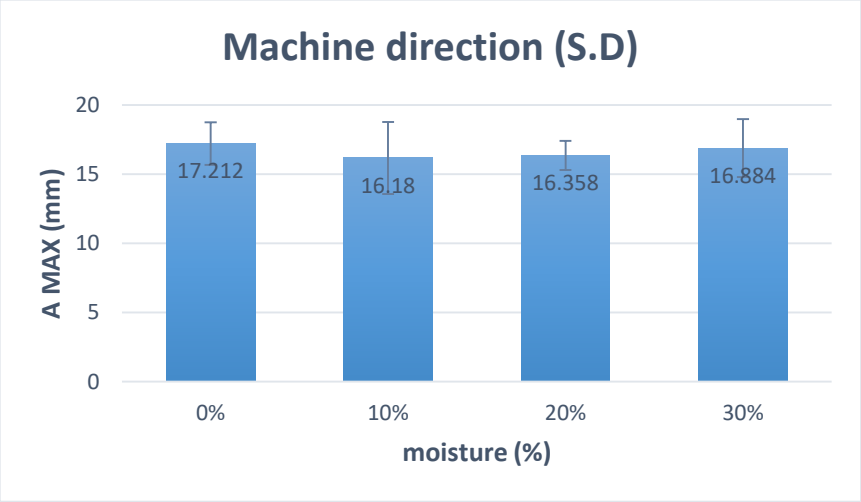

Figure 26: Graph shows the calculated average values of Amax(mm) and their standard deviation with respect to the different moisture levels in machine direction for tensile test.

From the above graph fig (24), the Amax (mm) values are relatively high for sample with 0%moisture, this shows that the deformability of the material is higher under a applied load in the sample with 0% moisture level. Then it is followed by sample with 30% moisture level, and the samples with 20% and 10% have very low deformations compared with other two in machine direction.

CROSS DIRECTION (30*28)

Table 84: Average and standard deviation values calculated for Amax(mm) according to their corresponding moisture levels in cross direction for tensile test.

S.NO	Moisture level	Average	Standard deviation
1	0%	22.51	1.47
2	10%	20.37	3.66
3	20%	21.49	2.18
4	30%	21.45	3.31

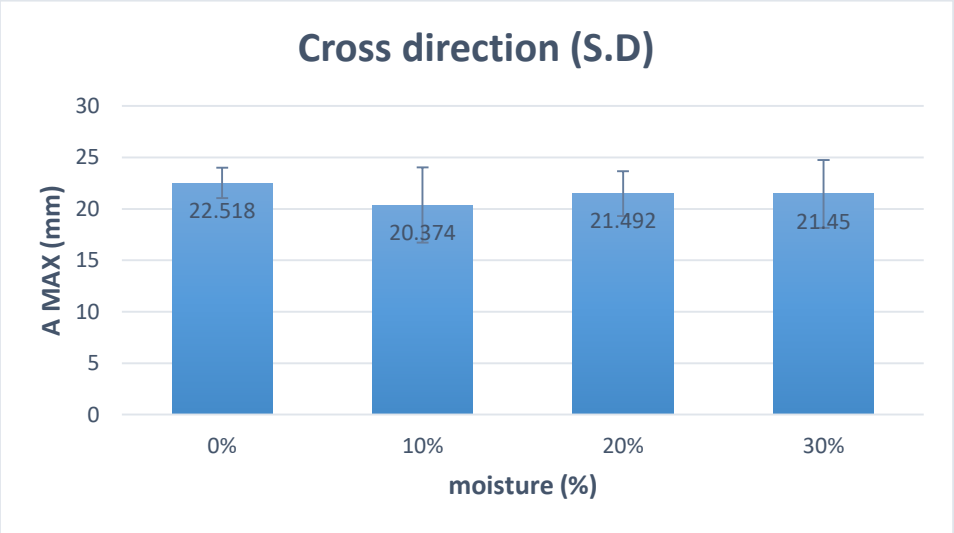

Figure 27: Graph shows the calculated average values of Amax(mm) and their standard deviation with respect to the different moisture levels in cross direction for tensile test.

From the above graph (fig 25), in cross direction also the Amax(mm) value for the sample with 0% moisture high compared to other samples. Followed by small differences with samples of 20%, 30% and 10% samples respectively. This shows that in both machine and cross direction there is not much differences in deformability values and sample with 0% have highest and sample with 10% possess lowest in both the direction.

MACHINE DIRECTION (28*30)

Table 85: Average and standard deviation values calculated for Work(joules) according to their corresponding moisture levels in machine direction for tensile test.

S.NO	Moisture level	Average	Standard deviation
1	0%	13.81	1.80
2	10%	13.02	2.45
3	20%	14.42	1.68
4	30%	12.39	2.18

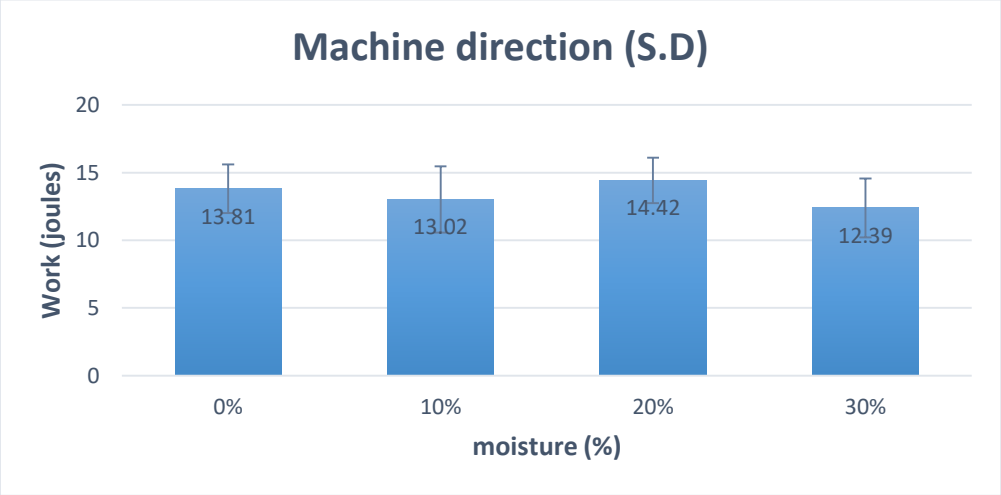

Figure 28: Graph shows the calculated average values of Work (joules) and their standard deviation with respect to the different moisture levels in machine direction for tensile test.

