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THE EXPERIMENT OF RECYCLED PAPER-MAKING PROCESS AND ITS WATER RESISTANCE ON A HOUSEHOLD SCALE INDUSTRIAL

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ABSTRACT

White paper waste is generally recycled into pulp as a basic material for making new sheets of paper. Recycled paper panels can be used as building elements. The objects of observation in this research include the manufacturing process and water resistance of recycled paper panels on a household scale. The method of making paper using a household blender compared with a paper chopper. The resulting paper pulp from these two tools is then mixed, printed, and tested for water resistance. Paper models without binding media were used as standards, compared with organic binding media made from tapioca flour and white adhesives. Four different paper thicknesses were made to test their water resistance performance. As a result, paper with a white adhesive binder can last more than 30 minutes after exposure to water and, when dry, can be reused. In contrast, paper without a binding medium is damaged by water.

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1. Introduction

Waste is one of the main problems that still occurs in the world. Paper has quite a complex waste problem from the process of making paper from paper pulp or pure wood, which causes a lot of waste and high pollution to post-use of paper, which causes waste. According to The World Counts (2023), waste production requires an average of 2,700 liters of water for 1 ton of paper. About 93% of paper comes from trees. About 50% of business waste is paper. Suvachan et al. (2021) stated that the paper manufacturing industry generates large amounts of waste. Rivera et al. (2016) noted that this waste is usually incinerated to produce energy or disposed of as a landfill. Wastepaper that has not been processed is a form of waste that has not been appropriately handled. The World Counts states that recycling 1 ton of paper saves around 1,400 liters of oil, 26,500 liters of water, and 17 trees. Even though a revolution in the use of electronic devices has been carried out and is predicted to reduce the use of paper, until 2023, the reduction in paper will not occur, and it is expected to double by 2030.

Indonesia also consumes a lot of paper. According to Sistem Informasi Pengelolaan Sampah Nasional data, Indonesia produces more than 18 million tons of waste annually, more than 10% of which is paper waste, and more than 38% of which comes from households. Mao et al. (2022) researched the possibilities of recycling paper for decarbonizing soil. Paper crumbling can be used to improve soil quality. However, there are other possibilities for utilizing recycled paper as building materials.

This paper aims to research the process of making recycled paper panels in a household-scale industry rather than using advanced technology. The reason for using simple, appropriate technology is society's general condition, which does not have unique skills and tools. It is hoped that with a simple production method, society can use and replicate the results of this research so that they have a broad impact.

2. Literature Review

Architecturally, paper can be used as partitions, finishing elements, and aesthetics in interior spaces. In Japan, paper has been used as a material for interior partitions or walls since ancient times, with the existence of shoji (Japanobjects.com, 2023). Several studies have been carried out regarding using paper as a building material, including recycled paper. Viscusi et.al. (2023) noted the importance of household recycling behavior impact. Their research in the U.S. showed that the price of recycled materials impacts the recycling process. Several studies examined the values and possibilities of using recycled

paper. Azevedo et al. (2019) examined waste produced by the paper industry. One of the conclusions drawn from this research is that waste in the form of paper fibers can be used for the ceramic and cement-based construction industry. Several researchers have carried out research focusing on using recycled paper materials.

Qin et al. (2022) examined recycled paper made from holocellulose fiber from the sisal plant fiber compared to cellulose fiber. Paper recycling experiments showed that holocellulose fibers experienced a decrease in strength of 28% compared to cellulose fibers, which experienced a reduction of 74.3%. Ang et al. (2020) examined the comparison of cellulose nanofiber (CNF) derived from wood pulp and recycled wood pulp. The CNF being compared is bleached de-inked pulp (DIP) recycled from eucalyptus fibers with bleached eucalyptus kraft (BEK). The energy required to use recycled paper is 7% lower, and the BEK tensile index can be increased by using DIP CNF as reinforcement. This research concludes that recycled paper pulp may be used as an alternative raw material for paper. Recycled paper material can be combined with other materials in buildings. Abdulmunem et al. (2023) conducted experiments using inner cladding using recycled wastepaper (RWP) with phase change materials (PCM) in polyvinyl chloride (PVC) panels in five rooms in Baghdad. During the experiments, the integration of PCM with 75% RWP increased the acoustic insulation by 7%, reducing the cooling and electrical energy by 19 and 16.3%.

