Sci. Technol. Arts Res. J., Oct.– Dec. 2024, 13(4), 44-53
DOI: https://doi.org/10.20372/star.V13.i4.04
ISSN: 2226-7522 (Print) and 2305-3372 (Online)
Science, Technology and Arts Research Journal
Sci. Technol. Arts Res. J., Oct. – Dec. 2024, 13(4), 44-53
Journal Homepage: https://journals.wgu.edu.et
Original Research

Production of pulp and paper from Enset fiber at a commercial scale

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Abstract

Pulp is a commodity originating from cellulosic fiber and used for papermaking. The source of cellulose is wood (like Eucalyptus.) and non-wood like Enset. Enset is a local plant that is a staple food for millions of people in Ethiopia. At the national level, we are importing pulp and paper with an estimated value of 130,000,000 USD on average. To minimize the import burden, we have implemented research out for pulp and paper making from Enset fiber at a commercial scale by using the soda method. The leftovers after food processing and the growth stage were collected and utilized by the industries locally. From Enset fiber, both brown and white paper have been made and characterized for their quality at a 30% virgin pulp and 70% recovered pulp mixture. Tensile, burst, and tear strength were selected and tested. According to the result, commercial paper was suited standard and a promising product to utilize Enset fiber as pulp instead of cutting and deforesting trees and bamboo for pulping.

Article Information

Article History:
Received: 14-10-2024
Revised : 21-11-2024
Accepted : 09-12-2024

Keywords:
Enset Fiber, Fiber Cooking, Cellulose Pulp, Enset Paper, White Paper, Brown Paper.

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INTRODUCTION

Pulp is a lignocellulosic fibrous material prepared chemically, semi-chemically, or mechanically from cellulosic fibers of wood, fiber crops, waste paper, or rags. Cellulose is abundantly found in wood and other lingo-cellulosic plants. It has been mainly derived from wood since Burgess and Watt in England employed caustic soda to pulp wood chips in 1851(Singh et al., 2019).

In chemical pulping, lignin and hemicellulose degrade into small water-soluble molecules, which are washed away from the cellulose fibers, and it is the dominant method over mechanical pulping, which involves-physically tearing the cellulose fibers apart.(Rahman et al., 2023). Paper production involves cooking, slurry formation, making paper on wire, and drying. The appearance and properties of the final products are supplemented and enhanced by finishing treatments, which can be simple processes where the reel is cut into sheets or more complex processes, such as coating or super-calendaring. Soda pulping is a chemical process that involves the application of sodium hydroxide as an extractor from lignin. The lignin polymer attaches to it and separates from cellulose. It has better use for easily pulped

materials like straw and some hardwoods(Singh et al., 2019). Several pulp and paper products are commercialized based on wood and non-wood sources. In Ethiopia there is a huge opportunity for resources, particularly biomass, exhibiting both long and short fiber for pulp making. For instance, enset fiber is one that is investigated to be a potential raw material where its physicochemical characteristics, like fiber length, fiber width, and cell, are characterized and compared with other plants. According to the comparison, the fiber obtained from enset is better than most of the listed plant fibers(Yemata, 2020).

Enset fiber has an excellent fiber length (1.75 mm), fiber diameter (22.15 μm), an acceptable Runkle ratio (0.55), and a flexibility coefficient (159.64). According to the study, high-strength mechanical properties and good surface properties of paper can be produced from banana pseudostem pulp with a more environmentally friendly pulping process(Melesse et al., 2022).

Ethiopia is the largest and most populated country in the Horn of Africa. This population rise resulted in more than 21,418,000 students being in school and demanding books, exercise books, and other packaging materials; however, there is no pulp industry that could have contributed to producing quality white paper.(Zerihun et al., 2018). Ethiopia's imports of paper and paperboard, articles of pulp, paper, and board were US$157.87 million in 2022, according to the United Nations COMTRADE database on international trade. Ethiopia Imports of Paper and Paperboard, Articles of Pulp, Paper, and Board—Data, Historical Chart, and Statistics—was last updated in October of 2024(ECONOMICS, 2024).

Moreover, horticulture, food, textiles, leather, foods, and cosmetics all import carton boxes because of quality problems in locally produced products. This whole problem goes back to the lack of virgin pulp and updated production systems(ECONOMICS 2024). More recently, there is one pulp mill called Adal Industrial PLC, established in 2018. Its capacity is designed to produce 7 tons of pulp within 9 hours, though in actual performance it is less than 4 tons daily due to a lack of resources and other constraints like foreign currency(MEFCC, 2017). Besides, two projects that were launched 10 years ago to produce pulp and paper in integrated mode are not in progress right now. Therefore, fundamental and sustainable problem-solving should be implemented based on the economic status and local opportunities of Ethiopia, particularly based on non-wood fibers. Enset (domesticated only in Ethiopia) has received special attention for manufacturing pulp and paper in Ethiopia. Here we have commercialized enset fiber for pulp and paper making at the national level.

