Improving Strength Properties of Recycled Paper by adding Virgin Jute Pulps

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Abstract

Strength properties are very important for paper grading; usually recycled fibre produce low grade paper. However, it is not easy to produce quality paper from recycled paper without addition of virgin pulp. In this study, the paper was made by mixing new pulps in different proportions with recycled pulp from used paper to explore their quality, and hence their various physical and mechanical properties were tested. A mixture of newsprint books and whiteprint books (1:1) was used to make recycled pulp through hydrapulper (a type of pulp-making machine). The reaction conditions were: temperature 50˚C, duration 30 minutes, pulp consistency 10%, sodium hydroxide (NaOH) 0.8% (w/w), sodium silicate (Na_2SiO_3) 0.8% (w/w), detergent 0.15% (w/w) and hydrogen peroxide (H_2O_2) 0.8%(w/w). The resulting pulp was thoroughly washed with tap water and the adhesive and plastic substances were removed with the help of a screening machine. Tossa jute fibre was used to make new pulp because its bastfibre and pulp quality is excellent. The fibres were first to cut into 1.5-2.0 inches and then pulp was made using the neutral sulfite anthraquinone (NS-AQ) method with an alkaline rate of 20% at 175˚C. The test papers of 8 cm diameter and 1.25 cm thickness were made by mixing the new pulp with the recycled pulp in seven proportions (90:10, 80: 20, 70: 30, 65:35, 60:40, 55:45 and 50:50).Then the physical and mechanical properties of the test papers such as freeness (rate of water removal from the pulp), tear index, tensile index, burst index, folding endurance were determined. Strength factor (Tear index × Tensile index) of produced paper are 406.29(90:10), 482.05(80:20), 588.15(70:30), 701.55(65:35), 757.26(60:40),745.53(55:45) and 820.83(50:50). The results showed that the quality of paper was increased with the increased ratio of jute fibre. It was also observed that "A" grade paper was obtained from a minimum 35% mixture of Jute pulp.

সারসংক্ষেপ

কাগজের গ্রেডিংয়ের জন্য শক্তি বৈশিষ্ট্যগুলি খুবই গুরুত্বপূর্ণ; সাধারণত রিসাইকেল্ড ফাইবার নিম্নমানের কাগজ তৈরি করে। তবে ভার্জিন পাল্প ছাড়া রিসাইকেল্ড পেপার থেকে মানসম্পন্ন কাগজ তৈরি করা সহজ নয়। এই গবেষণায়, কাগজের গুণগতমান অন্বেষণের জন্য পুনর্ব্যবহৃত পাল্পের সাথে বিভিন্ন অনুপাতে নতুন পাল্প মিশ্রিত করে কাগজ তৈরি করা হয়েছিল, এবং এদের বিভিন্ন ভৌত এবং যান্ত্রিক বৈশিষ্ট্যগুলি পরীক্ষা করা হয়েছিল। নিউজ বই এবং সাদা বইয়ের মিশ্রণ (১:১) হাইড্রোপাল্পার (এক ধরনের পাল্প তৈরির মেশিন)-এর মাধ্যমে পুনর্ব্যবহৃত পাল্প তৈরি করতে ব্যবহৃত হয়েছিল। বিক্রিয়ার শর্ত ছিল; তাপমাত্রা ৫০° সে., সময়কাল ৩০ মিনিট, মণ্ডের ঘনত্ব ১০%, সোডিয়াম হাইড্রোক্সাইড (NaOH) ০.৮% (w/w), সোডিয়াম সিলিকেট (Na_2SiO_3) ০.৮% (w/w), ডিটারজেন্ট ০.১৫% (w/w) এবং হাইড্রোজেন পারক্সাইড (H_2O_2) ০.৮% (w/w)। প্রাপ্ত মণ্ড ট্যাপের পানি দিয়ে পুঙ্খানুপুঙ্খভাবে ধৌত করা হয়েছিল এবং স্ক্রিনিং মেশিনের সাহায্যে আঠালো এবং প্লাস্টিক জাতীয়

