Title: Investigating the Interplay: Fiber Properties and Chemical Interactions in Wet Wipes

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ABSTRACT

Wet wipes are widely used across various sectors due to their convenience and popularity. Understanding the interaction between the fiber and solution formulation is crucial for maintaining product efficiency during shelf time until use. This research aims to investigate the effect of key ingredients on fiber degradation, which directly affects efficacy, and provide a reliable estimation of product lifetime using an accelerated test based on creep rupture. Additionally, amid the growing interest in substituting materials with eco-friendly alternatives, this study will explore possible options and examine the interactions of solutions with alternative biodegradable materials.

EXECUTIVE SUMMARY

Wipes are widely used in various sectors in wet and dry forms. Wet wipes can be employed either pre-wetted or on-demand, while pre-wetted wipes offer convenient usage, they also bring some challenges such as interaction between the solution formulation and the wipes which may lead to degradation and affect the efficacy and the lifetime of the product.

The objective of this project is: (1) to investigate the effect of key ingredients on the properties of the fiber, and (2) to examine relevant changes in the morphology and mechanical properties of the fiber.

For this purpose, an accelerated test method will be designed based on creep rupture while exposing the fibers to various types of formulations. This method aims to provide an estimated failure statistics of the fibers based on the Weibull distribution and to identify solutions to reduce or eliminate the impact of formulations on the properties of the fiber (Pourdeyhimi, 1987).

Tests will be conducted using hydrolytic degradation methods, employing mechanical testing (tensile strength) to identify degradation. Additionally, scanning electron microscopy will be utilized to observe changes in the surface layer of fibers resulting from degradation.

Given the increasing environmental concerns and the growing interest in substituting conventional polymers with biodegradable materials like cotton, hemp, PLA, PBS, etc., this study will explore the feasibility of using a suitable biodegradable material as a wet wipe substrate. Additionally, it will investigate potential interactions with formulations to provide an eco-friendly material with a reasonable lifetime.

Currently, the first stage of the timeline, which involves completing the literature review and patent landscape analysis, is in progress. Following the selection of fibers and formulations of interest, the next stage of the project will commence, which involves initiating the static degradation study.

INTRODUCTION

A wet wipe is a cleaning product consisting of an absorbent delivery substrate saturated with a solution formulation. The substrate can be made of nonwoven fabric and serves as the medium for delivering the cleaning solution. The formulation, which saturates the substrate, comprises various components depending on the intended application. It typically includes purified water as a solvent, along with preservatives, surfactants, pH adjusters, skin-benefiting agents, and other additives.

In this study, the focus is on investigating the degradation mechanisms of wet wipes and proposing strategies to enhance their performance and sustainability. Objectives include analyzing the impact of key ingredients on fiber properties, examining changes in morphology and mechanical properties, and identifying ways to mitigate formulation effects. Additionally, an accelerated test method based on creep rupture will be developed to estimate failure time reliably. The literature review underscores the importance of substrate and formulation selection in achieving optimal wipe performance.

OBJECTIVES

In order to provide a reliable statistic failure time of wet wipes an accelerated test method will be employed based on creep rupture coupled with immersion in formulation:

- To investigate the impact of key ingredients on the properties of the fibers including biodegradable alternatives
- To examine changes in the morphology and mechanical properties of the fiber to pinpoint the i=underlying of degradation mechanism
- Identify ways to reduce the impact of the formulation on the properties of the fiber of interest.

Literature Review

Wipes

Consumers expect wipes to absorb, retain, or release dust or liquid as needed, Wiping encompasses rubbing with something soft for cleaning purposes. Wipes, which can be paper, tissue, or nonwoven, involve gentle friction to remove dirt or liquid from surfaces (Rengasamy, 2014).

The substrate, is often a nonwoven fabric, ranging from 40 to 60 g/m^2, produced using various web formation methods such as spunlace (representing 49% of the market), air-laid, wet-laid, meltblown, spunbond, spunbond meltblown spunbond (SMS), CoForm, and bonding techniques including hydroentangling, needle punching & thermal bonding. Nonwoven fabrics manufactured through the spunlace process are known for their softness and flexibility (Cheriaa & Boubaker, 2022; Rengasamy, 2014).