From the above graph (fig 26), the work done in (joules) is higher for the sample with 20% in machine direction. This shows that the material has high strength and elasticity, and it needs higher level of work done to break it compared with the other samples. Then it is followed by sample with 0% and 10% with small amount of differences in it. And sample with 30% is relatively weak in machine direction so the work done is relatively low compared with other samples.

CROSS DIRECTION (30*28)

Table 86: Average and standard deviation values calculated for Work(joules) according to their corresponding moisture levels in cross direction for tensile test.

S.NO	Moisture level	Average	Standard deviation
1	0%	15.03	1.54
2	10%	12.75	2.67
3	20%	16.15	4.08
4	30%	14.80	3.32

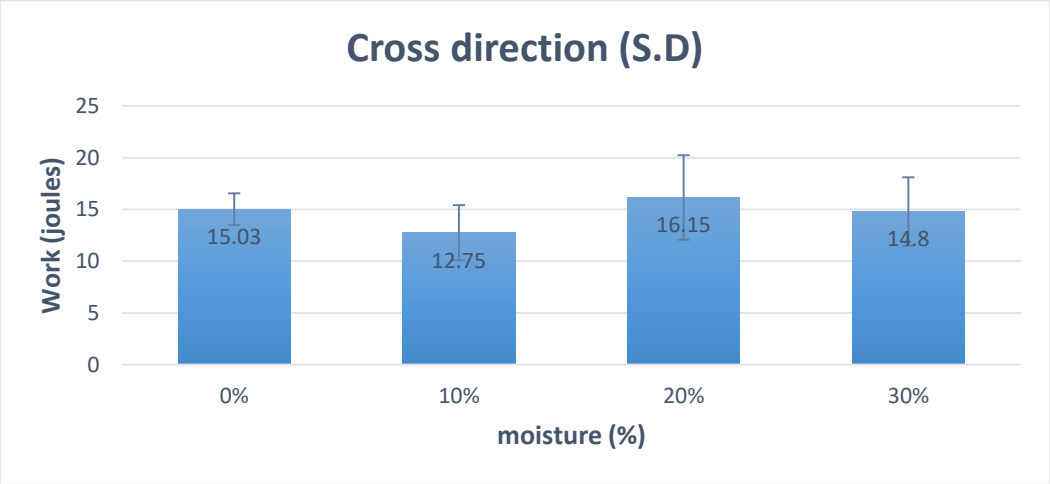

Figure 29: Graph shows the calculated average values of Work (joules) and their standard deviation with respect to the different moisture levels in cross direction for tensile test.

From the above graph (fig 27), in cross direction too, the sample with 20% possess high work done (in joules) values compared to other samples. It shows that the material with 20% have high strength and elasticity and work done is high in both the directions. Followed by the sample with 0% which have second higher values in both the directions. Then followed by sample with 30% and 10% which have lower values in cross direction.

4.6 THERMAL ANALYSIS:

After analyzing the tear strength results, the thermal analysis experiment was planned to know how the heat dissipates and evaporates from the sample of different moisture levels respectively. So thermal camera was used to proceed with this experiment. And for that the sample were prepared in the standard size (30*30) cm. totally 12 samples were prepared and for every moisture levels and thermal analysis was done with 3 samples respectively. So to start with, all the weights of the sample were measured one by one with respect to the different moisture levels respectively. And the weights of the samples are given in the tabular column below.

0% sample

Table 87: values of Initial and Final weight, for the samples with 0% moisture before and after pressing

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
1	72.6	71.2
2	70.2	69.2
3	75.1	73.8

10% sample

Table 88: values of Initial and Final weight, for the samples with 10% moisture before and after pressing

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
1	75.2	68.0
2	72.6	65.4
3	82.0	73.2

20% sample

Table 89: values of Initial and Final weight, for the samples with 20% moisture before and after pressing

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
1	82.6	68.4
2	84.8	71.2
3	86	73.2

30% sample

Table 90: values of Initial and Final weight, for the samples with 30% moisture before and after pressing

Sample	Initial weight (in grams)	Final weight (after pressing) (grams)
1	90.2	68.6
2	87.2	66.4
3	97.0	73.4

