A Physical and Tearing Behavior of Papers Produced Using Calico Fabric and Recycle Box Materials

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ABSTRACT

The increasing global demand for paper and the rising volume of fabric waste have become critical environmental concerns due to unsustainable production and disposal practices. Conventional paper production, heavily reliant on wood pulp, contributes to deforestation and resource depletion, while fabric waste exacerbates landfill overflows. This study investigates the potential of producing paper from recycled calico fabric waste blended with box paper pulp in specific ratios ranging from 20% to 80% to evaluate the mechanical and physical properties of the resulting paper. Fabric waste and box paper were processed into pulp, combined in precise ratios, and shaped into sheets using a mold-based paper-making technique. The produced paper was tested for tearing resistance, thickness, weight, and absorbency properties. Results demonstrated that higher calico fabric content enhanced absorbency and flexibility but reduced tearing resistance. The optimal composition, determined by balancing tearing resistance, flexibility, and absorbency, was found at a 50% calico fabric and 50% box paper ratio, contributing to greater rigidity and mechanical strength. This composition was selected as optimal due to its balance of high mechanical strength, adequate absorbency, and flexibility, making it suitable for practical applications. The final composition balanced these properties, providing an eco-friendly alternative for applications such as sustainable packaging and artistic materials. This study highlights an environmentally friendly approach to paper production, offering a sustainable alternative to conventional methods and integrating circular economy principles by repurposing calico fabric and box paper waste.

Keywords: Fabric, Recycle, wood pulp, Box Materials

INTRODUCTION

Paper is an indispensable material integral to human civilization for centuries, playing a pivotal role in communication, education, packaging, and various industrial applications. However, the growing global demand for paper has raised significant environmental concerns due to traditional production methods that rely on wood pulp from trees, depleting forests and consuming large amounts of water and energy while releasing pollutants (Akhai, T., 2024). Thus, finding sustainable solutions for paper production is essential. Recycling mitigates the environmental impact of paper production by reducing the need for virgin wood pulp, conserving forests, minimizing landfill waste, and requiring less energy and water (Kaur, G., et al., 2021). However, the growing demand for recycled paper and limitations in current recycling methods necessitate innovative approaches and alternative fiber sources. This study focuses on using recycled calico fabric (unprocessed cotton, rich in cellulose) and box paper (recycled cardboard) as raw materials. Calico fabric offers tensile strength and durability, while box paper adds structural rigidity, making them suitable substitutes for wood pulp in producing high-strength paper for packaging and stationery (Cheng et al., 2019).

BACKGROUND

Paper, a fundamental medium in human civilization, has a rich history that dates back over two thousand years. Its invention is attributed to Cai Lun, an official in the Eastern Han Dynasty of China, who around 105 AD developed the earliest known paper-making process (Ferrara et al., 2021)). Before the advent of paper, ancient civilizations utilized materials such as clay tablets, papyrus scrolls, and animal skins for recording information, which were often expensive and labor-intensive to produce (Christopher, 1996)

As paper-making technology spread from China to the Islamic world and then to Europe, it transformed the way knowledge was preserved and shared across different cultures and eras. The 19th century also saw the rise

of wood pulp as a primary raw material, replacing traditional fibers like cotton and linen rags. This shift not only lowered the cost of paper production but also facilitated the growth of the newspaper and publishing industries, which became central to public discourse and education (Hernandez, R., 2021). The era's technological innovations laid the groundwork for modern paper production methods and expanded the material's use in various sectors, including printing, packaging, and conservation. In addition to these traditional uses, paper plays a crucial role in modern packaging, providing solutions for protecting and transporting goods across global supply chains (Kumar, 2022). However, the environmental impact of paper production has become a significant concern in recent decades, as the industry is associated with deforestation, water consumption, and waste (Ferrara et al., 2021). This awareness has spurred efforts to promote sustainability within the paper industry, including the development of recycled paper products and the exploration of alternative fibers such as agricultural residues and bamboo (Esa, 2022). Researchers are also investigating novel uses for paper in emerging fields such as electronics, where paper-based substrates and components are being developed for applications in flexible displays and sensors (Hernandez, 2021). Additionally, there is a growing interest in creating paper products that contribute to a circular economy by improving recyclability and reducing waste (Browns, 2022). The future of paper technology will likely be shaped by a combination of scientific research, technological advancements, and a commitment to environmental sustainability, ensuring that paper continues to be a valuable material for future generations (Nakamura, 2015).