Nonwoven sheets are composed of a blend of natural fibers (pulp, cotton, bamboo etc), synthetic fibers (regenerated viscose, lyocell, PP, PET, ETC), or a combination of both. Synthetic fibers encompass materials derived from petrochemical products among which polypropylene and polyester are the most common ones used in wipes. (Cheriaa & Boubaker, 2022; Durukan & Karadagli, 2019). The web formation process, bonding, and surface texturing is crucial for attaining the desired characteristics of wiping products (Rengasamy, 2014).

There are various categorization for wipes, they can be classified as disposable or semi-durable. Disposable wipes are designed for single-use purposes, providing advantages such as preventing contaminant transition through surfaces, while semi-durable ones can be employed for limited durations (Rengasamy, 2014). Wipes are also classified as flushable and non-flushable. A variety of sanitary products, including moist wipes, moist toilet papers, cleansing cloths, and feminine hygiene products, are marketed globally as flushable. Flushable wipes despite the wet strength they have while using, must be dispersed completely when immersed in water, The International Nonwovens and Disposables Association (INDA) and the European Disposables and Nonwovens Association (EDANA) have provided guidelines to define the characteristics of a flushable wipes as following (Durukan & Karadagli, 2019):

- Effective clearance of toilets and well-maintained drainage pipes when used according to the supplier's instructions.
- Compatibility with wastewater conveyance systems, ensuring it passes through without causing blockages or operational issues.
- Disintegration to the extent that it is unidentifiable in effluent leaving on-site and municipal wastewater treatment systems, as well as in digested sludge from wastewater treatment plants.

In another classification wipes are divided into consumer wipes (baby wipes, household cleaning wipes and personal care wipes) and industrial wipes (food service wipes, industrial general wipes, Industrial specialty wipes and medical wipes) (Rengasamy, 2014).

Wipes are categorized into dry and wet wipes, widely used in personal care, household, and industry application. Convenience is a key advantage of wet wipes, as they offer a quicker and easier cleaning solution compared to using liquid and separate cloths or paper towels (Rengasamy, 2014).

Dry wipes typically comprise a substrate, commonly nonwoven fabric, which can be electrostatically charged to improve dirt and dust collection for household cleaning. The mass, thickness, absorption, and air permeability of dry wipes can be evaluated using standards such as EDANA NWSP 130.1 R0, EDANA NWSP 120.1 R0, EDANA NWSP 010.1.R0, and NWSP 070.1.R0, respectively (Cheriaa & Boubaker, 2022).

Wet Wipes

In this section, we explore deeper into wet wipes, considering that the research criteria focus on these products, which consist of two main components, the absorbent delivery substrate and a solution formulation saturating mentioned substrate, the solution formulation could be either a single or multi compound (Crémieux et al., 2005; Rengasamy, 2014).

The primary criteria for selecting nonwoven materials intended for wet wipes applications include wet and dry strength, friction coefficient, softness level, liquid retention, absorption capacity, and dynamic wiping efficiency. For wet wipes, it's essential for some fibers to possess a sufficiently high surface energy to enable them to be wetted by the formulation. This ensures that the wipe remains tolerant to formulation and retains the applied liquid within the product until use (Cheriaa & Boubaker, 2022).

High-quality wet wipes should remain moist for an extended period, ensure even distribution of formulation, effectively remove dirt, offer a plush and gentle feel, serve multiple purposes, leave behind no undesirable residues from either the solution or the substrate, exhibit increased resistance to microbial growth, and be biodegradable and environmentally friendly (Rengasamy, 2014).

Baby wipes are among the most popular wet wipes for cleaning baby skin. Maintaining the pH of these wipes close to the skin's natural pH, around 5, is imperative (Lavender et al., 2012). The convenience of wet wipes has led to the expansion of cosmetic formulations offered in sealed sachets. Originating from baby hygiene products, wet wipes are now widely used in various applications including face cleansing, eye cleansing, makeup removal, aftershaves, and treatment of oily skin, etc (Crémieux et al., 2005).

The material used for baby wipes is typically a nonwoven fabric, commonly comprised of viscose rayon and polyester fibers and a combination viscose and polyethylene terephthalate (PET) for cosmetic wipes, Cotton or other cellulose fibers may also be included in the mixture used for wet wipes, adding to their absorbency and softness. (Crémieux et al., 2005; Lavender et al., 2012; Cheriaa & Boubaker)

The inclusion of viscose fibers in wet wipes contributes to their necessary wettability owing to the fibers' high surface energy. Additionally, these fibers help minimize friction during the wiping process across the skin. meanwhile the polyester or polypropylene fiber provides the strength and durability (Cheriaa & Boubaker, 2022).

