

FROM WASTE TO WORTH: COMPARATIVE ANALYSIS OF MECHANICAL PROPERTIES IN RECYCLED PAPER

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How can handmade recycled paper contribute to the reduction of waste? If paper is recycled in order to reduce waste, would there be any changes in its properties?

INVESTIGATION

This study to make recycled paper using the waste paper from Ulaanbaatar Empathy School. The quality of paper estimated tear resistance, ink absorbing capacity and speed.

AIM

We do not have paper recycling system, therefore we encouraged to recycle the waste paper using easygoing method. We aimed to provide recycled paper to our school club running by students.

OBJECTIVE

The Objective of this project to make a simple and sustainable method for recycling waste paper within our school. We collected paper from different sources including as used notebooks, office paper (A4), carton paper, used tissue paper for hand drying, and glossy paper. In Mongolia, we produced 186,000 tons of paper waste from 2,402,500 tons of total solid waste ending up with completely no recycled system [1].

RESEARCH QUESTION

How to make recycled paper and choose correct paper based on their mechanical properties?

BACKGROUND RESEARCH

Paper is most useful thing in daily school life to communicate, educate, report and even exam. However, it is changed into waste if we cannot recycle properly. Recycling paper is not only affected for biology group students but also to make our school environmentally friendly. First of all, we collected waste from different sources and then estimated mechanical properties to choose suitable recycled paper to use.

HYPOTHESIS

We thought that we can make strong and durable recycled paper if we determined suitable ratio of raw paper materials.

VARIABLES

Table 1. List of variables of the research

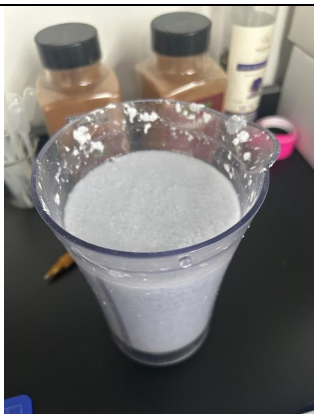
Independent Variable: Paper type, Mixture ratio	1. 4 types of paper prepared: A4 paper, tissue paper, carton paper, glossy paper. 2. 4 sets of mixture of A4 : Carton are prepared: 20:80, 50: 50, 80:20, 90:10.
Dependent Variable: • Tear resistance • Ink absorbing capacity and speed	First, A4 paper, tissue paper, carton paper, glossy papers tear resistance, Ink absorbing capacity and speed were measured. Secondly, recycled A4 paper, tissue paper, carton paper, glossy papers tear resistance, Ink absorbing capacity and speed were measured.
Controlled Variable: 1. Mass of dry waste paper 2. Time of soaking the paper 3. Rinsing time 4. Volume of water we used 5. Drying time 6. Time to make paper pulp	
Uncontrolled Variable: 1. Room temperature 2. Room humidity 3. Fiber content 4. Size of paper pulp used for recycle	

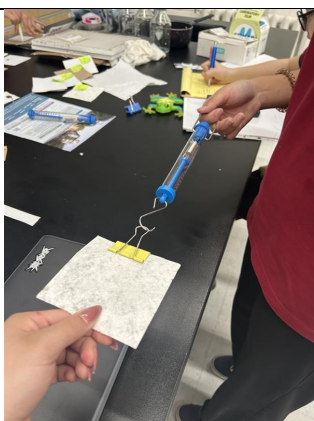
MATERIAL AND EQUIPMENT

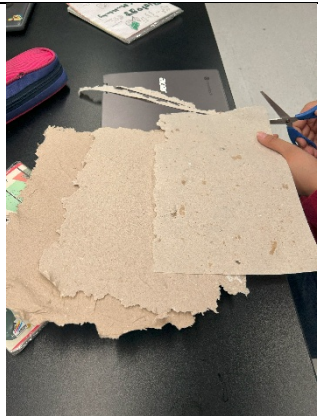
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|----------------------------|----------------------------|
| 1. 20L water container – 4 | 7. 21cm : 29.7cm frame – 4 |
| 2. Scissors – 6 | 8. Blender 2L – 1 |
| 3. 500mL beaker – 2 | 9. Spatula – 6 |
| 4. Digital weight – 1 | 10. Sponge – 6 |
| 5. Dynamometer 20 N – 2 | 11. Stapler – 4 |
| 6. Rulers – 6 | 12. Drying Pan – 6 |
| | 13. Timer – 3 |

METHOD

Recycled paper was made following procedure:

No	Procedure	Picture
1	Collecting waste papers from restroom, kitchen, library, and school canteen.	
2	Cut 1 kg papers from each type into the tiny pieces, and soak it in 10 L of water for 24 hours.	
3	Weight 200 grams of wet paper. Blend it for 10 minutes to make a pulp.	
4	The 200 grams of shredded paper were dissolved in 5 liters of water, and the paper was then extracted. At this stage, the paper is extracted from the solution using a pan, forming a thin layer of paper on the surface of the pan.	