পদার্থগুলি অপসারণ করা হয়েছিল। তোষা পাটের ফাইবার নতুন পাল্প তৈরিতে ব্যবহার করা হয়েছিল কারণ এর বাস্ট ফাইবার এবং মণ্ডের গুণগতমান চমৎকার। ফাইবারগুলিকে প্রথমে ১.৫-২.০ ইঞ্চি করে কেটে নেওয়া হয়েছিল এবং তারপরে ১৭৫° সে. তাপমাত্রায় ২০% ক্ষারীয় মাত্রায় নিউট্রাল সালফাইট অ্যানথ্রাকুইনোন (NS-AQ) পদ্ধতি ব্যবহার করে মণ্ড তৈরি করা হয়েছিল। পুনর্ব্যবহৃত মণ্ডের সাথে নতুন মণ্ড সাতটি অনুপাতে (৯০:১০, ৮০:২০, ৭০:৩০, ৬৫:৩৫, ৬০:৪০, ৫৫:৪৫ এবং ৫০:৫০) মিশিয়ে ৮ সে.মি. ব্যাস এবং ১.২৫ সে.মি. পুরুত্বের পরীক্ষণ কাগজ তৈরি করা হয়েছিল। তারপর পরীক্ষণ কাগজের ভৌত ও যান্ত্রিক বৈশিষ্ট্য যেমন ফ্রিনেস (মণ্ড থেকে পানি অপসারণের হার), টিয়ার সূচক, টেনসাইল সূচক, বার্স্ট সূচক, ফোল্ডিং সহনশীলতা নির্ধারণ করা হয়েছিল। উৎপাদিত কাগজের গুণগতমান (টিয়ার ইনডেক্স এবং টেনসাইল ইনডেক্স এর গুণফল) হল ৪০৬.২৯ (৯০:১০), ৪৮২.০৫ (৮০:২০), ৫৮৮.১৫ (৭০:৩০), ৭০১.৫৫ (৬৫:৩৫), ৭৫৭.২৬ (৬০.৪০), ৭৪৫ (৫৫:৪৫) এবং ৮২০.৮৩ (৫০:৫০)। ফলাফলে দেখা গেছে যে পাটের ফাইবার যুক্ত হওয়ার অনুপাতের সাথে কাগজের গুণমান বৃদ্ধি পেয়েছে। আরো দেখা গেছে যে, ন্যূনতম ৩৫% পাটের মণ্ডের মিশ্রণ থেকে চমৎকার মানের ("এ" গ্রেডের) কাগজ পাওয়া গেছে।

Key words: Blending, Jute pulp, NS-AQ pulping, Recycled pulp, Strength properties.

Introduction

The worldwide consumption of writing paper, printing paper, and newsprint is contracting, while packaging, tissue papers and other hygiene products are increasing (Berg and Lingqvist 2017). Paper industry mainly uses 90% wood based virgin fibre for chemical and mechanical pulp (Jahan 2003). Wood based fibre resources are declining at an alarming rate resulting in an acute crisis of raw material supply to the industries. Over the past several years, over 60% of all paper produced in the United States has been recycled and similar amounts are used worldwide (Scott 2011). In Bangladesh bamboos and hardwood species were the main raw materials in Karnaphuli Paper Mills Limited (KPML). However, the paper mill could not reach their targets of daily paper and packaging material production due to scarcity of raw materials and electricity supply. So, it is very urgent to find a new source of pulp making raw materials for attaining continuous supply of papers and boards. Recycled paper could be an important process to meet the deficiency of pulp and preserve trees in the forest. At present, almost all of the paper mills in Bangladesh are using imported pulp and recycled paper as raw materials for paper, paperboard and corrugated board. Paper produced with recycled fibre has great environmental benefits. One metric ton of recycled paper instead of virgin paper saves 4 cubic meters of wood (Shylo and Harmer 2016), 39% of total energy, 58% of greenhouse gasses, 9% of water usage, 56% of ocean acidification, 13% of hazardous air pollutants, 20% of mercury emissions and26% of dioxin emissions (Kinsell 2018). In addition to this, wastepaper can be recycled up to 5-8 times before its fibres become too short and unsuitable for further paper production (Shylo and Harmer 2016; CannyIdeas 2016).