On the other hand, the dimensional characteristics of nonwoven fabrics, such as surface density, thickness, porosity, pore size, and structure, predominantly influence fiber strength, absorbency, and liquid diffusion behavior. Typically, greater volume porosity leads to increased vertical wicking rates, irrespective of the presence of hydrophilic or hydrophobic fibers, which makes 100% synthetic nonwoven also appropriate as wet wipe substrate (Salama et al., 2021).

The solution formulation is another key component of wet wipes, primarily comprising water as a solvent, along with preservatives, pH adjusters, skin-benefiting agents, and surfactants. The concentration of each component varies depending on the intended use; for example, baby wipes prioritize preservatives and skin-benefiting agents, whereas cleaning wipes emphasize surfactants (Rodriguez et al., 2020; Salama et al., 2021).

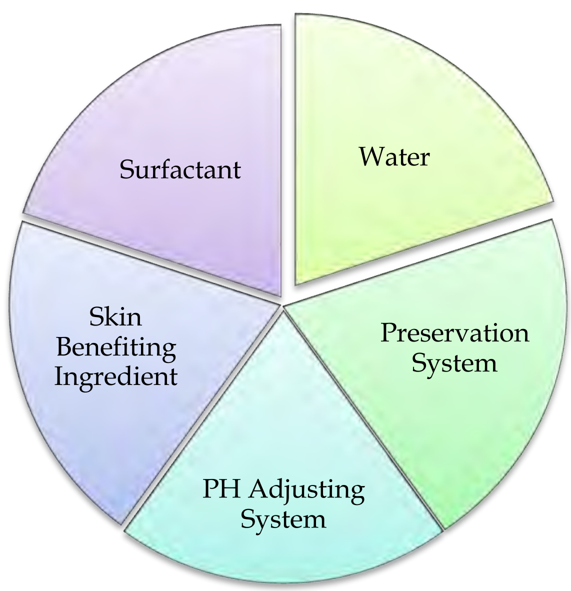

Figure. 1. Formulation composition of wet wipes

In the subsequent sections, we will explore the substrate and formulation in more depth.

Nonwoven Substrate

Nonwovens, fibrous porous materials, can serve as absorbent media (Das et al., 2012). A variety of polymers are used in nonwoven wipes, which can be derived from natural fibers, synthetic fibers, or a combination of both. This section discusses the different types of polymers that could be employed in wet wipes.

Polypropylene

One of the common polymers used in the nonwoven industry is isotactic polypropylene, valued for its ease of handling, good processability, thermal stability, and resistance to aqueous solutions and organic solvents. Its properties depend on factors such as average molar mass, average weight mass, and polydispersity index, which can be altered by oxidative degradation(Bertin et al., 2010). PP nonwovens are renowned for their exceptional softness, uniformity, and lightweight characteristics. This is attributed to their high absorbency, breathability, and cost-effectiveness, factors that contribute to their increasing demand (Jeong et al., 2005).

Poly Lactic Acid

Poly(lactic) acid (PLA) is increasingly recognized as an eco-friendly alternative to synthetic polymers due to its biodegradability and impressive properties, including high mechanical strength and biocompatibility. Derived from renewable resources such as corn and sugarcane through fermentation, PLA's monomer is lactic acid, which exists in two optically active forms: L-lactide and D-lactide. PLA polymerization can occur through direct polymerization or ring-opening polymerization, resulting in three stereochemical forms: LL-lactide, DD-lactide, and DL-lactide (also known as meso-lactide), which is a combination of L-lactide and D-lactide. PLA has a glass transition temperature of 55°C and a melting temperature of 175°C (Garlotta, 2001; Qi et al., 2017).

Major weakness of PLA is its brittleness, in order to overcome this deficit, it is utilized in blend with other plasticizers or ductile polymers such as poly butylene succinate (PBS), polycaprolactone (PCL) & polyethylene glycol (PEG) (Su et al., 2019).

The research question focuses on assessing PLA's potential as a biodegradable substitute for current substrates. It seeks to determine if PLA fibers, alone or in conjunction with other plasticizers like PBS, can attain the required wet strength for use and maintain satisfactory degradation properties afterward.