MATERIALS AND METHODS

Raw material

In the first place, a laboratory scale was conducted to validate the possibility of papermaking from enset raw material. Enset leftovers were collected from local areas such as Butajira, Walkite, the Sidama region, and the Wonchi area. The collected samples were chopped into pieces, cooked, and made into paper according to the scheme (Figure 1). The purpose of cooking was to separate cellulose from lignin and hemicellulose (Figure 2). For cooking purposes, we mixed raw material, 1 kg of enset, and 0.2 kg of caustic soda in 5 L of water at 120 °C. The product was tested for paper product approval and validated (Figure S1).

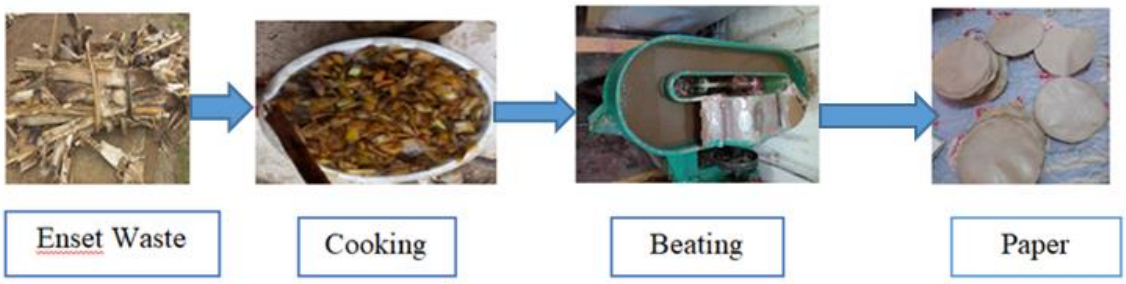

Figure 1. *Laboratory scale paper making*

The byproduct black liquor with the highest lignin content was collected and preserved for further application. Moreover, the lignin content of the pulp and paper was so high that cooking time and liquor amount needed to be adjusted and were done during scaling up (Lemma et al., 2023; Duangkaew et al., 2024; Filipova et al., 2023).

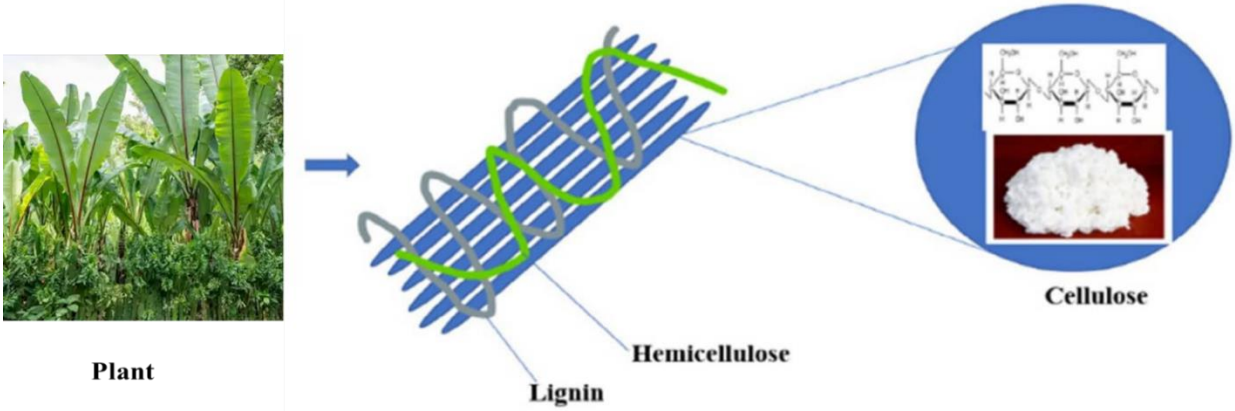

Figure 2. *Cellulose extraction from plant biomass*

Ethio-pulp and paper SC certified the product that it satisfies its local standards consumed by the factory. (Figure S2)

Validation of the working principle

The highest pulp yield was obtained when 20% (0.2 kg NaOH) in 1 kg of enset raw was used at 120 °C and a 5:1 solution-to-stalk ratio. Therefore, the paper made at laboratory scale was tested and verified at the Ethio-pulp and paper SC laboratory and satisfies local standards(Bijok et al., 2022).