0%

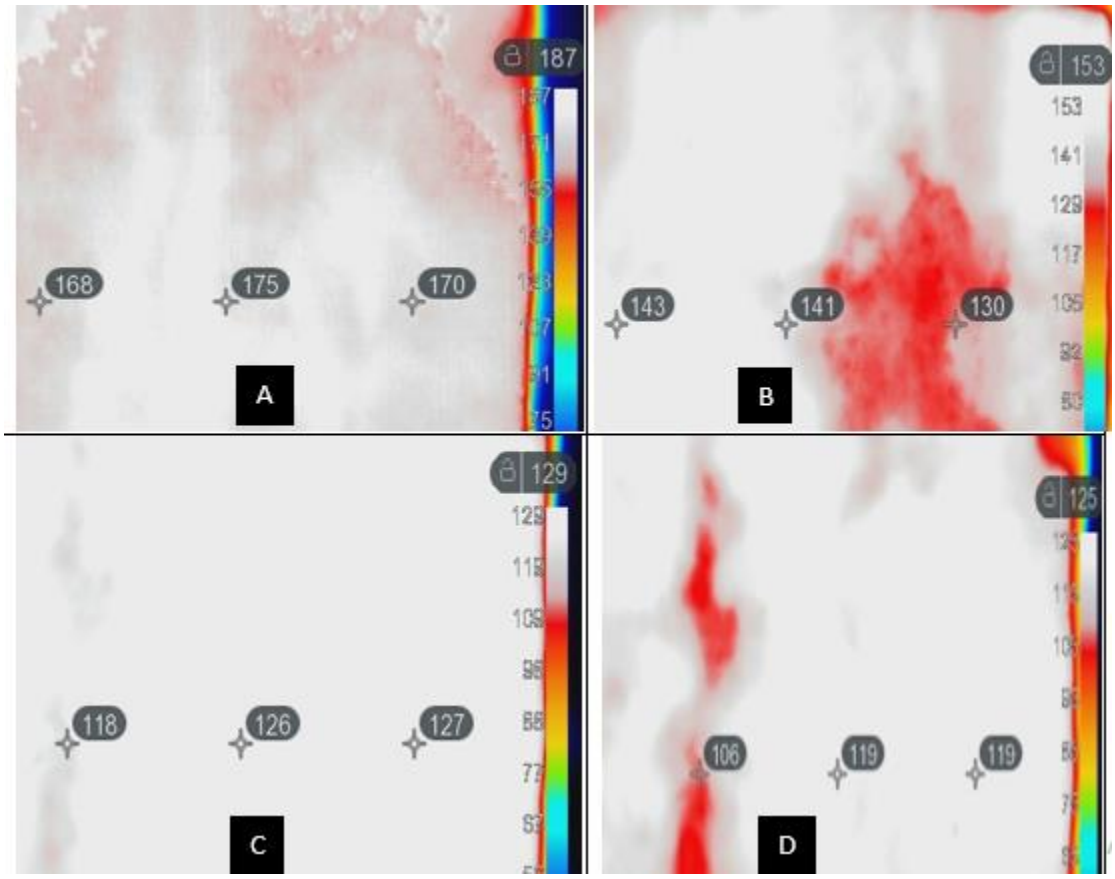

Figure 30: shows the pictures taken from the thermal camera at different time intervals for the 0% moisture sample.

10%

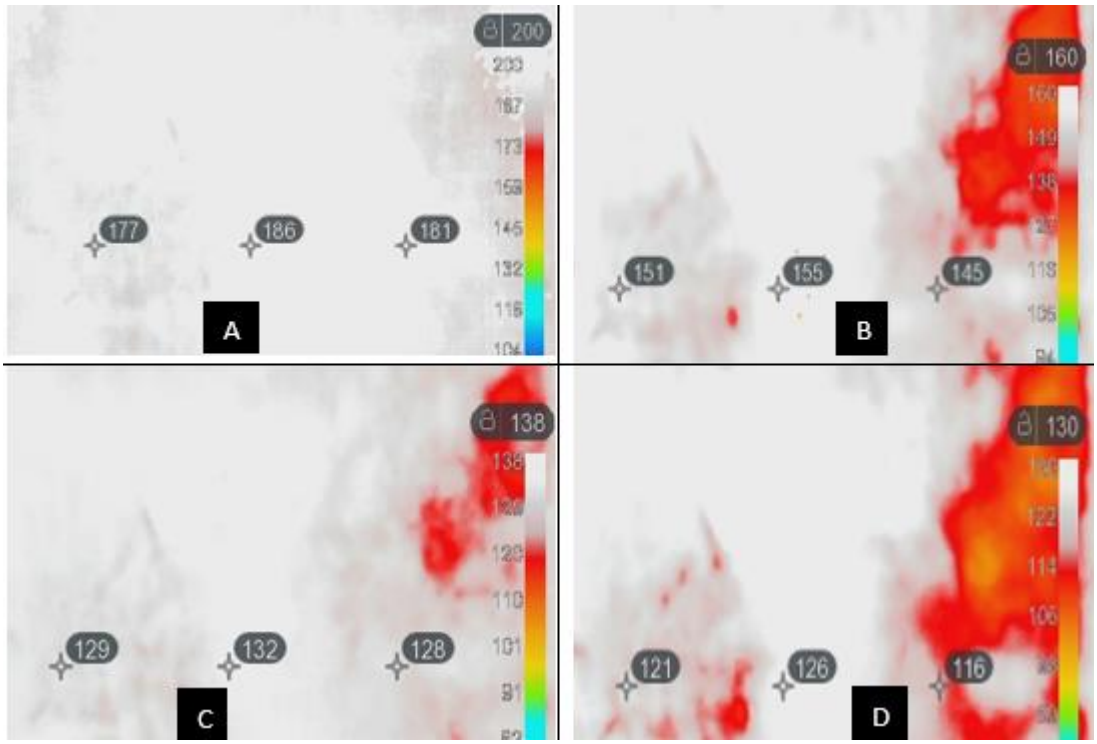

Figure 31: shows the pictures taken from the thermal camera at different time intervals for the 10% moisture sample.