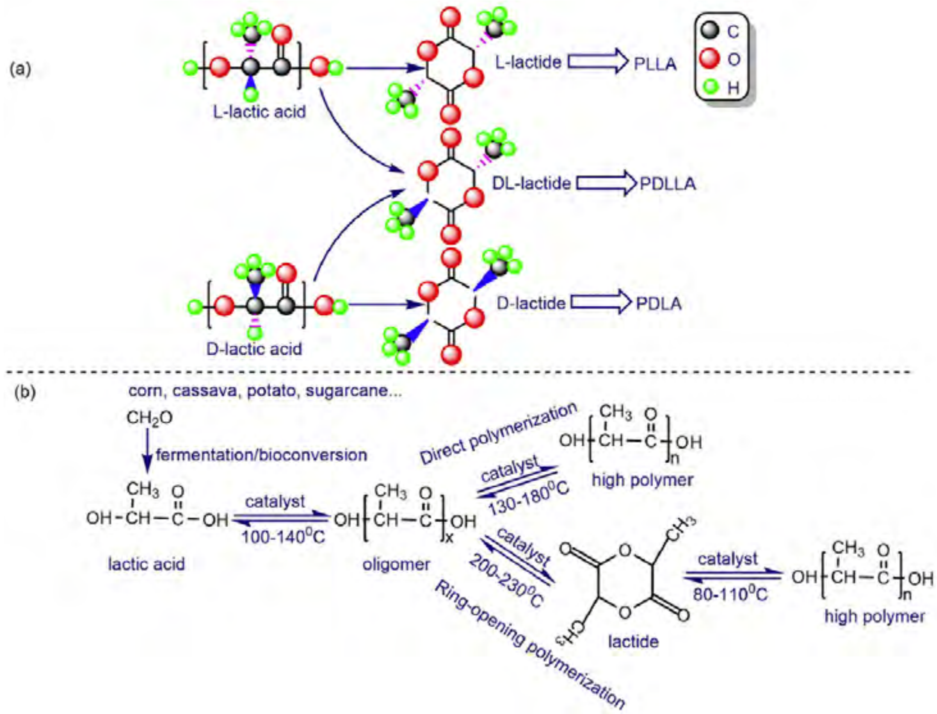

Figure. 2. (a) three stereochemical forms of PLA (b) Polymerization methods of PLA (Qi et al., 2017)

Solution formulation

As mentioned earlier, the choice of formulation ingredients largely depends on the intended application. There is a growing desire to use safer and biodegradable chemicals, which must also be compatible with other ingredients and the substrate. The Environmental Protection Agency (EPA) provides lists of safer chemicals and regulations to guide the selection and use of chemicals.

For instance, considering baby wipes, it's preferable to contain a high percentage of purified water, water alone is insufficient for effectively removing water-insoluble residues from baby skin and for preventing microbial growth or maintaining a healthy skin pH. Therefore, in addition to purified water, a baby wipe should include an extremely mild surfactant to reduce surface tension for improved cleaning. It should also incorporate a preservation system to maintain freshness before and during use, and a pH adjusting system to match the pH of infant skin (pH: 4.5–6). Optionally, the wipe may contain skin-benefiting ingredients to reduce frictional damage and replenish skin lipids, as well as perfumes and vitamins (Cheriaa & Boubaker, 2022).

Considering the aquas phase comprises the majority component of wet wipes presence of a reliable preservative is vital to prevent microbial growth and any contamination during manufacturing, storage and until the wipes are used (Crémieux et al., 2005). Due to the predominance of hydrophobic preservatives in wet wipes, their efficacy diminishes when applied to substrates containing a mix of hydrophobic and hydrophilic fibers. This results in an uneven protection, with the preservative primarily interacting with the hydrophobic fibers, leaving the aqueous phase and hydrophilic fibers exposed. Therefore, meticulous selection of the preservative system is paramount to ensure comprehensive protection across the entire substrate (Salama et al., 2021).

Baby wipe cleaning systems typically contain coco-glucoside and lauryl glucoside (nonionic sugar-derived surfactants), along with emollients like glycerin and glyceryl oleate, and citric acid as a pH adjuster and chelator, containing 97% water and free of alcohol, fragrance, essential oils, soap and other detergents (Lavender et al., 2012).