Scaling up

At this stage, we have determined mass balance and energy balance along with the necessary equipment.

Raw material

For every ton of enset raw material, there was 200 kg of caustic soda in 5000 L of water. The temperature required was 1200°C, and pressure was read at 6 psi to complete digestion within 4 hours as prescribed by the procedures in the literature (Bijok et al., 2022;Huang et al., 2017). Based on the material adjustment, the scaled-up procedure was undergone at Barguba

Trading PLC. Company. In this industry, we have adjusted the steam and production line, and pulp was made and blended with waste paper at different blending proportions. The result was so good, and the certificate was provided, which signifies the potential of enset fiber for pulp and paper making in Ethiopia (Figure S1).

RESULTS AND DISCUSSION

Commercialization was conducted in two cases at Adal Industrial PLC, where standard pulp-making procedures and machines were installed. The first case was conducted by making paper from virgin pulp alone. The paper made was so strong and even looked like a metal sheet. This paper was both brown and white. The pressure gage reads at 6 psi, the temperature at 1200°C, and the cooking time is 4 hours. This was so important in the realization of making paper from enset waste in Ethiopia at a commercial scale(Zhong et al., 2018).

The second case was blended with waste paper. The blending ratio was conducted to study the effect of virgin pulp in such a way that 100:1, 90:10, 80:20, 70:30, 60:40, and 50:50 waste paper to virgin enset pulp were used, respectively. The most effective, economical, and moderate-quality product was obtained at a ratio of (70:30) waste paper to virgin enset pulp, respectively (Figure. 3). In fact, the proportions 90:10, 80:60, 40:60, and 50:50 are also allowable based on the desired product. For example, when there is strong paperboard demand, the amount of pulp to be utilized increases, whereas where there are other ordinary papers required, the proportion of pulp decreases. (Haile et al., 2021; Sheikhi et al., 2013).

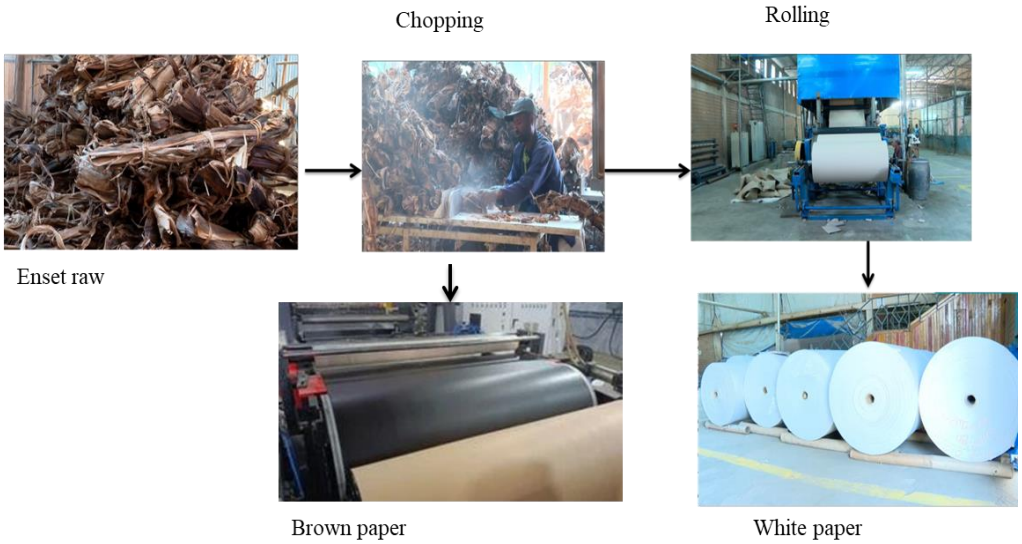

Figure 3. *White and brown roll paper made from enset at commercial scale*

Commercial white and brown paper has been made from enset fiber (Figure 3). The white paper made was at different thicknesses and is mainly for duplicating and writing papers whose common gram age is 80 GSM. However, mainly the company manufactures brown paper, like fluting medium, test liner, and Kraft liner. The quality test result obtained from the Ethiopian Conformity Assessment Authority is shown in Table 1 and Figures S3-S5. The tested result indicated quality was better than TAPPI standards (4236). In the recent result, the tear strength was greater than 4236 and proved its better performance.

Table 1

Tensile strength, tear strength, and burst strength test results for paper with various thickness.