5	The paper is removed from the pan and placed on a dryer, where it is dried at room temperature for 48 hours.	
6	After that, samples of the paper before and after recycling were cut into 10×10 cm pieces. The tear resistance of the samples was determined using a dynamometer.	
7	The same samples were also used to study ink absorption and ink spreading rate. For this, 1 mL of black ink was dropped onto each sample, and after it was fully absorbed and dried, the diameter of the resulting stain and the time taken for complete spreading were measured.	

8	After studying the properties of the recycled paper, mixtures of A4 and cardboard paper in ratios of 20:80, 50:50, 80:20, and 10:90 were prepared, and the properties of the recycled paper were measured.	
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SAFETY PROCEDURE

1. **Material Sorting:** Implement safety protocols for handling various types of paper. For instance, avoid mixing contaminated materials with clean recyclables to minimize health risks.
2. **Equipment Safety:** Ensure that machinery used in the recycling process is well-maintained and that workers are trained on safe operation procedures.
3. **Personal Protective Equipment (PPE):** Ensure that workers wear appropriate PPE such as gloves, safety glasses, and masks to guard against dust and potential allergens.
4. **Choose the Right Scissors:** Use the appropriate type of scissors for the task (e.g., safety scissors for children, sharp household scissors for general use).
5. **Focus:** Pay attention while cutting. Avoid distractions that could lead to accidents.

RESULTS AND DISCUSSION

The figure 1 shows the tear resistance (N/m^2) of different types of paper — Glossy Paper, Cardboard, A4, and Tissue — before (blue) and after (red) recycling.

All types of paper show a significant decrease in tear resistance after recycling. Glossy paper has the highest tear resistance before recycling (424.2 N/m^2) but drops dramatically after recycling (10 N/m^2). Cardboard, A4, and Tissue also show noticeable reductions.

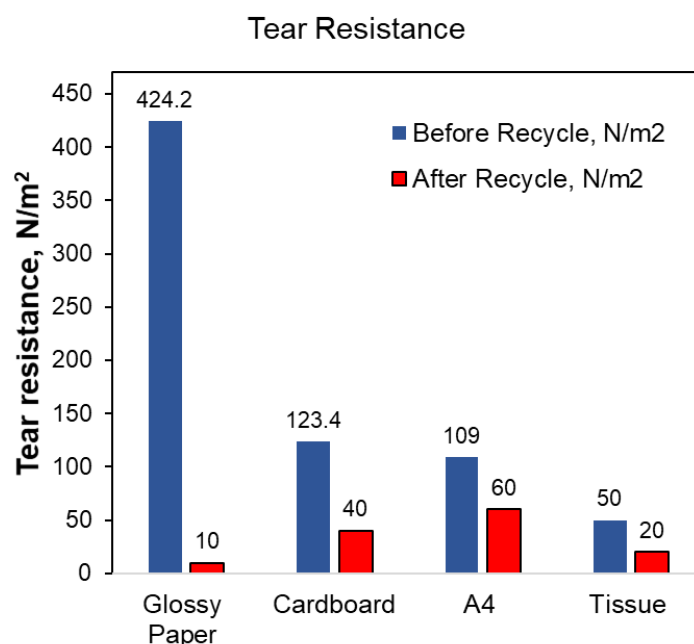


Figure 1. Tear resistance papers before and after recycle

The decrease in tear resistance after recycling the paper may be due to the following reasons. During recycling, mechanical processes like pulping, agitation, and drying break down and shorten the cellulose fibers [2]. Shorter fibers mean the paper matrix becomes weaker and less able to resist tearing.

In figure 2, before recycling, Cardboard has the largest ink diameter ($\sim 5.8 \text{ cm}$), indicating that ink spreads significantly on its surface, likely due to its texture or absorbency. Tissue follows with $\sim 2.4 \text{ cm}$, while Glossy Paper ($\sim 1.3 \text{ cm}$) and A4 ($\sim 1.1 \text{ cm}$) have smaller diameters, suggesting smoother or less absorbent surfaces. This graph shows how recycling affects ink spread on four paper types: Cardboard, Tissue, A4, and Glossy Paper. The blue bars (before recycling) are always taller than the red bars (after recycling), meaning the ink diameter shrinks after the process. For Cardboard, it's a huge drop—from 5.8 cm to 1.2 cm ! Tissue goes from 2.4 cm to 1.9 cm , while A4 and Glossy Paper see smaller changes: 1.1 cm to 0.9 cm and 1.3 cm to 0.8 cm , respectively. This means less ink spreading, which is great for printing—smaller ink dots can make text or images sharper and clearer, perfect for high-quality prints.

Recycling likely changes the paper's texture or absorbency. Cardboard's big reduction suggests it gets less porous, so ink can't spread as much. A4 and Glossy Paper, probably smoother to start with, don't change as drastically—maybe their surfaces resist the recycling effects more. Also, the ink diameters are more consistent after recycling, shrinking from a range of 1.1 cm to 5.8 cm down to 0.8 cm to 1.9 cm.