There is no limitation for cosmetic formulation they can vary from encompassing aqueous, hydro alcoholic, emulsion or oil-based composition as long as their viscosity guarantee obtaining an acceptable saturation (most common 3-4 g of liquid per gram of delivery system) and uniform distribution along the substrate (Adam et al., 2009).

Wet wipe's formulation can include various functional components. The following tables provide suggested compositions for these formulations.

Table 1: Formulation composition (Cheriaa & Boubaker, 2022)

Ingredient	**Function**	**Notes**
Purified water	Aqueous phase	
Cetrimonium chloride	Cationic surfactant	Disperse water and oil- antimicrobial and antistatic activities
Polysorbate 20	Non-ionic surfactant	Emulsifier
Aleo barbadensis leaf extract	Soothing and nourishing extract	
Olea europaea (olive) fruit extract	Antimicrobial agent	
Prunus amygdalus duicis (sweet almond) fruit extract	Antioxidant agent	Source of E & B vitamins
Glycerin	Natural humectant	
Allantoin	anti-irritant	
Polyquaternium-7	inhibits the buildup of static electricity	
Tetrasodium salt	Biodegradable chelating agent	
Tocopheryl acetate	Synthetic form of vitamin E	
Glyceryl Cocoate	Solubilizer	Improve surfactant performance

Ethylhexylglycerin	enhances the antimicrobial efficacity	
Phenoxyethanol	Natural preservative	
Ethylenediaminetetraacetic Acid	A preservative	
Natural Perfumes		

Table 2: Wet wipe formulation (Salama et al., 2021):

Trade Name/ INCI[1]	Function
Water /Aqua	Solvent
Chamomile extract	Humectant
Panthenol	Skin conditioning
Glycerin	Humectant
Sodium citrate	
Tween 20 / Polysorbate 20	Surfactant (nonionic)
Preservative	Preservative
Vitamin E / Tocopherol	Antioxidant
Miranol C2M /Disodium cocoamphodiacetate	Surfactant (anionic)

Table 3 provides a formulation composition based on polyaluminum chloride, an inorganic polymer commonly used in water treatment processes due to its highly effective cleaning properties. Suggested formulations emphasizes on the minimization of the number of ingredients and primarily employ chemicals derived from natural resources. Alkyl polyglucoside (APG) is utilized as a renewable nonionic surfactant to offer good foaming, wetting, and cleaning (Cumberland & Ochomogo, 2009).

Table 3: All-purpose cleaner Polyaluminum compositions (Cumberland & Ochomogo, 2009)

Ingredient	A	B	C	D
Polyaluminum Chloride	0.80	1.20	1.65	1.90
APG (Glucopon ® 425 N)	0.00	3.80	2.60	1.80
APG (Glucopon ® 215)	2.60	0.00	0.00	1.20
Ethanol	3.00	4.00	3.25	2.75
Glycerol	1.30	1.50	1.10	0.90
Fragrance	0.50	0.25	0.75	0.60
Preservative	0.50	0.25	0.75	0.60
Water	Balance	Balance	Balance	Balance

Other compositions feature active chlorine species as a bleaching agent, which proves effective for disinfecting, bleaching, and cleaning various soft and hard surfaces. To address concerns regarding odor and surface erosion, these

[1] International Nomenclature of cosmetic ingredients

compositions are offered with low bleach concentrations ranging from 0.005% to 0.5% free available chlorine. They aim to achieve at least a 3-log reduction in Clostridium difficile and tuberculosis (Timothy P., 2021).

Table 4: Sodium Hypochlorite Compositions (Timothy P., 2021)

Sample	NaOCl ppm	SLS (wt%)	LO (wt%)	SXS (wt%)	t-butanol (wt%)	Silicate (wt%)	pH
A	2000	-	0.05	0.1	0.5	-	10.5
B	2000	-	0.05	0.1	0.1	-	10.5
C	2000	0.05	-	-	0.1	-	10.5
D	2000	0.05	-	-	0.5	-	10.5
E	3000	0.05	-	0.033	-	-	11
F	2000	-	-	-	-	-	10
G	2000	0.05	-	-	-	-	10
H	2000	-	-	-	-	-	11.6
I	2000	0.05	-	-	-	-	11.6
J	2000	-	0.03	-	-	-	10.5
K	2000	-	0.03	-	0.1	-	10.5
L	2000	0.03	-	-	0.1	-	10.5
M	2500	-	0.03	-	-	-	11
N	2500	-	0.03	-	0.1	-	11
O	2500	0.03	-	-	-	-	11
P	2000	-	0.05	0.1	0.1	0.25	10
Q	2000	-	0.05	0.1	0.1	0.25	10.5
R	2500	-	0.05	0.1	0.1	0.25	10.5
S	2500	-	0.05	0.1	-	0.25	10.5
T	2000	-	0.1	0.1	0.1	0.25	11
U	2500	-	0.05	0.1	-	0.25	11
V	2000	-	0.03	-	-	0.25	10.6
W	2500	-	0.03	-	-	0.25	10.6
X	2000	-	0.05	0.04	-	0.25	10.6