It is also possible to mix recycled paper material with other materials. Cusido et al.(2015) examined the use of paper mud in clay brick mixtures in industry. Research shows that paper mud is suitable for use as a clay mixture because it still has mechanical strength, improved thermal and acoustic qualities, does not produce hazardous materials when burned, and the result is similar to ceramic products that use 100% clay. Kumar et al. (2021) combined waste paper with personal protection equipment (PPE) kits, which were formed into pulp to make recycled paper. The ratio of PPE kits to used paper is adjusted to needs. For example, to reduce echoes in the auditorium, it is recommended to use recycled paper boards in a ratio of 30% PPE kits to 70% used paper. Suryandono and Wihardyanto (2017) researched the durability of recycled paper boards mixed with cement and using tapioca glue as a binder. The soaking experiments showed that recycled paper boards with a thickness of 1 cm could last for about 20 minutes. With the addition of cement, recycled paper can last more than 30 minutes.

Viera et al.(2016) examined the technical, economic, and environmental benefits of using a paper-mud mixture on clay bricks. Paper mud is used for 10% of the weight of conventional clay bricks burned at a temperature of 750C. Technically, this brick meets the mechanical standards requirements in Brazil. Release of SO2, NOx, TOC, CO, and other materials according to standards. The mixture can reduce prices by as much as 3% compared to conventional clay bricks. Thieblesson et al. (2024) added a recycled paper panel with starch and clay mortar to increase fire resistance. They found that adding 10% clay to the recycled paper mixture can meet the class E resistance to fire requirements.

3. Research Method

This research uses experimental methods. The model-making process is carried out in the laboratory and then tested. The manufacturing process's effectiveness level is recorded based on the paper volume and the time required to recycle the recycler into pulp. There are two objects of observation in the process of making recycled paper. The first aspect is the effect of soaking time on the melting speed. The second is the effectiveness and efficiency of using a household blender with a specially made blender. Then, the printing and drying process continues to prepare recycled paper as panel material. After the recycled paper is finished, the object of observation is the recycled paper's resistance to water. The flow diagram of the research process can be seen in Figure 1. The orange color shows observations on the process of making recycled paper. The blue color shows experimental observations of water resistance.

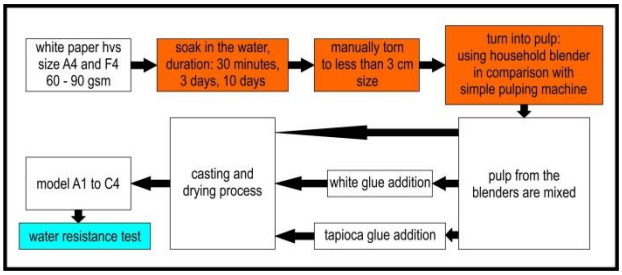

Figure 1. Research process flow diagram.
Source: Researcher documentation

The process of making recycled paper begins by soaking the paper in water. The duration of soaking time varies between 30 minutes, 3 and 10 days. After washing, the paper is made into pulp using a blender commonly used in households to crush food. As a comparison of the pulping process, a household blender, which is usually used for food ingredients, and a simple paper shredder, which is generally used in small, micro, and medium businesses (MSMEs). The results of the paper pulp made with a household blender and a paper shredding machine are visually and physically similar. The resulting paper pulp through these two processes is mixed in the same ratio to make recycled paper.

In this research, recycled paper was made into three models. The first is paper, which uses bonds between paper pulp without additional binding media. The second model uses tapioca flour as a binding medium, and the third uses white glue.