METHODOLOGY

The calico fabric, chosen for its natural, unprocessed properties, serves as the primary material in this study. This innovative approach to papermaking aligns with the principles of environmental sustainability. The chapter discusses the transformation of calico fabric into pulp, followed by the formation of paper sheets using specific tools and techniques. Key equipment such as trays, sponges, and molds is highlighted, alongside the rationale for their selection and usage. This study focuses on transforming calico fabric and box paper into paper products, evaluating their respective contributions to the paper's properties at different material ratios. Five distinct material ratios are examined: 50% Box/50% Fabric, 60% Box/40% Fabric, 70% Box/30% Fabric, 60% Fabric/40% Box, and 70% Fabric/30% Box. By assessing these ratios, the research aims to identify the optimal combination for strength, flexibility, and other desirable paper qualities. Each ratio is subjected to laboratory tests to provide quantitative data on tearing resistance, thickness, weight and absorbency rates. These tests are designed to meet the study's objective of evaluating the feasibility of calico fabric as a sustainable alternative for paper production.

The production process begins with the preparation of calico fabric and box paper as separate pulp materials. These are processed individually to ensure uniformity before being mixed in the desired ratios. The resulting paper sheets are formed using molds pressed to remove excess water and dried in a controlled environment to maintain structural integrity. Each stage of the process is carefully monitored to minimize variability and ensure consistency across samples. The testing methods employed to assess the properties of the produced paper include tearing resistance, thickness measurement, and absorbency tests to determine the paper's quality and applicability. Instruments like the Digital Elmendorf Machine and thickness gauges are used to ensure reliable and accurate assessments. A flow chart summarizing the overall methodology is presented below, providing a clear visual representation of the steps undertaken in this research. This serves as a guide to understanding the process flow and ensures systematic tracking of the study's progress.

Figure 1. Flow process of the research
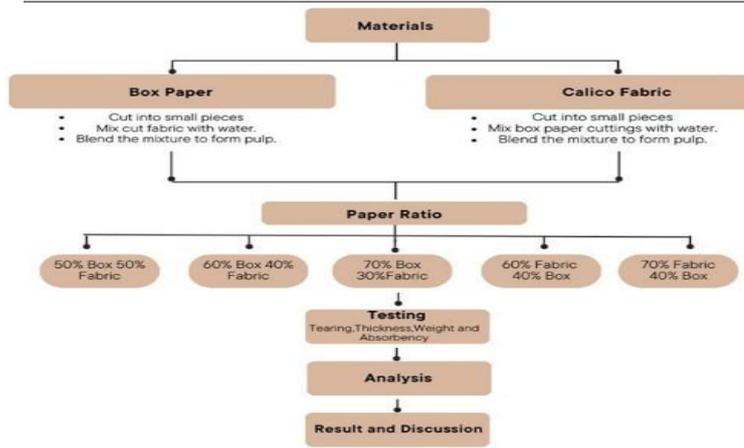
Testing

The produced paper undergoes a comprehensive series of tests to evaluate its overall quality and suitability for a range of applications. These tests are fundamental for assessing the functional properties of the paper, ensuring it conforms to the desired performance standards, and determining its appropriateness for specific uses. By conducting these tests, we can ensure that the paper not only meets but exceeds industry expectations. The testing follows ASTM D6798 standards for tearing resistance, ASTM D645 for thickness, and ASTM D646 for absorbency.

Tearing Resistance Test

Tearing resistance is measured using a Digital Elmendorf Machine, an advanced device designed specifically for determining the durability of materials. This test evaluates the amount of force required to propagate an existing tear in the paper, which provides critical information about its strength and resilience under mechanical stress. This is particularly important for applications where the paper will be subjected to frequent handling or rough conditions. Results are recorded in Newtons (N) or grams per square centimeter (g/cm^2), and repeated tests are conducted to ensure accuracy and consistency. For each ratio tested, three replicates are measured to ensure reproducibility of results. The dimensions of each paper sample are 20 cm x 20 cm. The testing follows ASTM D6798 standards for tearing resistance.