S.No	Characteristics tested	Specification/method	Results for the various paper thickness		
			140 GSM	160 GSM	170 GSM
1	*Tensile strength* (kN/m)	ES ISO 1924-3:2015			
	Machine direction		5.664	4.11	2.78
	Cross direction		2.951	2.05	5.18
2	*Tear strength (mN)*	ES ISO 1974:2012			
	Machine direction		5296	6303	5796
	Cross direction		4847	5482	6678
3	*Bursting strength (kPa)*	ES ISO 2758:2014	170	195	196.27

CONCLUSION

Pulp and paper were manufactured at commercial scale from enset fiber by using the soda method. The paper made was white and brown. The brown paper was used for carton box making and white paper for A1, 2, 3, and 4 papers. The product quality test was conducted, by ISO method where tear strength was found to be so much higher than the other two parameters, tensile and burst strength. When compared with TAPPI standard; the recent result is better. The product produced was suited the standard and utilized by carton-making factories and the white ream was consumed by printing purposes.

CRediT authorship contribution statement

Desissa Yadeta: drafting and writing original article, Conception, Validation, review & editing.
Natea Abdo: Conceptualization, Investigation, Data curation, methodology.
Eskindir Solomon: experimentation and testing
Milkesa Jagema: Supervision

Declaration of competing interest

The authors declare that there is no conflict of interest.

Data availability

Data will be made available on request

Acknowledgment

The authors thank the Department of Chemical and Technology, Manufacturing Industry Development Institute, bio and emerging technology institute Addis Ababa, Ethiopia for providing the necessary supports.

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Supplementary Materials

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Email: bargubatradingplc@gmail.com

Ref. No BT/I361/AY/011/22
Date Aug:3/08/2022

TO WHOM IT MAY CONCERN

A research team led by D/r Desisa Yadeta and Natea Abdo in collaboration with Barguba Trading PLC has successfully completed a trial stage production of non-wood pulp. The team has successfully converted a by-product from an indigenous plant to paper with satisfactory results.

We would like to extend our sincere gratitude to D/r Desisa and the team for the relentless effort they put in for the realization of this project.

Sincerely

0911 206764
0114 450036

D/Manager
Brook Desalew

Products and Services

Paper and Paper products
Pocket, Table and Wallet Napkins
Toilet Tissue Paper
Carton Boxes, Bunching Rolls and Sheets
Edible Oil
Agricultural Seed Cleaning Service
Egg Tray
Import and Export

Figure S1. *The first certificate given for the scaling up of enset raw material for pulp and paper making.*