Three models of recycled paper were created. First, paper without binding media. This model is made by placing recycled paper pulp directly into a mold to dry. The mixture ratio for the first model is 1 kilogram of paper pulp with 15 liters of water. The second model is recycled paper mixed with water and tapioca starch binder. The organic binder is made by mixing 250 grams of tapioca flour in 5 liters of water and cooking over low heat using a gas stove. This mixture was stirred for about 15 minutes until smooth, thickened, showed signs of gelatinization, and changed color from powdery white to cloudy transparent (Figure 2). Once ready, mix the recycled paper and tapioca glue until evenly mixed with a ratio of 1 kilogram of paper pulp, 5

liters of liquid tapioca glue, and 10 liters of water. The third model uses Fox brand white glue as a binding medium. White glue is mixed with recycled paper until evenly distributed and printed. The ratio used is the same as tapioca flour, namely 250 grams of white glue mixed with 5 liters of water. The mixture of recycled paper and white glue is stirred until evenly mixed with a ratio of 1 kilogram of paper pulp, 5 liters of liquid white glue, and 10 liters of water.

Figure 2. Making tapioca flour glue.
Source: Researchers' documentation

After mixing evenly, all the recycled paper models were poured into a square wooden mold measuring 20 × 20 centimeters. To speed up drying, a sponge is used to absorb water by pressing and sucking water from the surface of the paper (Figure 3). The three paper models are printed into sheets with four different thicknesses, namely 1.5, 3, 4, and 5 mm. The drying process is carried out for about four weeks by placing it on a cloth, airing it at room temperature, and not exposing it directly to sunlight.

Figure 3. Paper printing process and drying with a sponge.
Source: Researchers' documentation

4. Results and Discussions

4.1 Recycled Paper Model-Making Process

The process of making recycled paper panels begins with soaking the paper. All paper used is white HVS paper between 60 – 90 grams in size A4 and F4. The hypothesis in this process is that soaking in water will make it easier to destroy the paper. Three different time durations are used. First, soak for 30 minutes to wet all parts of the paper. The second duration is 3 days to make the paper softer, making it easier to destroy. The longest duration used in this research was 10 days, with the aim that the paper had started to rot so it would be easier to eliminate. The paper with different soaking durations is then crushed manually by tearing it to a size of ± 5 cm to make it easier to pulverize. During the observations, it was found that there was no significant difference in the tearing process of paper soaked for more than 30 minutes. When all paper parts are wet, they can be processed further. Apart from the smell that appears due to the rotting process around the 8th day, paper that has been soaked for too long is more difficult to tear manually because the paper sticks together. It is recommended to make recycled paper until it is thoroughly wet and then shredded into smaller sizes to fit and make the pulping process easier. A household blender does not allow it to be used for whole A4 or F4 size paper, even if it is wet.

After being torn into smaller sizes, the paper is then blended. The blender used is a Cosmos blender type CB 282 with a capacity of 2 liters. This blender was chosen to represent a commonly used blender in households and is readily available on the market. For the record, this blender's primary function is for food ingredients and not paper. The specifications for paper shredding equipment made explicitly for MSMEs are 0.5 HP with a capacity of 20 liters. During the experiment, the capacity written on both machines could not be used optimally. For the blender, only about 0.25 kilograms of wet paper goes in. The paper shredding process is also not optimal because the blender stops automatically every 15 – 25 seconds to cool the machine. It takes more than 3 minutes, not including waiting for the blender to cool down and crush the paper. Blender cooling times vary. The UMKM paper shredding machine is used to shred around 4 kilograms of paper and takes around 1 minute, not including the time to adjust the paper's position so that the machine spins again. This machine does not require rest time to cool down, but there are times when it stops rotating because the paper gathers near the cutting blade, so it needs to be stirred/rearranged. Blender machines specifically for paper are much more effective and efficient in processing time. For pulp results, visually and physically, the two blenders are similar, but there is no significant difference.

The resulting paper pulp that has been mixed and molded is then dried under normal room conditions without drying in the sun. The dryness level of the material is seen visually and physically. After the color of the paper becomes brighter, it will be ready for testing in around four weeks for a thickness of 5 millimeters. The thinnest paper in this experiment, with a thickness of 1.5 millimeters, only took about four days to dry. In this research, a total of 12 models were prepared. Physically and visually, the A model has a rougher surface and feels more fragile. Model C feels the most solid and strong. Details of the model and its description can be seen Table 1.