20%

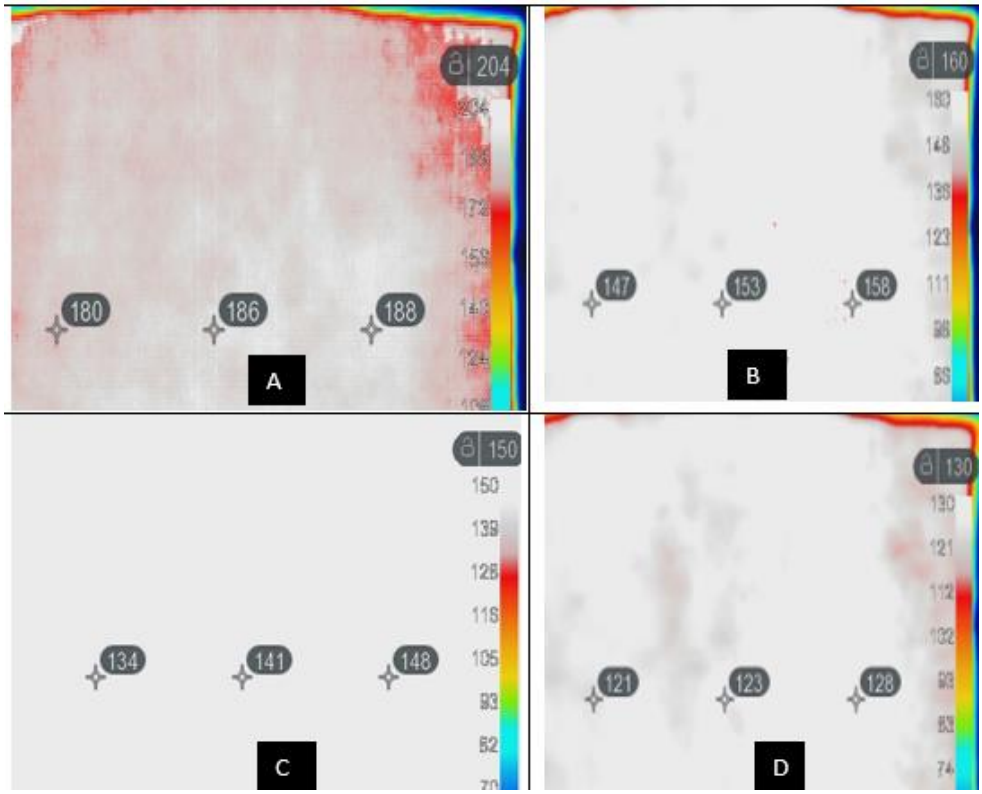

Figure 32: shows the pictures taken from the thermal camera at different time intervals for the 20% moisture sample.

30%

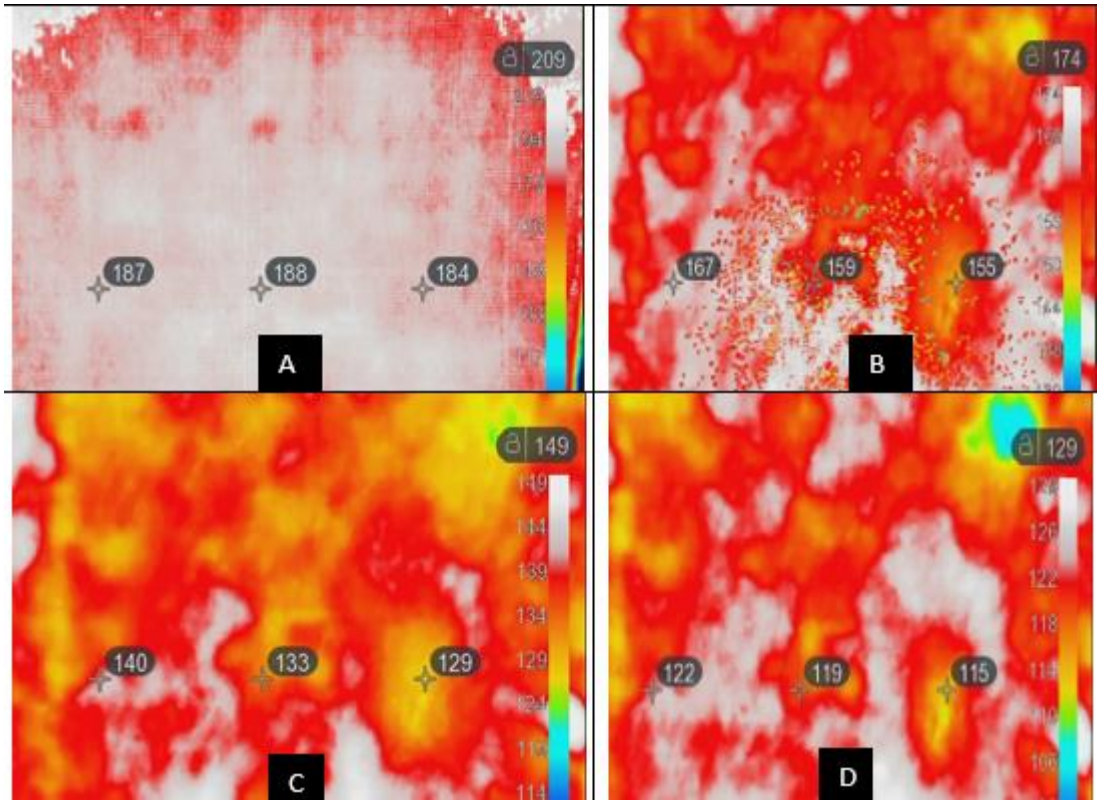

Figure 33: above shows the pictures taken from the thermal camera at different time intervals for the 30% moisture sample.

Table 91: shows the time interval and the respective temperatures of the sample at different moisture levels.

	15 seconds	30 seconds	45 seconds	60 seconds
Sample 0%	187℃	153℃	129℃	125℃
Sample 10%	200℃	160℃	138℃	130℃
Sample 20%	204℃	160℃	150℃	130℃
Sample 30%	209℃	174℃	149℃	129℃

The procedure of doing this experiment are, first the sample should be prepared and wetted according to their respective moisture levels and kept separately. Then the initial weight of the sample should be noted down. And then the sample is kept in the hot pressing machine about one minute at temperature of 225℃. Then the sample is taken out immediately and placed in the wooden block. and using the thermal camera the pictures are taken at different time intervals within a minute. With that pictures the heat dissipation from the different samples are analyzed accordingly.