Degradation

The interaction between the substrate and chemicals can lead to degradation, impacting the efficiency and lifespan of the product. Therefore, a thorough understanding of the degradation process is essential.

Degradation could be whether heterogenous or homogeneous also called as surface and intramolecular degradation of polymer, three types of chemical degradation occur (Qi et al., 2017):

- Scission of the main chain

- Scission of the side chain
- Scission of the intersectional chain

Hydrolysis is the main degradation process in polymers containing ester bonds (Pourdeyhimi, 1987).

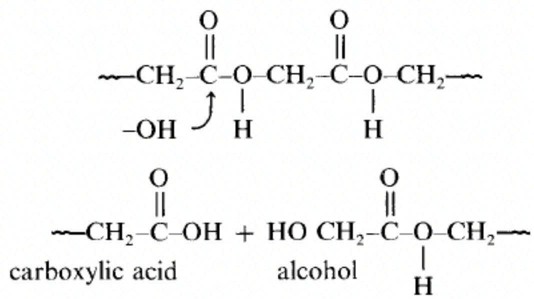

Figure. 3. Hydrolysis of ester bond (Pourdeyhimi, 1987)

Polypropylene degradation depends on the amount of oxygen and on the generated radicals from thermal decomposition of peroxide, its degradation largely depends on the H-abstraction rates from C-H bonds by alkoxyl radicals by peroxide degradation (Bertin et al., 2010).

PLA is degraded by simple hydrolysis of ester bond with no requirement of presence of microorganisms to catalyst this hydrolysis. Chemical hydrolysis breaks down the ester bonds of PLA into carboxylic acid and alcohol, facilitated by hydration. However, achieving complete hydrolysis requires significant energy and time and degradation rate depends on the size and shape, isomer ratio and temperature of hydrolysis (Garlotta, 2001; Qi et al., 2017).

Accelerated Test Method

Creep Rupture

In this research, an accelerated test method will be utilized based on the theory of breaking kinetics and creep rupture, coupled with various solution formulations, to estimate the effect of key ingredients on the lifetime of the specimens. The theory of breaking kinetics emphasizes that tensile strength distribution and mechanical breakdown are time-dependent. This theory makes assumptions about the lifetime (required time for breaking) of fibers under a constant load. (Coleman, 1957).

The viscoelastic behavior of polymers, characterized by a combination of springs and dashpots, influences their response to applied loads. Initially, when a load is applied, the dashpots restrict the instantaneous extension of the springs, resulting in a nonlinear stretching of the material. This initial response includes an elastic extension, followed by viscous plastic straining, known as primary creep, where the strain rate decreases over time. Subsequently, the material transitions into secondary creep, characterized by a nearly constant strain rate, also referred to as steady-state creep. During this phase, which typically dominates the test duration, the specimen undergoes minimal creep, exhibiting a viscous-like extension. Ultimately, the material experiences a rapid increase in strain during the tertiary creep stage, culminating in specimen rupture. This rupture is a consequence of the material's gradual weakening over time when subjected to constant stress or load (Ohring, 1995).

Creep can be viewed as a delicate interplay between work hardening and thermal softening or recovery. It progresses through three distinct stages: initially, hardening dominates, followed by a phase where both processes are in equilibrium, and finally, softening takes precedence, leading to microfracture and stress instabilities. Towards the end, the creep rate intensifies due to reduced specimen area. Engineers utilize two test methods to analyze material creep: steady-state creep rate tests, which subject specimens to varying stress and temperature conditions without inducing failure, and creep rupture tests, where higher stress and temperature levels accelerate failure, offering insights into short-term or long-term material life predictions (Ohring, 1995).