Table 1. The models and the detailed specifications

Specification	Thickness (millimeters)			
	1.5	3	4	5
Recycled paper without glue	Model A1	Model A2	Model A3	Model A4
Recycled paper with tapioca glue	Model B1	Model B2	Model B3	Model B4
Recycled paper with white glue	Model C1	Model C2	Model C3	Model C4

Source: Researchers' documentation

4.2 Recycled Paper Water Resistance

Once ready, the twelve models were tested for water resistance by placing them in water. Three buckets filled with water, recycled paper models, and a stopwatch/time measurement were prepared to record this process. Three parameters measure water resistance: wet, slightly damaged, and destroyed. Wet means that all parts of the recycled paper are exposed to water, which is indicated by a change in color to a darker color. Slight damage is marked by a change in shape in the form of bending to a small tear (less than 3 cm) when the paper is lifted. Crushed means a tear of more than 3 cm, or the paper cannot be removed from the water because it is crushed. The wet and heavily damaged/destroyed conditions during the experiment can be seen in Figure 4. The water in the bucket was calm, and there was no wind influencing it, but when the paper was submerged, there was water movement due to the damage checks being carried out. The water resistance hypothesis for recycled paper is that the thicker the paper, the more resistant it is to water. Likewise, the binding media mixture affects the durability of the paper.

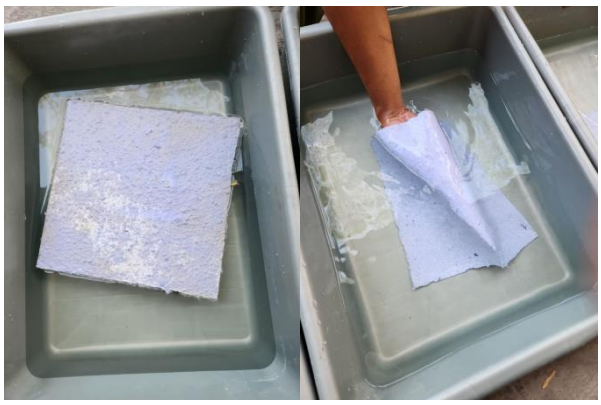

Figure 4. The process during the experiment was partially wet (left) and damaged/destroyed (right).
Source: Researchers' documentation

The experimental test of the resistance of paper of all models with a thickness of 1.5 mm to water can be seen in Table 2. Recycled paper without a binding media mixture does not have high resistance to water because once it touches water for less than 1 second, it immediately gets wet and sinks. When it was lifted from the bottom of the bucket, it immediately buckled, and after about 20 seconds, a large tear broke. Tapioca glue only increases the resistance by 2 to 3 times to get wet sinking. And slightly damaged. However, the model has a reasonably strong bond because even though it bends in the water, it doesn't tear until around the 5th minute when a big tear occurs. The white glue on the C1 model has a significant effect compared to the A1 and B1 models. Despite having a similar thickness, the C1 model lasts about 60 times longer than the A1 model or 4 times longer than the B1 model. The use of binding media in the form of glue significantly influences the water resistance of recycled paper. The binding medium in white glue makes the model take longer to get wet when tested.

Table 2. The water resistance experiment result of 1.5 mm thickness recycled paper

Model name	Resistance duration		
	Wet	Small damage	Severe damage
Model A1	Less than 1 second	2 seconds	20 seconds
Model B1	2 seconds	6 second	5 minutes
Model C1	1 minute 50 second	3 minutes	20 minutes

Source: Researchers' documentation

Table 3 shows the results of experiments on the resistance of recycled paper with a thickness of 3 mm to water. The A2 model gets wet quickly, even when placed on the water's surface. The B2 model is about 3 times more wet-resistant, and the C2 model is about 80 times more moisture-resistant than the A2 model. The C2 model is robust; even after more than 7 minutes, it only bends slightly even though it is wet. Until the specified experimental time limit, namely 30 minutes, the C2 model remained undamaged even though it had been submerged and could survive being lifted from the water. Model C2 was then dried again.