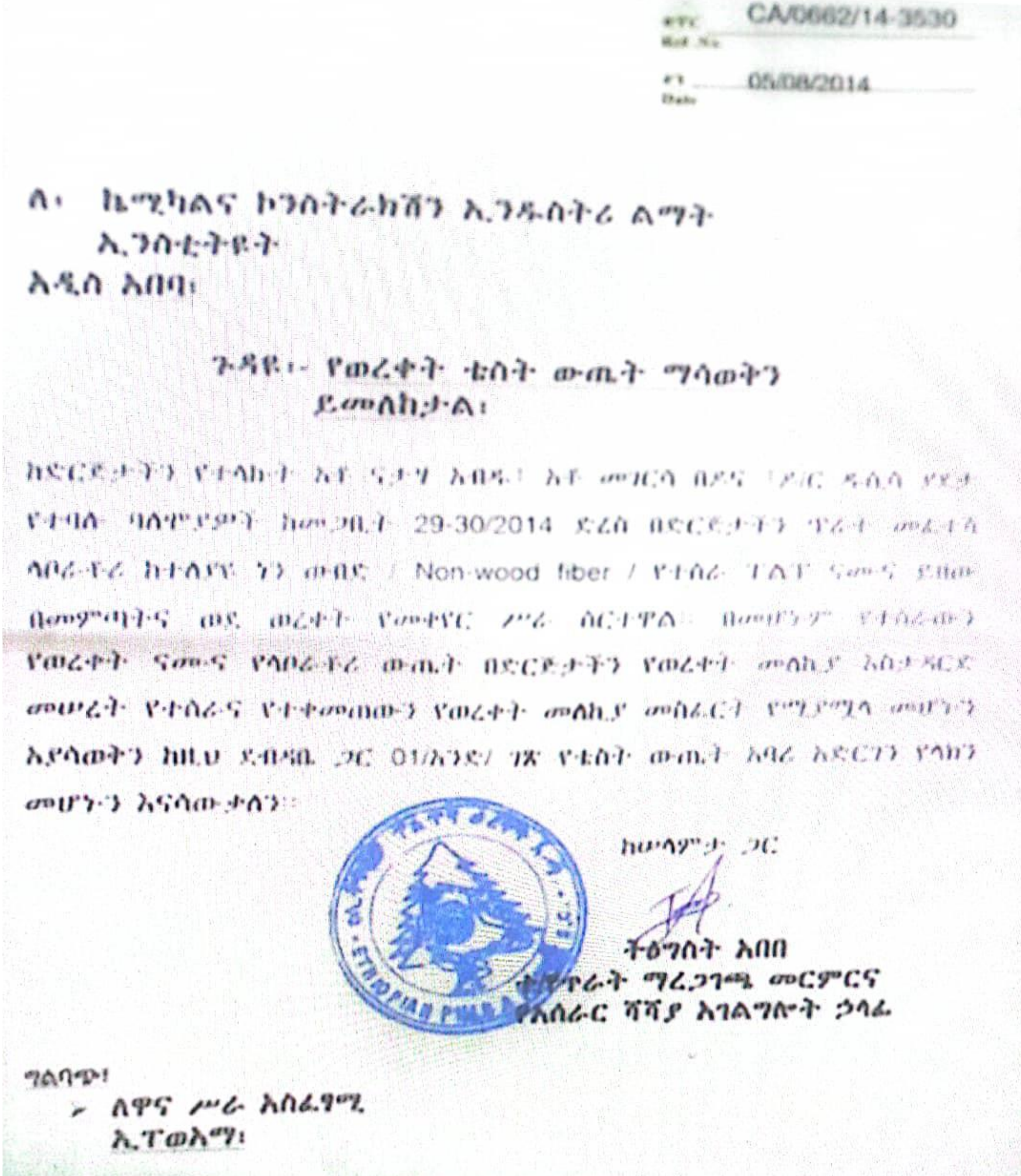

Figure S2. *The certificate of approval for pulp and paper made from enset fiber at laboratory scale.*

Client Sample code: 140 GSM
(Brand)
Type of sample: Pulp paper
Laboratory Designation Number 16169002
Sampled and submitted by Client
Date tested: 29/02/2024-07/03/2024
Method /Specification

S/N	Characteristics tested	Specification/Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1.	Tensile strength in kN/m						
	• Machine direction	ES ISO 1924-3:2015	--	--	--	5.664	--
	• Cross direction		--	--	--	2.951	--
2.	Tear strength, in mN						
	• Machine direction	ES ISO 1974:2012	--	--	--	5296	--
	• Cross direction		--	--	--	4847	--
3.	Bursting strength in kPa	ES ISO 2758:2014	--	--	--	170	--

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Zemene Mulualem Position Higher Analyst Sign.

ISO/IEC 17025:2017 Accredited Testing Laboratory:

11145 ☎ 011 6 46-05-69, Fax. 011 6 45-97-20, E-mail info-cs@eca-e.com
Web site: www.eca-e.com
BOLE SUBCITY, WOREDA 6

Figure S3. *The tensile strength, burst factor and tear factor test result for paper whose thickness 140GSM*

Client Sample code: 160 GSM
(Brand)
Type of sample: Pulp paper
Laboratory Designation Number 16169003
Sampled and submitted by Client
Date tested: 29/02/2024-07/03/2024
Method /Specification

S/N	Characteristics tested	Specification/Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1.	Tensile strength in kN/m						
	• Machine direction	ES ISO 1924-3:2015	--	--	--	4.11	--
	• Cross direction		--	--	--	2.05	--
2.	Tear strength, in mN						
	• Machine direction	ES ISO 1974:2012	--	--	--	6303	--
	• Cross direction		--	--	--	5482	--
3.	Bursting strength in kPa	ES ISO 2758:2014	--	--	--	195	--

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Yared Fikre Position Analyst II Sign.

Figure S4. *The tensile strength, burst strength and tear strength test result for paper whose thickness 160GSM*

Date sample Received:
Client Sample code: 170 GSM
(Brand)
Type of sample: Pulp paper
Laboratory Designation Number 16169004
Sampled and submitted by Client
Date tested: 29/02/2024-07/03/2024
Method /Specification

S/N	Characteristics tested	Specification/Test Method	Standard Requirements			Test result	Comment
			Min	Nom	Max		
1.	Tensile strength in kN/m						
	• Machine direction	ES ISO 1924-3:2015	--	--	--	2.78	--
	• Cross direction		--	--	--	5.18	--
2.	Tear strength, in mN						
	• Machine direction	ES ISO 1974:2012	--	--	--	5796	--
	• Cross direction		--	--	--	6678	--
3.	Bursting strength in kPa	ES ISO 2758:2014	--	--	--	196.27	--

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Zemene Mulualem Position Higher Analyst Sign.

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Figure S5. *The tensile strength, burst strength and tear strength test result for paper whose thickness 170GSM*