From the pictures and the table above, it clearly indicates during the different time intervals how the heat gets dissipated from the samples of four different moisture levels. Starting from 0% moisture level, it shows the gradual decrease in temperature after taking it from the hot pressing machine at different time intervals. And also it is observed that, heat dissipates very faster and temperature decreases rapidly compared with the other samples. The heat dissipation from the moisture levels (10%, 20%) are little bit similar to each other when it is compared with respect to its temperature and time. and in both moisture levels heat dissipates in rate lower than that of 0% moisture level, and in 30% moisture level it is observed that heat dissipates at very low rate in the beginning and at last it begins to dissipates very fastly.

5 CONCLUSION:

This project is mainly based on the difficulties that was faced in the Ideal factory with the Recycled non-woven material which is used in the manufacturing of Automobiles. the major problem is due to the bad mechanical properties of this recycled non-woven material, that affects its performance in molding process and in end use. So it was planned to study the material mechanical properties with various moisture levels like 0%, 10%,20%, 30%, because these values represent humidity level that should be used. and it would be not suitable to mold samples that have 100% added weight in humidity. And we chose to study sample of dimensions 30*30 as we were able to mold them and study them in our lab in suitable conditions.

Totally, two tests were carried out with the Recycled non-woven material which was brought from the ideal factory. First test was the 3-point bending test; this test is mainly used for finding the stiffness of the material. So with samples of 4 different moisture levels namely 0%, 10%, 20%, 30% were used for this bending test. The force (F max) in newton (N) was calculated separately for the different moisture levels separately. From the graph, of force (Fmax) the down trend line can be seen from the moisture level starting from 0% to 20% in machine direction. But the 30% moisture level have the Fmax value slightly different and high than that of other moisture levels. This is because the sample was not homogenous, and not selected precisely. So this may be factor affecting its Fmax value in machine direction. As it was not homogenous and material have different fiber compositions, the fiber orientation of the 30% moisture sample also varies, and also, the natural fibers that are randomly positioned in the sample have different properties (and also, it absorbs moisture a lot) which may cause some irregularities in the sample. And this material was also filled with plastic fibers which may distributed unevenly may also cause irregularities in the sample.so it can also influence the F max values of this sample. But in cross direction the Fmax values followed a down trend line starting from 0% to 30%. But the values of 20% moisture sample was high then 10% with difference of very small amount in cross direction. And 30% sample has low force values compared to the other moisture levels. From analyzing the force values on both direction, the result shows that the 0% moisture level sample have the very high force values in both the machine and cross direction, and also the values were also almost equal in both the directions. This shows that the sample with 0% moisture were stiffer than the other moisture level materials. Although the material looks brittle the stiffness of the material is good compared with other materials. And from this test, it shows the 0% moisture material can also withstand high loads, as it has high stiffness values compared to the other samples.10% and 20% moisture level samples have the second and third high stiffness values following the 0% moisture level samples. And these two moisture levels also have same force values in both machine and cross direction. At last comes the 30% moisture level sample having totally different force values in both directions. So from the 3-point bending test, it is clear that sample with low moisture level and maintained in the normal atmospheric conditions have the better stiffness values than that of the samples with more moisture in it.

The second test is the tensile test, which determines the strength and elongation properties of the material. From the four samples of different moisture levels, the graphs are plotted individually for the force (in newton), from the graph it is clear to understand that the moisture with 20% samples withstands higher force then the other moisture level samples in both the machine and cross direction. And also it is clear that in machine direction the fiber orientation is very good as it requires more force to break for all the moisture level samples compared with that of the cross direction. And the elongation of samples is lower in machine direction compared with that of the cross direction. From the values in the graph, it is evident that 20% moisture samples have good strength and mechanical properties, followed by the sample with 0% moisture level sample and closely to that comes 10% moisture level sample. And in 30% moisture level sample, have a huge difference in strength compared with the 20% moisture level sample in machine direction. And it shows that the samples with 30% moisture content are relatively weak in their strength compared to other samples. So as the moisture level increases, it has a direct influence on fiber to fiber friction, so with moisture level 30% the material becomes very weak as the result of friction between the fiber increases. So moisture level 30% or above 30% is not suitable for industrial use and these materials are relatively weak with their mechanical strength compared to other moisture level samples. But the moisture with 20% samples possess very good mechanical strength, and as the materials are made up of recycled fibers of different compositions, it is evident that the materials are having higher percentage of natural fibers in it. Because the mechanical properties of natural fiber increases with increase in moisture percentage. And as result it is evident that 20% is good in mechanical properties on both machine and cross directions then the other moisture level samples.

And while considering the A max value in tensile test, it looks similar for all moisture level samples having a very little differences in both the machine and cross directions respectively. And also from the graph, it is evident that it follows the similar trend line in both machine and cross directions.

So from both the tests, it is evident that moisture levels with 0%, 10% and 20% performs well in both the machine and cross directions and have good mechanical properties than that of 30% moisture sample. The deviations of 30% moisture sample were relatively high compared to other samples in both the directions, so it cannot be considered as material having good mechanical properties. And the values of 0%,10% and 20% have values very close to each other in both directions and it is considered that the material within this moisture level can have good mechanical properties.

Additional to this test, thermal analysis was also done to find out how fast the heat dissipates from the material having different moisture level 0%,10%,20%,30% respectively. From the study it is found that from sample having 0% moisture level cools down faster than that of other samples with different moisture levels. 10% and 20% samples cools down little bit slower than that of 0% moisture level. And 30% moisture level sample has comparatively low rate of cooling than that of other samples. when 0% moisture level sample is placed in room temperature after heating, the natural fibers in the material tend to absorb more moisture from the surroundings, as the result it cools down faster than the other samples. But the other samples with little moisture in it already will not absorb the more moisture from the surroundings, as the result it

cools down slower than that of 0% moisture level sample. And if this test is done with larger sample size, then more detailed results can be obtained from this thermal analysis in future.