Thickness Test

Thickness testing is conducted using a thickness gauge, which measures the distance between two surfaces when the paper is gently compressed. This parameter is essential for determining uniformity and assessing the paper's suitability for specific applications, such as printing or artistic use. Variations in thickness can impact the appearance and performance of the paper, making this test a critical component of quality control. Thickness is recorded in millimeters (mm), and multiple measurements are taken across different sections of the sample to ensure even distribution. The testing follows ASTM D645 standards for thickness.

Weight Test

Weight is a measure of the mass of paper samples, which provides critical insights into the consistency and suitability of the material for specific applications. This property is significant in determining the paper's handling characteristics, transportability, and usability for various tasks. The weight of the samples is measured using a digital scale. The measurements are documented in grams (g), allowing for the comparison of different material ratios. The dimensions of the paper samples are 20 cm x 20 cm, and weight is measured after drying to ensure consistency across all samples.

Absorbency Test

The absorbency test evaluates how well the paper can take in and retain liquids, which is a vital property for applications such as writing, filtration, or packaging. Using a plastic pipette, a controlled volume of liquid is placed on the surface of the paper, and the time taken for the liquid to be fully absorbed is recorded in seconds. This test provides insights into the porosity and fiber arrangement within the paper. Papers with higher absorbency may be more suitable for tasks like blotting or dyeing, while lower absorbency is preferred for applications requiring water resistance.

Data collected from these tests are systematically recorded and analyzed to determine the relationship between material ratios and the resulting paper properties. Additionally, qualitative observations, such as visual assessments of texture, flexibility, and uniformity, are documented to provide a comprehensive evaluation of the paper's overall performance. These findings not only validate the effectiveness of the chosen methodology but also guide future improvements in sustainable paper production. Each absorbency test is repeated three times for each material ratio to ensure consistency and reliability of results. The testing follows ASTM D646 standards for absorbency.

RESULTS AND DISCUSSION

The paper samples were prepared using different compositions of fabric and box material to evaluate their mechanical performance trends across material compositions. The results clearly demonstrate that the physical and mechanical properties of paper produced from calico fabric and box paper are strongly influenced by the proportion of each constituent fibre. Variations in fibre morphology, density, and bonding behaviour resulted in measurable differences in thickness, weight, tearing resistance, and absorbency. In general, increasing calico fabric content enhanced flexibility and absorbency, whereas increasing box paper content improved rigidity and dimensional stability. These findings confirm that the functional behaviour of the composite paper is governed by the interaction between long, flexible textile fibres and shorter, more compact recycled box fibres.

Visual Comparison

The texture, color, and uniformity of the samples varied significantly based on the composition ratios. Higher fabric content produced smoother and more flexible paper, while higher box content resulted in more rigid and rougher paper. Visual inspection revealed distinct surface and structural differences among the samples. Papers with higher calico fabric content exhibited a softer texture and more visible fiber networks, indicating less compact fiber packing. This structure promoted higher porosity, which directly influenced absorbency behavior. In contrast, samples containing a higher proportion of box paper showed smoother and more rigid surfaces with reduced fiber visibility, reflecting stronger fiber compaction and bonding. The balanced composition (50% box paper and 50% calico fabric) exhibited the most uniform surface appearance, suggesting effective inter-fiber bonding between textile and paper fibers. This visual uniformity is indicative of improved load distribution under mechanical stress and supports its selection as an optimal composition for multifunctional applications. A qualitative comparison is summarized below:

Table 1. Visual of papers with different compositions

Composition	Image	Description
50% Box 50% Fabric		Balanced texture with moderate fiber visibility. Some surface roughness, resulting in intermediate mechanical strength and absorbency.
60% Fabric 40% Box		Soft and uneven texture. Visible fiber clumping due to higher fabric content, contributing to improved water absorption.
70% Fabric 30% Box		Highly textured surface with noticeable fiber alignment. Increased absorbency but with some inconsistencies in water penetration rates.
60% Box 40% Fabric		Smoother surface with less visible fiber texture. Better tearing strength due to increased box material, but reduced water absorbency.
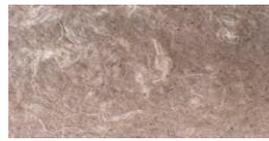
70% Box 30% Fabric		Rigid surface with minimal fiber visibility. High tearing strength and low absorbency due to dominant box material.