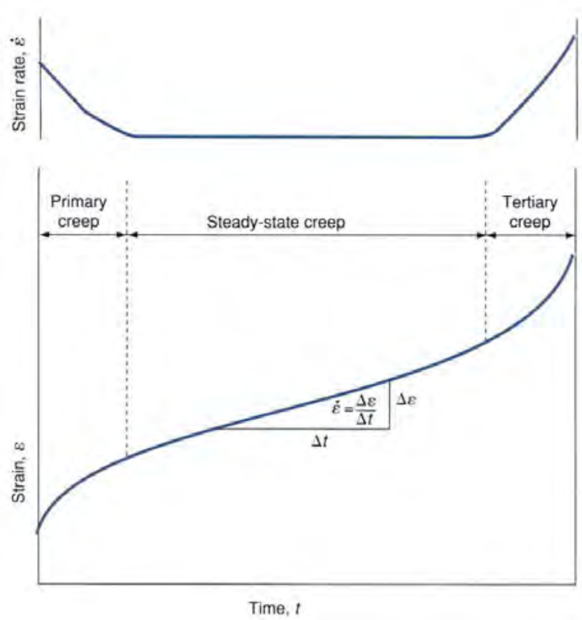

Figure. 4. Plastic strain versus time during creep testing at T>0.5Tm (Ohring, 1995)

To estimate the statistical time of failure, an apparatus like the one used in Pourdeyhimi's research was employed which is close version of “creep rupture” apparatus developed by Wagner et al, this device comprises a rack equipped with 30 microswitches (minimum of 30 specimen is required to provide a reliable database), which are normally closed and open when subjected to a 15g load. Individual specimens are affixed between stainless steel tabs and suspended from the switches while immersed in a test tube filled with buffer solution or any other desired liquid. To prevent evaporation, the test tubes are sealed with corks. The specimens will undergo testing at different temperatures to observe hydrolysis degradation occurring above the glass transition temperature (T_g) (Pourdeyhimi, 1987).

If a long fiber is composed of shorter unit lengths connected in series, and the strengths of these links are independent and identically distributed random variables, then the weakest link rule determines the strength distribution of the long fiber. Specifically, if the strength distribution of the unit lengths follows a Weibull distribution with scale parameter “a” and shape parameter “b”, then the strength distribution of the long fiber can be determined accordingly (Schwartz et al., 1986).

The data collected from the experiment will be analyzed using the Weibull distribution to estimate the probability of failure under different conditions. The cumulative distribution function is defined by the following formula, where "a" and "b" represent the scale and shape parameters, respectively, which will be estimated from the data (Pourdeyhimi, 1987; Weibull, 1939):

$F(t)=1- e^{-\frac{t}{a}^{b}}$

$\ln\left(1-F(t)\right) = -(\frac{t}{a})^{b}$

$\ln\left(\frac{1}{1-F(t)}\right) = (\frac{t}{a})^{b}$

$\ln\left[ln\left(\frac{1}{1-F(t)}\right)\right] = bln\frac{t}{a}$

$\ln\left[ln\left(\frac{1}{1-F(t)}\right)\right] = b\ ln(t) - b\ ln(a)$

The plot of $\ln(\ln\left(\frac{1}{1-F(t)}\right)])$ versus ln(t) from the obtained data will lie on a straight line with slope b and -b ln(a) as interception, where an unbiased estimate of F(t) is $\frac{N_i}{N+1}$ where Ni is ith failed specimen at ith failure time, and N is total number of observations, if sample be large enough the Weibull parameters can be estimated by the least square procedure or maximum likelihood estimation (Pourdeyhimi, 1987).

$t = a\ln\left(\frac{1}{1-F(t)}\right)^{\frac{1}{b}}$ Time to failure

Based on the variables in the research, the parameters will be determined using linear regression analysis. Additionally, the linearity of the plot of the variable versus the scale parameter can offer a reliable estimate of the effectiveness of the variable on degradation and failure time.

Degradation affects the mechanical properties of the product. Therefore, tensile strength testing will be a good measure to analyze the effect of formulation on the degradation of the substrate. Several studies in the literature discuss the mechanical properties of nonwovens under water aging or exposure to other solutions.