6 FUTURE WORK:

In the future work, it is important to study and test the sample with moisture level within 20%. It is better to take more tests and study about the samples having moisture level in between 10% and 20%. Like the samples with 12%, 15%, 18% moisture level can still show some good improved mechanical properties compared to this set of samples. And also the sample with 5% of moisture level can be also be tested for getting clear idea about the influence of moisture in this materials.

And also in future, it will be also better to test the materials with larger size samples, the samples we tested here were relatively small in size so that we could not find more difference in test results. As the materials are not homogenous, it is better to do study and do test with larger size samples, which can give better and more accurate results, as it also helps for industrial purpose too. Because in industries they will deal mostly with larger set of materials for pressing and molding. So by doing test with larger samples it can provide more information and accurate results for the automotive industries.

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SUPPLIMENTRY MATERIALS:

The tables below present the calculations for finding out the effective thermal conductivity.

Table 92: Thickness(mm) value of the samples.

	Thickness (mm)
Sample 1	7.1333333
Sample 2	7.0666666
Sample3	7.3666666
Sample4	7.0666666
Sample5	7.2666666
Average(mm)	7.18
Thickness in (m)	0.00718

Then the corresponding values of U1 voltage for the five samples are taken respectively. And their values are as follows.

Table 93: Values of U1(mv) voltage of the samples

	U1(mv)
Sample 1	1.56
Sample 2	1.68
Sample 3	1.617
Sample 4	1.55
Sample 5	1.54

Then, immediately we switch to channel 105 and note down the values of U2 values. And their readings are noted respectively.

Table 94: values of U2(mv) voltage of the samples

	U2 (mv)
Sample 1	0.157
Sample 2	0.153
Sample 3	0.149
Sample 4	0.142
Sample 5	0.135

From the above values, we calculated the values of ΔT

$$\Delta T = 25.2 * U2 - 0.1504$$

$$\lambda = 15.94 * U1(mv). \frac{L(m)}{\Delta T \ \ (C)}$$

Table 95: calculated value of ΔT for the samples from the above equation.

	$\Delta T = 25.2 * U2 - 0.1504$
Sample 1	39.1616
Sample 2	42.1856
Sample 3	4.0598
Sample 4	38.9096
Sample 5	38.6576
Average	39.90248

Then with the known value of U1, we can calculate $\frac{Q}{A.t}$

Using the formula Q/ (A.t) = 15.94. U1, the value are as follows

$$\lambda = 15.94 * U1(mv). \frac{L(m)}{\Delta T \ \ (C)}$$

Table 96: Calculated values of heat transfer for the samples

	Q/ (A.t)
Sample 1	24.8664
Sample 2	26.7792
Sample 3	25.77498
Sample 4	24.707
Sample 5	24.5476
Average	25.33504

Then from this values we calculated, we can calculate the value of

$$\lambda = 15.94 * U1(mv). \frac{L(m)}{\Delta T \ (C)}$$

Table 97: Calculated values of heat conductivity for the samples

	λ
Sample 1	0.004559
Sample 2	0.004558
Sample 3	0.004558
Sample 4	0.004559
Sample 5	0.004559
Average	0.004559

Then, with the help of this value we got from above table, we found the value of thermal Resistance (R) of that material.

$$R = \frac{L(m)}{\lambda}$$

Table 98: Calculated values of thermal resistance for the samples

	Thermal resistance – R
Sample 1	1.57488016
Sample 2	1.575312183
Sample 3	1.575093366
Sample 4	1.574841138
Sample 5	1.57480161
Average	1.574985691

BENDING TEST:

D2 10%(30 *28) (C.D)

Table 99: values measured for finding thickness for 10% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.46	1.5	1.52	1.493
Sample 2	1.42	1.5	1.44	1.453
Sample 3	1.39	1.4	1.42	1.403
Sample 4	1.36	1.38	1.35	1.363
Sample 5	1.32	1.34	1.35	1.336
Sample 6	1.33	1.35	1.36	1.346
Sample 7	1.33	1.35	1.37	1.35
Sample 8	1.39	1.4	1.43	1.406
Sample 9	1.49	1.53	1.54	1.52
Sample 10	1.62	1.67	1.72	1.67
Sample 11	1.93	1.97	1.94	1.946
Sample 12	1.54	1.55	1.57	1.55
Sample 13	1.66	1.65	1.63	1.646

Table 100: values measured for finding width for 10% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	20.78	20.74	20.94	20.82
Sample 2	20.17	20.28	20.48	20.31
Sample 3	18.81	19.06	19.1	18.99
Sample 4	20.07	20.14	20.24	20.15
Sample 5	21.63	21.9	21.81	21.78
Sample 6	19.7	19.79	19.82	19.77
Sample 7	19.04	19.2	19.51	19.25
Sample 8	20.69	20.83	21.14	20.88
Sample 9	19.89	19.96	19.99	19.94
Sample 10	20.68	20.71	20.73	20.70
Sample 11	20.93	20.9	20.77	20.86
Sample 12	19.57	19.43	19.48	19.49
Sample 13	19.58	19.74	19.84	19.72

C6 10% (28*30) (M.D)