Physical Properties

The thickness and weight of the paper samples were measured to assess their structural and physical properties. Thickness (mm) was measured at five different locations to ensure consistency, and the weight was measured for a consistent sample size of 3 cm × 3 cm.

Table 2. Thickness (mm) and Weight (g) Measurements of Paper Samples

Label	Composition	Average Thickness (mm)	Average Weight (g)
A	50% Box 50% Fabric	0.241	1.206
B	60% Box 40% Fabric	0.265	1.442
C	70% Box 30% Fabric	0.222	1.166
D	60% Fabric 40% Box	0.238	1.674
E	70% Fabric 40% Box	0.210	1.710

The measured thickness and weight values varied systematically with material composition, highlighting the influence of fiber density and packing efficiency. Samples with higher calico fabric content generally exhibited greater thickness but lower density, reflecting the bulky and loosely packed nature of textile fibers. Conversely, box paper–rich samples showed reduced thickness and increased compactness due to the shorter and denser recycled fibers. Notably, the 50% box–50% fabric sample achieved a moderate thickness and weight, suggesting an optimal balance between bulk and structural integrity. This balance is critical for applications requiring both strength and flexibility, such as specialty packaging or artistic paper products. The observed trends are consistent with previous studies reporting that fiber length and flexibility play a decisive role in determining paper bulk and mass distribution (Zhang et al., 2022).

The results demonstrate a clear relationship between the structural composition of the paper and its thickness and weight. Thickness varies significantly across the samples, with higher fabric content resulting in thicker samples. For example, the 70% Fabric composition (Sample E) exhibited the highest thickness of 1.710 mm, while the 70% Box composition (Sample C) had the lowest thickness of 1.166 mm. This is consistent with findings by Zhang (2022), which highlight that increased thickness correlates with greater mechanical properties, such as tearing strength and stiffness. The denser and more uniform fiber distribution in higher fabric content contributes to the increased thickness and improved mechanical   performance (Zhang, 2022).

Similarly, weight measurements reflect the material composition of the samples. The 60% Box, 40% Fabric composition (Sample B) recorded the highest weight of 0.265 g, whereas the 70% Fabric, 30% Box composition (Sample E) exhibited the lowest weight of 0.210 g. Samples with higher box content tend to be heavier due to the dense and compact structure of the box material, while those with higher fabric content are lighter due to the fibrous and less dense nature of the fabric. This aligns with findings by Smith et al.

(2021), which emphasize the role of material density in determining paper weight and its applications.

Tearing Behavior

Tearing strength was tested across three samples. The results are shown in

Table 3. Tearing Strength Measurements

Tearing Strength (N)	Standard Deviation (N)	Composition
3.25	0.14	50% Box / 50% Fabric
3.25	0.16	60% Box / 40% Fabric
4.30	0.48	70% Box / 30% Fabric
3.72	0.16	60% Fabric / 40% Box
4.17	0.28	70% Fabric / 40% Box

Tearing resistance results indicate that fiber composition significantly affects the paper's resistance to crack propagation. Samples with higher calico fabric content demonstrated improved tearing resistance due to the presence of long, flexible cellulose fibers that bridge cracks and distribute stress more effectively. This behavior aligns with established findings that longer fibers enhance energy absorption during tearing by improving fiber pull-out resistance and inter-fiber bonding (Kumar et al., 2022). However, the highest tearing strength was not observed at the extreme fabric-rich composition alone, but rather in samples where sufficient box paper content contributed to structural rigidity. This suggests that tearing resistance is governed by a balance between flexibility (from fabric fibers) and stiffness (from box paper fibers). Excessive rigidity can promote brittle failure, while excessive flexibility may reduce resistance to tear initiation. The moderate standard deviation values further indicate acceptable reproducibility, though variability in high box-content samples suggests uneven fiber distribution during sheet formation.

The results reveal that tearing strength improves with higher fabric content. The 70% Fabric, 30% Box sample exhibited the highest tearing strength (4.17 N), while the 60% Box, 40% Fabric sample had the lowest tearing strength (3.25 N). This trend can be attributed to the strong and flexible nature of fabric fibers, which enhance the paper's resistance to tearing. Studies by Kumar et al. (2022) support this observation, indicating that fibers with high flexibility and strength contribute to superior tearing resistance in paper materials. Similarly, research by Cheng (2021) highlights that cellulose-rich fibers significantly enhance inter- fiber bonding and tearing strength.