Table 3. The water resistance experiment result of 3 mm thickness recycled paper

Model name	Resistance duration		
	Wet	Small damage	Severe damage
Model A2	3 seconds	30 seconds	20 seconds
Model B2	10 seconds	2 minutes	8 minutes 30 seconds
Model C2	2 minutes 45 seconds	7 minutes 50 seconds	More than 30 minutes

Source: Researchers' documentation

Similar to 3 mm paper, the water resistance experimental results of paper with a thickness of 4 mm show significant differences between models A3, B3, and C3. As seen in Table 4, the A3 model remains the weakest and is easily damaged, from when it gets wet to when it breaks. Even though it gets wet relatively quickly, namely around 20 seconds, the B3 model has a resistance of 5 minutes until the model bends, and it takes around 20 minutes for significant tears. The C3 model took over 6 minutes to get wet and lasted 30 minutes without tearing or falling apart. Like the C2 model, the C3 model also survives when lifted from the water surface. A special note is that the C3 model does not sink even when it gets wet. It is possible that even though the surface of the recycled paper board is all wet and visually even, the inside is still dry, so the C3 model does not sink. The other models with a thickness of 3 mm and less than 3 mm fell during the experiment.

Table 4. The water resistance experiment result of 4 mm thickness recycled paper

Model name	Resistance duration		
	Wet	Small damage	Severe damage
Model A3	12 seconds	40 seconds	1 minute 14 seconds
Model B3	20 seconds	5 minutes	20 minutes
Model C3	6 minute 10 second	10 minutes 10 seconds	More than 30 minutes

Source: Researchers' documentation

White glue binding medium provides high resistance to recycled paper. The A4 model without bonding media remains wet and disintegrates relatively quickly. Although the B4 model got damp and bent, it didn't sink. Model B4 floats in water and can survive without significant tearing/destruction for more than 30 minutes. Models B4 and C4 were then removed and dried from the water.

Table 5. The water resistance experiment result of 5 mm thickness recycled paper

Model name	Resistance duration		
	Wet	Small damage	Severe damage
Model A4	20 seconds	1 minute 10 seconds	2 minutes
Model B4	40 seconds	15 minutes	More than 30 minutes
Model C4	8 minute	More than 30 minutes	More than 30 minutes

Source: Researchers' documentation

The hypothesis in this research was that the thicker the paper, the more resistant it is to water. Likewise, the presence of a binding medium affects the resistance of recycled paper to water. With the same mixture, the A4 model has 20 times more resistance to wet resistance, 35 times more resistance to light damage, and 60 times more resistance to heavy damage/crushing than the A1 model. The B4 model has 20 times the wet resistance, 150 times more resistance to light damage, and more than 30 times the resistance to heavy damage/crushing compared to the B1 model. The C4 model has 5 times the wet resistance, more than 10 times the resistance to light damage, and more than 1.5 times the resistance to heavy damage/crushing compared to the C1 model. In particular, models C3 and C4 exceeded the experimental time limit in this study, namely 30 minutes, to monitor until destruction. Although Model B4 experienced light damage, severe damage/destruction did not occur until the time limit of the experiment.

5. Conclusion

Recycled paper has the potential to be used as panel material, which can be used as partitions or architectural elements in interior spaces or building interiors. Following the research hypothesis, the thicker the paper, the more resistant it is to water. The binding element also significantly increases the water resistance of the paper. The C4 model has 24 times the wet resistance of the A4 model and can withstand damage for more than 30 minutes. The A4 model only lasted about 2 minutes before falling apart.

This research concludes that paper, as the primary material without a mixture of other materials, is already water resistant, provided that a bonding medium in the form of glue needs to be added. Based on experiments, tapioca glue can be used as a binding medium for recycled paper panels with a minimum thickness of 4 mm. It can withstand significant damage even if exposed to water for 20 minutes. Using white glue bonding media, a panel with a thickness of 3 mm is sufficient because it can last more than 30 minutes when in contact with water. Meanwhile, even though it has the most significant thickness, recycled paper without binding media does not have high resistance to water. Paper without a binder absorbs water very quickly, and because it doesn't have a binder, the model soon experiences water damage.

This research shows the possibilities of using recycled paper for building materials, such as constructing a panel using recycled paper for room partitions, especially in the interior setting. Recycled paper panels are also easy to be shaped. This adds other possibilities for using recycled paper panels as decorative interior elements.

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