Table 101: values measured for finding thickness for 10% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.95	1.98	1.99	1.97
Sample 2	1.9	1.94	1.96	1.93
Sample 3	1.92	1.9	1.94	1.92
Sample 4	1.9	1.92	1.93	1.91
Sample 5	1.89	1.9	1.92	1.90
Sample 6	1.88	1.91	1.96	1.91
Sample 7	1.88	1.96	1.92	1.92
Sample 8	1.87	1.88	1.9	1.88
Sample 9	1.81	1.84	1.88	1.84
Sample 10	1.79	1.8	1.82	1.80
Sample 11	1.75	1.79	1.82	1.78
Sample 12	1.95	1.99	2	1.98

Table 102: values measured for finding width for 10% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	20.4	20.63	20.8	20.61
Sample 2	18.47	18.69	18.79	18.65
Sample 3	21.4	21.46	21.62	21.49
Sample 4	20.37	20.4	20.11	20.29
Sample 5	22.58	22.65	22.71	22.64
Sample 6	20.09	20.13	20.02	20.08
Sample 7	20.41	20.49	20.68	20.52
Sample 8	19.46	19.6	19.66	19.57
Sample 9	20.04	20.11	20.32	20.15
Sample 10	18.29	18.4	18.32	18.33
Sample 11	19.96	20	20.2	20.05
Sample 12	19.35	19.31	19.34	19.33

D6 20% (30*28) (C.D)

Table 103: values measured for finding thickness for 20% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.86	1.83	1.81	1.833
Sample 2	1.82	1.84	1.86	1.84
Sample 3	1.86	1.87	1.91	1.88
Sample 4	1.88	1.9	1.93	1.90
Sample 5	1.93	1.94	1.96	1.94
Sample 6	1.95	1.93	1.97	1.95
Sample 7	1.95	1.96	1.97	1.96
Sample 8	1.95	1.98	1.96	1.96
Sample 9	1.96	1.98	1.99	1.97
Sample 10	1.77	1.8	1.79	1.78
Sample 11	2.13	2.18	2.11	2.14
Sample 12	2.07	2.08	2.1	2.08

Table 104: values measured for finding width for 20% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	21.37	21.39	21.45	21.40
Sample 2	20.67	20.84	20.92	20.81
Sample 3	20.05	20.13	20.2	20.12
Sample 4	20.93	21.14	21.04	21.03
Sample 5	18.57	18.71	18.8	18.69
Sample 6	22.69	22.37	22.4	22.48
Sample 7	19.03	19.07	19.11	19.07
Sample 8	20.48	20.53	20.35	20.45
Sample 9	20.43	20.61	20.1	20.38
Sample 10	19.11	19.4	19.52	19.34
Sample 11	18.22	18.36	18.84	18.47
Sample 12	20.85	20.84	20.91	20.86

C7 20% (28*30) (M.D)

Table 105: values measured for finding thickness for 20% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.03	2.04	2.08	2.05
Sample 2	2.07	2.08	2.09	2.08
Sample 3	2.06	2.08	2.09	2.07
Sample 4	2.04	2.05	2.07	2.05
Sample 5	2.06	2.08	2.1	2.08
Sample 6	2.02	2.05	2.07	2.04
Sample 7	2.04	2.05	2.1	2.06
Sample 8	2.03	2.08	2.07	2.06
Sample 9	2.02	2.05	2.06	2.04
Sample 10	2.05	2.07	2.06	2.06
Sample 11	1.96	2.01	2.04	2.00
Sample 12	2.03	2.02	2.07	2.04

Table 106: values measured for finding width for 20% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	21.53	21.67	21.71	21.63
Sample 2	19.97	19.87	19.92	19.92
Sample 3	21.45	21.6	21.53	21.52
Sample 4	20.75	20.79	20.85	20.79
Sample 5	19.7	19.76	19.82	19.76
Sample 6	20.75	20.84	21.03	20.87
Sample 7	20.94	21.15	21.17	21.08
Sample 8	21.42	21.31	21.38	21.37
Sample 9	18.99	19.07	19.22	19.09
Sample 10	20.68	20.89	21	20.85
Sample 11	19.11	19.17	19.33	19.20
Sample 12	19.63	19.97	20.03	19.87

10A 28*30 (30%) (M.D)

Table 107: values measured for finding thickness for 30% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.1	2.11	2.12	2.11
Sample 2	1.98	1.99	1.96	1.97
Sample 3	2.1	2.12	2.08	2.1
Sample 4	2.09	2.14	2.12	2.11
Sample 5	1.98	2.0	1.96	1.98
Sample 6	2.08	2.10	2.16	2.11
Sample 7	2.07	2.08	2.1	2.08
Sample 8	2.05	2.06	2.07	2.06
Sample 9	1.99	2.0	2.03	2.00

Table 108: values measured for finding width for 30% moisture sample in machine direction.

	Value 1	Value 2	Value 3	Width(mm)
Sample 1	21.01	21.2	21.36	21.19
Sample 2	20.4	20.68	20.47	20.51
Sample 3	19.8	20	20.02	19.94
Sample 4	19.4	19.59	19.46	19.48
Sample 5	19.25	19.36	19.43	19.34
Sample 6	21.72	21.84	21.91	21.82
Sample 7	20.16	20.2	20.32	20.22
Sample 8	20.72	20.84	21.04	20.86
Sample 9	19.65	19.58	20.02	19.75

9B 30*28 (30%) (C.D)

Table 109: values measured for finding thickness for 30% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.12	2.14	2.15	2.13
Sample 2	2.08	2.07	2.11	2.08
Sample 3	2.02	2.05	2.06	2.04
Sample 4	2.01	2.04	2.05	2.03
Sample 5	2.0	2.1	2.3	2.13
Sample 6	2.0	2.1	2.2	2.1
Sample 7	1.96	1.97	2.0	1.97
Sample 8	1.95	1.96	1.93	1.94
Sample 9	1.93	1.9	1.87	1.9

Table 110: values measured for finding width for 30% moisture sample in cross direction.