Physical properties of paper made from wastepaper are not suitable due to short fibre (Adu *et al.* 2018). Virgin pulp provides higher grade paper products due to their longer fibre lengths (Sheikhi *et al.* 2013). Quality paper products can also be produced from recycled pulp by mixing with certain percent of virgin pulps; because with recycling fibre lengths gradually decrease. In the search for a potential long-fibre substitute for softwood pulp, Akhtaruzzaman and Shafi (1995) suggested jute fibre as an appropriate solution. Jute is a natural fibre containing a high value of cellulose and low lignin content (13.7%) (Nahar 1987). The fibre length (2.5 mm) is also good (Shafi *et al.* 1993b). This favors the pulping of jute fibre. It was reported that NS-AQ pulping is a promising process for pulping of jute fibre (Akhtaruzzaman *et al.* 1988; Akhtaruzzaman 1994; Shafi *et al.* 1993a).

Besides, most popular kraft pulping process in the worldwide (Misbahuddin *et al.* 2019) paper industries has some disadvantages including low yield and the paper mill effluent characteristically containing lignin, suspended solid, sulfur and sulfur compound (Ruiz 2011). Bad odor of effluent creates an unhygienic environment. The NS-AQ process of jute pulping reduces this bad odor (Shafi *et al.* 1993a). Therefore, the study is undertaken to improve strength properties of recycled packaging material by blending with virgin jute pulp in various proportions.

Materials and Methods

Raw material collection and processing

Waste paper (newsprint book and whiteprint book) were collected from wastepaper supplier at Aturar Depo in Chattogram. Waste papers were shorted for removing stapler pins, treats and laminating paper. Physical strength of waste paper like tear, tensile, burst and folding endurance were evaluated. Jute fibre was collected from Chattogram local market. The fibres had been cut into 1-1.5″ size and stored into a polythene bag for preparation of pulp.

Hydrapulping of recycled pulp

A mixture of newsprint books and whiteprint books (1:1) was used to make recycled pulp through hydrapulper (Gear ratio: 1:2:1 hydrapulper size: 3.0 ft, Impellor rpm: 800 Impellor, dia: 18.5 inch, Machine serial: P57-1907) a type of pulp making machine.

Table 1. Reaction conditions for hydrapulping of recycled pulp

Parameters	Value	Role
Temperature	50°C	-
Duration	30 minutes	-
Pulp consistency	10%	-
Sodium hydroxide (NaOH)	0.8%	pH maintenance
Sodium silicate (Na_2SiO_3)	0.8%	Ink collector
Detergent	0.15%	Surfactant
Hydrogen peroxide (H_2O_2)	0.8%	Deinking

Thereafter, pulping is done for 10 minutes at 15amp current, adding 150 ml. H_2O_2 for bleaching; again hydrapulping for 15 minutes according to Table 1. The resulting pulp was thoroughly washed with water and the adhesive and plastic substances were removed with the help of a Johnson Vibratory Screening machine. The wet pulp was passed through a screw press to remove excess water and then pulp was refreshed by pulp mixture.

Jute pulping

Six pulps were prepared with neutral sulphiteanthraquinone (NS-AQ) process (Shafi *et al.* 1993a). In this purpose 250 g of oven dry jute fibre were charged in the 2 liter stainless steel autoclaves placed in an electrically heated air bath. Analytical grades of Na_2SO_3 and Na_2CO_3 were used as cooking chemicals. Cooking time was 3.5 hours at 175°C. The time required to raise this temperature from room temperature was 90 minutes. The liquor to fibre ratio was 7:1 (v/w). Active alkali (AA) dose was 20% and anthraquinone charge was 0.1%. After each cook, the fibres were discharged and the black liquor was collected for residual alkali determination. The cooked fibres were taken in a screen box and washed overnight under running water to wash out the residual liquor. These were stirred slightly with water in a bucket by a slow speed electric mixture. The pulp slurry was then screened through 0.012 inch wide slot ftat (Johnson vibratory) screen to separate any uncooked material from the pulp. The wet pulp was passed through a screw press to remove excess water, and then samples were taken for dry matter content. The pulp yield was determined. The kappa number was determined using TAPPI methods T236 cm-85.