However, the 70% Box, 30% Fabric sample showed a high variability in tearing strength (standard deviation = 0.48), likely due to inconsistencies in fiber distribution and bonding during production. The standard deviation, a statistical measure of data dispersion, was calculated using the formula:

where represents each individual data point, is the mean tearing strength, and is the total number of observations. This calculation involved determining the mean tearing strength, finding the deviations of each data point from the mean, squaring these deviations, averaging them, and finally taking the square root of the result (Kozak et al., 2020). The resulting standard deviation highlights the extent to which the tearing strength measurements varied from the mean value.

Future work could focus on improving fiber alignment techniques to reduce variability. The tearing strength results are consistent with findings from other studies, such as those by Smith (2020), where increased fiber content contributed to higher tensile and tearing strength in paper materials. Additionally, investigations by Smith (2020) demonstrated that optimized fiber processing techniques improve the uniformity and mechanical properties of composite papers. Incorporating these advancements could further enhance the performance of fabric-based paper products.

Absorbency test

The absorbency test measured the time taken for water to penetrate the paper samples. The results are presented in Table 4. The absorbency results show that higher fabric content significantly improves water absorbency. The 70% Fabric, 30% Box sample had the shortest absorbency time (4.03 s), reflecting the hydrophilic nature of fabric fibers. In contrast, the 70% Box, 30% Fabric sample recorded the longest absorbency time (12.84 s), indicating lower water penetration due to the compact, less absorbent box material.

Absorbency results showed a strong inverse relationship between box paper content and water penetration rate. Samples with higher fabric content absorbed water more rapidly due to increased porosity and the hydrophilic

nature of cotton-based cellulose fibers. In contrast, box paper–rich samples exhibited delayed absorbency, attributed to denser fiber packing and reduced capillary pathways. The rapid absorbency observed in fabric-dominant samples highlights their suitability for applications such as blotting paper, filtration media, or artistic uses requiring ink absorption. Meanwhile, the slower absorbency of box-rich compositions suggests potential for packaging applications where moisture resistance is advantageous. These findings demonstrate that absorbency can be effectively tailored by adjusting fiber ratios, enhancing the functional versatility of recycled paper products.

These findings suggest that fabric content can be optimized for applications requiring high absorbency, such as tissue paper or absorbent packaging materials. Additional studies could explore how different fabric types of influence absorbency rates.

Table 4. Absorbency Time Measurements

Composition	Average time (s)
50% Box 50% Fabric	7.89
60% Box 40% Fabric	9.96
70% Box 30% Fabric	12.84
60% Fabric 40% Box	4.38
70% Fabric 30% Box	4.03

Regression analysis between Weight and Tearing Strength

The regression analysis reveals a significant inverse relationship between weight (g) and tearing strength (N) of paper samples. The linear regression equation, $y = -18.21x + 8.16$, suggests that as the weight of the paper increases, the tearing strength decreases. This outcome is likely due to the increased rigidity and reduced flexibility of heavier paper samples, especially those with a higher proportion of box material. The scatter plot clearly demonstrates this trend, with data points closely following the regression line, indicating strong consistency in the data. A negative correlation coefficient of $r \approx -0.92$ further supports this relationship, emphasizing the substantial impact of weight on tearing strength. Regression analysis revealed a strong negative correlation between paper weight and tearing strength, indicating that heavier samples tended to exhibit lower tearing resistance. This relationship suggests that increased mass, often associated with higher box paper content, leads to increased stiffness and reduced flexibility, making the paper more susceptible to tear propagation.

While the correlation coefficient indicates a strong linear relationship, it is important to recognize that tearing behavior is influenced by multiple interacting variables, including fiber orientation, bonding efficiency, and moisture distribution. Therefore, although weight is a significant predictor, it should be interpreted in conjunction with microstructural factors. The observed trend is consistent with prior studies reporting superior tearing resistance in lighter, more flexible fiber networks (Smith et al., 2020).