Cheriaa & Boubaker analyzed the tensile strength of both dry and wet samples according to IS 15891-3 using a tensile testing machine (LLOYD LR 5 K) with an autographic recorder. Wet samples were soaked in a solution containing a non-ionic wetting agent before testing. A constant rate of extension was applied, and specific strength and fabric density were calculated using following equations (Cheriaa & Boubaker, 2022):

$$Specific\ strength\ (N.m.kg^{-1} = \frac{Breaking\ tensile\ strength}{Area\ density\ \times\ Thickness}$$

$$Fabric\ density\ (Kg.m^{-3} = \frac{Area\ density}{Thickness}$$

Kollia et al. employed a hydrothermal aging method to examine the impact of absorption on the mechanical properties of the flax biocomposites. This involved conducting tensile strength tests using an Instron 8872 servo-hydraulic testing machine, following ASTM-D3039 and EN ISO 14125 standards, results show that the hydrothermal aging process significantly affects the strain to failure, as water absorption leads to higher ultimate values, particularly with increasing temperature. Conversely, drying the samples tends to reduce the strain to failure (Kollia et al., 2020).

Considering the effects water aging could cause, in second phase of the research the control will involve immersing the fiber in water alone to examine its effects separately from other variables.

Scanning Electron Microscopy (SEM) will be used in the research to assess the impact of degradation on the appearance and physical properties of materials, consistent with common practice in degradation studies (Kollia et al., 2020; Yu et al., 2023).

SUMMARY & CONCLUSIONS

Wet wipes play a crucial role in various cleaning and hygiene applications, offering convenience and efficiency. The choice of substrate and formulation is essential to ensure optimal performance and user satisfaction.

Degradation, influenced by factors like substrate composition, formulation and environmental conditions, can impact the mechanical properties and performance of wipes. Accelerated test methods, such as creep rupture testing, can provide valuable insights into the lifetime of wipes under different conditions.

Ongoing research is focused on examining the effect of key ingredients on degradation by assessing the mechanical and morphological properties of wipes. The aim is to propose solutions to minimize such effects and provide accelerated test methods that offer reliable statistics on failure time. Additionally, exploration into alternative biodegradable materials as substrates aims to enhance the performance, sustainability, and user experience of wet wipes.

FUTURE WORK

The initial subject and time planning for this project was as follows:

1. Literature Review — Jan. -Jun. 2024
2. Static degradation study — June 2024 – June 2025
3. completion of accelerated testing — June 2025 – June 2026
4. Thesis & publications — June – Aug. 2026

Currently, the first stage of the timeline, which involves completing the literature review and patent landscape analysis, is in progress. Following the selection of fibers and formulations of interest, the next stage of the project will commence, which involves initiating the static degradation study.

In static degradation study fibers will be freely immersed in the solution at constant temperature in test tubes and placed in circulating air oven. Due to the importance of decoupling the impact of water aging from the chemical fiber interaction the control samples of this phase will be immersed in water alone. The morphology and mechanical properties of the fibers will be examined periodically.

In third phase fibers will be freely immersed in the solution at constant temperature in test tubes and placed in circulating air oven to mimic storage condition range of temperatures may applied. And a 0.2 M phosphate buffer at pH 7.0 will be used as control medium. Fibers will be removed periodically to test their morphology and mechanical properties.

This phase aims to establish a comprehensive database of the statistical time to failure under various conditions to enhance understanding of their reliability (Pourdeyhimi, 1987)

The objective is to create a substantial database, prompting the development of an apparatus capable of accommodating 30 or more specimens. Which will be designed and built based on previous work done by Pourdeyhimi, et.al.

This device comprises a rack with 30 or more microswitches, initially closed and opened with a 15 g load. Individual specimens will be suspended between stainless steel tabs, ensuring they experienced a load of no more than 3 to 5 g for the control samples. For accelerate aging, the load will be equal to ~ 80% of their ultimate tensile stress.

The specimens will be immersed in test tubes filled with the appropriate solution and sealed with corks to minimize evaporation. The test tubes were then placed in a temperature-controlled bath. Once loaded, a minicomputer, connected to a specialized data control station, monitored the time. Specimen failure would trigger the opening of corresponding switches, altering their logical state, and recording the time to failure. The setup resembles a "creep rupture" apparatus developed by Wagner et al. for studying stress rupture of Kevlar filaments (Pourdeyhimi, 1987).

Analysis of the data is best suited using the Weibull distribution, known for effectively describing failure statistics in various mechanical and electronic scenarios. Past success with this distribution in analyzing clinical vascular graft failures was noted (Pourdeyhimi, 1987).

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