Hand sheet making and physical testing

The test papers of 8 cm diameter and 1.25 cm thickness were made by mixing the new pulp with the recycled pulp in seven proportions (90:10, 80: 20, 70: 30, 65:35, 60:40, 55:45 and 50:50).The pulp samples were beaten in a PFI mill to achieve a Canadian Standard Freeness (CSF) (rate of water removal from the pulp) of 250±3 ml (SCAN-C 21:65) and hand sheets were made. These were then conditioned at 23±1°C temperature and 50±2% relative humidity and tested according to SCAN-C 28:69 for determining the physical strength properties such as tear index, tensile index, burst index and folding endurance (Biswas *et al.* 2017).

Statistical analysis

The physical strength properties were evaluated from five sheets for each beating. Then the mean and standard deviation were calculated. The graphical extrapolated values at 250 CSF were represented by regression.

Results

Active alkali consumption of neutral sulphiteanthraquinone (NS-AQ) pulping of jute was 19.41%. The yield of jute pulping was found 69.71% on average and the average kappa number was 11.60. The lignin content of a pulp sample was (1.74%) calculated by multiplying the kappa number by a factor of 0.15 (Jiang 1992). Physical strength properties such as tear, tensile, burst and folding endurance were evaluated in the newsprint book and whiteprint book (Table 2). Newsprint books and whiteprint books were selected for recycling pulp. The paper sheets made from 100 percent recycled pulp and also recycled pulp blending with different proportions of jute pulps (90:10, 80:20, 70:30, 65:35, 60:40, 55:45 and 50:50) physical strength properties were calculated (Table 3).

Table 2. Physical strength properties of different grade waste paper.

Paper grade	Tear index (Nm/g)	Tensile index (mNm^2/g)	Burst index ($KPam^2/g$)
Newsprint book	7.57±0.82	56.18±2.77	2.18±0.11
Whiteprint book	5.04±0.30	48.22±3.73	2.31±0.35

Table 3. Physical strength properties of paper sheet made from different proportions of mixing of recycled (newsprint book and whiteprint book) and new (jute) pulp.

Recycled Pulp (%)	New Pulp (%)	Beating (rpm)	CSF	Tear Index (mNm^2/g)	Tensile Index (Nm/g)	Burst Index ($KPam^2/g$)	Folding Endurance (log10d)
100	0	0	300	6.38±0.00	32.97±2.27	2.09±0.14	1.13±0.04
		1000	250	6.01±0.28	40.82±1.67	2.40±0.23	1.40±0.10
		1500	220	6.19±0.00	44.07±2.01	2.52±0.19	1.47±0.11
90	10	0	320	8.93±0.29	34.74±2.23	2.49±0.13	1.55±0.09
		1000	290	8.52±0.50	42.60±1.72	2.91±0.30	1.90±0.20
		2000	230	8.40±0.59	51.20±1.17	3.50±0.16	2.01±0.16
80	20	0	400	10.72±0.84	35.52±3.13	2.50±0.12	1.61±0.10
		500	380	11.26±1.05	40.14±2.62	2.79±0.21	1.80±0.11
		1500	320	9.80±0.59	45.81±5.41	3.47±0.18	2.12±0..07
		3500	220	8.97±1.08	54.75±0.90	3.96±0.45	2.35±0.21
70	30	0	440	11.00±0.29	38.93±3.77	2.63±0.26	1.67±0.15
		500	410	12.23±0.58	45.86±1.87	3.25±0.31	1.95±0.10
		2000	310	11.03±0.29	55.57±2.41	4.30±0.23	2.46±0.10
		4000	220	10.69±0.58	58.66±1.72	4.62±0.35	2.64±0.13
65	35	500	450	13.39±0.29	43.71±3.73	3.22±0.71	1.82±0.15
		2000	330	12.80±0.58	55.81±1.97	4.53±0.51	2.41±0.15
		4000	230	11.43±0.29	59.86±2.57	4.78±0.76	2.60±0.08
60	40	500	460	16.81±0.28	43.45±2.77	3.60±0.22	2.12±0.09
		2500	310	13.79±1.55	55.32±2.17	4.52±0.41	2.78±0.11
		4500	200	11.68±1.40	60.52±0.81	5.44±0.21	2.81±0.09
55	45	1000	450	17.32±0.29	49.74±2.26	4.04±0.25	2.16±0.07
		2500	340	13.22±0.77	56.90±1.59	4 94±0.25	2.80±0.08
		4500	230	13.51±1.24	59.94±1.13	5.82±0.36	2.70±0.18
50	50	1000	470	15.82±1.17	51.33±1.73	3.77±0.51	2.12±0.14
		2500	350	15.32±0.49	56.42±3.04	4.84±0.81	2.60±0.11
		4500	240	13.06±0.50	62.35±2.29	5.74±0.80	2.82±0.05