Figure 2. Regression graph between weight and tearing strength

Regression Between Weight and Tearing Strength
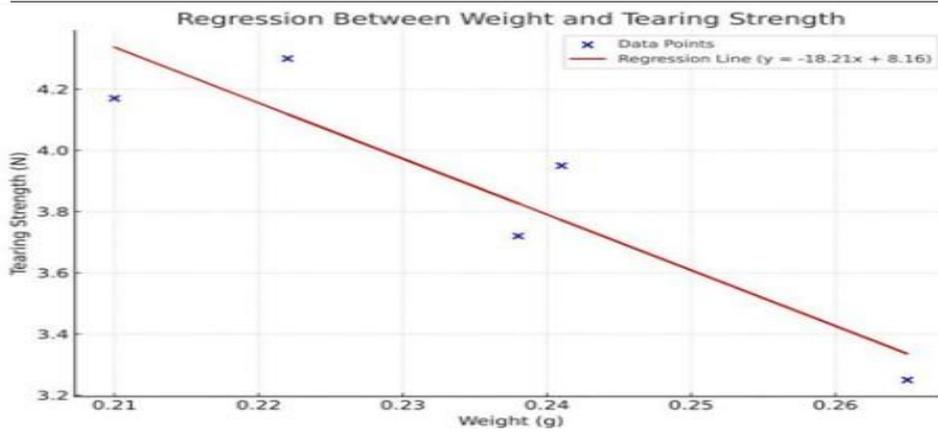
However, it is important to critically assess the strength of this correlation. While the correlation is strong, the inverse relationship may be influenced by other factors, suc as fiber orientation, moisture content, or inconsistencies in sample preparation. The weight discrepancy observed during testing could have contributed to some of the variability in the data. While the impact of this discrepancy on the overall trend is presumed to be minimal, addressing such inconsistencies in future studies is crucial to improve the accuracy and reliability of the regression model. This can be achieved by ensuring more uniform sample sizes and considering additional variables, such as fiber bonding efficiency, environmental conditions during drying, or variations in moisture content.

In comparison with existing literature, the results are largely consistent with findings by Smith et al. (2020), who reported that lighter materials tend to exhibit superior tearing resistance due to their greater flexibility and reduced brittleness. This aligns with the trend observed in our samples, where lightweight papers, often with a higher fabric content, demonstrated higher tearing strength due to their flexible and hydrophilic properties. On the other hand, heavier samples with more box material exhibited lower tearing strength because their compact structure reduces flexibility, making them more prone to tearing.

CONCLUSION

This study evaluated the feasibility of producing sustainable paper using calico fabric and box paper as raw materials. The findings demonstrate that paper made from these materials exhibits desirable mechanical properties, such as tearing resistance, thickness, and absorbency, which vary based on the composition used. Paper with a higher proportion of calico fabric exhibited enhanced tensile strength and reduced absorbency times, making it suitable for applications requiring durability and moisture resistance. Conversely, compositions with more box paper provided greater tearing resistance and structural stability, highlighting their potential for heavy-duty uses, such as packaging.

Based on the combined analysis of visual characteristics, thickness, weight, tearing resistance, and absorbency, the 50% box paper–50% calico fabric composition demonstrated the most balanced performance. This composition achieved adequate tearing strength, moderate absorbency, and uniform structural properties, making it suitable for a wide range of practical applications. Importantly, it also represents an efficient utilization of both textile and paper waste, reinforcing the sustainability objectives of this study.

The optimal ratio of calico fabric to box paper depends on the intended application, as variations in material proportions significantly influence the final paper properties. Compositions with higher calico fabric content showed superior tensile strength and absorbency, while those with higher box paper content enhanced tearing resistance. These results demonstrate the versatility of using recycled materials to achieve tailored paper properties, which can serve a variety of industrial and commercial applications.The findings underscore the potential of calico fabric and box paper as eco-friendly alternatives to traditional wood pulp. By reducing reliance on virgin wood fibers, this approach supports sustainability, reduces environmental degradation, and aligns with circular economy principles. However, discrepancies in weight measurements observed during this study suggest the need for consistent weight tracking during the testing phases to ensure accurate analysis. Despite the small-scale scope of this study, the results lay a strong foundation for future research into scalable production methods, reinforcing the viability of using recycled materials in sustainable paper production.

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