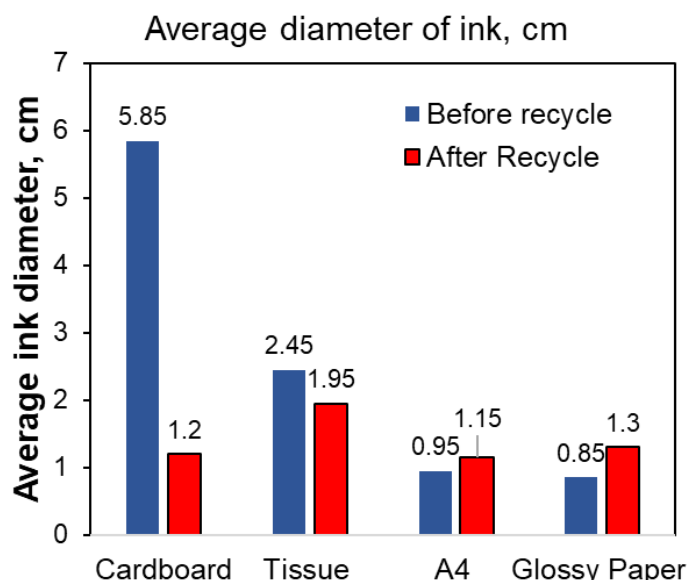


Figure 2. Average ink diameter spread on paper

After this we choose to mix A4 and Cardboard paper because they have highest tear resistance after recycle. In figure 3, shows what happens when you mix A4 and Cardboard in different ratios to make recycled paper. It looks at two things: how strong the paper is (tear resistance, in blue) and how much ink spreads on it (ink diameter, in orange). The x-axis goes from a 20:80 A4-to-Cardboard mix to a 90:10 mix. The blue line, tear resistance, starts super high at 40 N/m² when there's mostly Cardboard (20:80). But as you add more A4, it drops a lot, down to just 5 N/m² at 90:10. That makes sense—Cardboard's thicker and tougher, while A4 is flimsier, so more A4 means the paper tears more easily. The orange line, ink diameter, is interesting. It starts at 1.2 cm at 20:80, jumps up to 1.8 cm at a 50:50 mix, then drops back to 1.2 cm at 90:10. So, ink spreads the most when the mix is balanced—maybe because Cardboard soaks up ink while A4's smoother surface doesn't, and together they create a sweet spot for ink spread. Basically, more A4 makes the paper weaker but can help with printing since less ink spread (at 90:10) means sharper prints. It's a trade-off between strength and print quality.

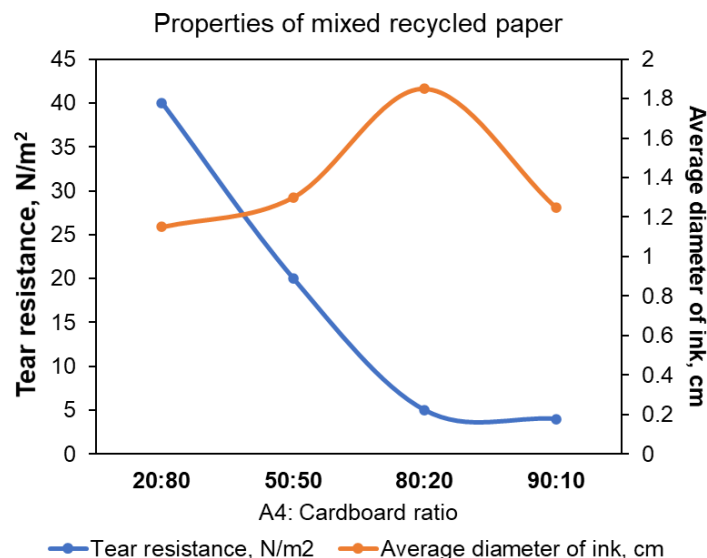


Figure 3. Properties of mixed recycled paper

In table 2 shows ink spreading speed by second. We use paper sample with 10cm×10cm.

Table 2. Ink spreading speed

Paper type	Before recycling, second	After recycle, second
A4	15	4
Tissue	35	4
Cardboard	67	5
Glossy paper	97	5
20:80 (A4:Cardboard)	-	9
50:50 (A4:Cardboard)	-	4
80:20 (A4:Cardboard)	-	21
90:10 (A4:Cardboard)	-	9

CONCLUSION

Recycling significantly enhances paper quality by reducing ink spread, improving print sharpness. For Cardboard, ink diameter decreases from 5.85 cm to 1.2 cm, and for A4, it drops from 1.15 cm to 0.95 cm post-recycling. Mixing A4 and Cardboard at a 20:80 ratio optimizes both strength and printability, achieving a tear resistance of 40 N/m² and an ink diameter of 1.2 cm. This blend leverages Cardboard's durability, which persists after recycling, ensuring robust paper. Although tear resistance falls to 5 N/m² at 90:10, the 20:80 mix balances resilience and minimal ink spread, making it ideal for durable, high-quality recycled paper.

REFERENCES

- [1] Solid waste Report 2021 from Environmental and Economy system, National Statistics Office of Mongolia, p-11.
- [2] Hubbe, M.A. (2007). "Paper's Resistance to Tear and Pulling Apart" BioResources, 2(1), 32–63.