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	20.05	20.09	20.27	20.13
Sample 2	20.37	20.61	20.55	20.51
Sample 3	19.31	19.46	19.66	19.47
Sample 4	20.10	20.12	20.16	20.12
Sample 5	19.31	19.57	19.48	19.45
Sample 6	21.81	21.91	21.96	21.89
Sample 7	20.18	20.3	20.40	20.29
Sample 8	20.68	20.78	20.81	20.75
Sample 9	19.36	19.41	19.10	19.29

TENSILE STRENGTH:

28*30 (10%)

Table 111: Values measured for thickness in 10% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.01	1.97	2.05	2.01
Sample 2	1.93	1.9	1.82	1.88
Sample 3	1.99	1.94	1.9	1.94
Sample 4	1.91	1.97	2.06	1.98

Table 112: Values measured for width in 10% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.57	5.52	5.3	5.46
Sample 2	4.93	4.8	4.98	4.90
Sample 3	4.86	4.96	5	4.954
Sample 4	5.13	5.09	4.96	5.06

Table 113: Values measured for thickness in 10% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.86	1.9	1.88	1.88
Sample 2	1.82	1.89	1.94	1.88
Sample 3	1.93	1.85	1.85	1.87

Table 114: Values measured for width in 10% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.11	5.07	5.09	5.09
Sample 2	4.84	4.97	5.08	4.96
Sample 3	4.7	4.63	4.58	4.63

30*28 (10%)

Table 115: Values measured for thickness in 10% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2	2.01	1.99	2
Sample 2	2.13	2.08	2.07	2.09
Sample 3	1.95	2.02	1.94	1.97

Table 116: Values measured for width in 10% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.13	5.01	4.96	5.03
Sample 2	5.21	5.14	5.07	5.14
Sample 3	4.93	5.03	5.05	5.00

Table 117: Values measured for thickness in 10% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.23	2.1	2	2.11
Sample 2	2.23	2.18	2.13	2.18
Sample 3	2.19	2.09	2.14	2.14

Table 118: Values measured for width in 10% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.1	5.14	5.13	5.12
Sample 2	5.19	5.07	5.07	5.11
Sample 3	4.97	4.97	5.07	5.00

28*30 (20%)

Table 119: Values measured for thickness in 20% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.91	1.99	2.02	1.97
Sample 2	1.84	1.94	1.84	1.87

Table 120: Values measured for width in 20% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.11	5.16	5.21	5.16
Sample 2	5.0	4.99	5.03	5.0

Table 121: Values measured for thickness in 20% samples for tensile test in machine direction

	Value 1	Value2	Value 3	Thickness (mm)
Sample 1	1.98	1.94	1.96	1.96
Sample 2	2.01	1.99	1.95	1.98
Sample 3	1.99	1.96	1.92	1.95
Sample 4	2.06	2.02	1.96	2.01

Table 122: Values measured for width in 20% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.35	5.27	5.19	5.27
Sample 2	4.74	4.75	4.88	4.79
Sample 3	4.96	4.99	5.04	4.99
Sample 4	5.04	5.03	4.99	5.02

30*28 (20%)

Table 123: Values measured for thickness in 20% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.08	2.08	2.03	2.06
Sample 2	2.10	2.15	2.15	2.13

Table 124: Values measured for width in 20% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	4.78	4.79	4.85	4.80
Sample 2	4.76	4.77	4.86	4.79

Table 125: Values measured for thickness in 20% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.04	2.02	2.06	2.04
Sample 2	1.99	2	1.99	1.99
Sample 3	1.94	1.87	1.91	1.90
Sample 4	1.93	1.9	1.97	193

Table 126: Values measured for width in 20% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.14	5.17	5.16	5.15
Sample 2	5.45	5.46	5.45	5.45
Sample 3	5.07	5.07	5.1	5.08
Sample 4	5.1	4.86	4.89	4.95

28*30 (30%)

Table 127: Values measured for thickness in 30% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.06	2.02	1.98	2.02
Sample 2	2.04	2.01	1.93	1.99
Sample 3	2.09	2.04	1.95	2.02
Sample 4	2.02	1.98	1.93	1.97

Table 128: Values measured for width in 0% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	4.98	5.01	5.06	5.01
Sample 2	5.32	5.23	5.21	5.25
Sample 3	4.82	4.8	4.83	4.81
Sample 4	4.95	5.18	5.18	5.10

Table 129: Values measured for thickness in 30% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.88	1.96	1.98	1.94
Sample 2	1.87	1.91	2.01	1.93
Sample 3	1.95	2.03	2.12	2.03

Table 130: Values measured for width in 30% samples for tensile test in machine direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	5.17	5.21	5.19	5.19
Sample 2	4.97	5.1	5.08	5.05
Sample 3	4.96	4.95	4.97	4.96

30*28 (30%)

Table 131: Values measured for thickness in 30% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	2.07	2	1.99	2.02
Sample 2	1.93	2.08	1.95	1.98
Sample 3	2.08	2.08	2.12	2.09

Table 132: Values measured for width in 30% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Width (mm)
Sample 1	4.64	4.86	4.97	4.82
Sample 2	5.06	5.05	4.94	5.01
Sample 3	5.23	5.2	5.12	5.18

Table 133: Values measured for thickness in 30% samples for tensile test in cross direction

	Value 1	Value 2	Value 3	Thickness (mm)
Sample 1	1.91	1.94	1.95	1.93
Sample 2	1.88	1.85	1.9	1.87
Sample 3	2.06	2.08	2.07	2.07

Table 134: Values measured for width in 30% samples for tensile test in cross direction

	Value 1	Value 2	Value3	Width (mm)
Sample 1	5.01	5.01	5.07	5.03
Sample 2	5.27	5.2	5.18	5.21
Sample 3	5.36	5.22	5.13	5.23