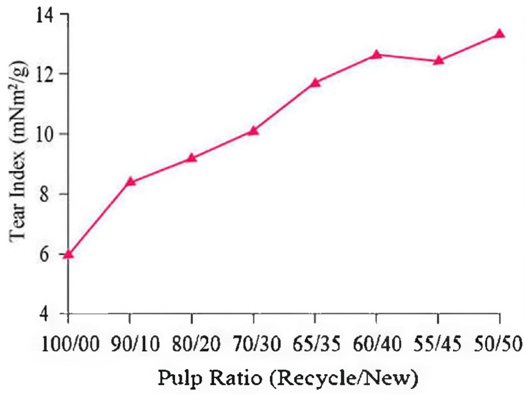

Figure 1. Tear index versus pulp ratio at 250 CSF

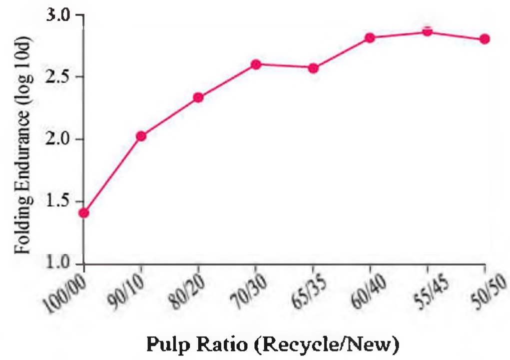

Figure 4. Folding endurance versus pulp ratio at 250 CSF

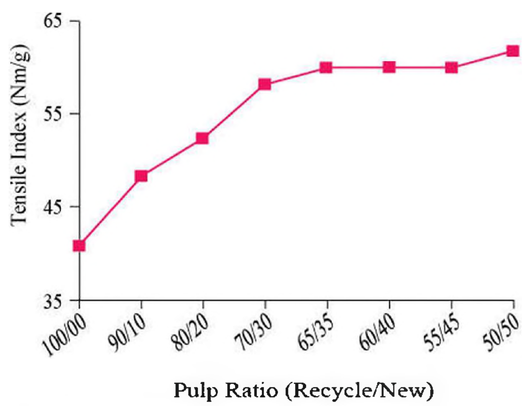

Figure 2. Tensile index versus pulp ratio at 250 CSF

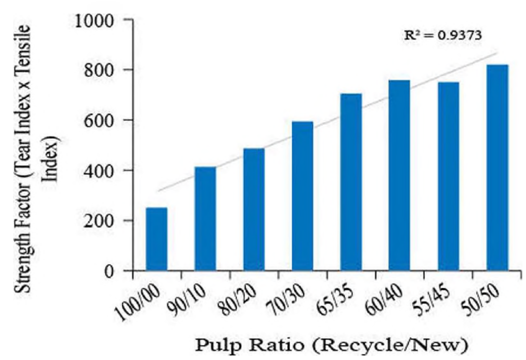

Figure 5. Paper strength at different pulp ratios

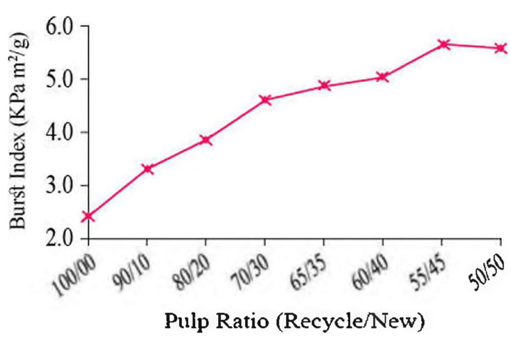

Figure 3. Burst index versus pulp ratio at 250 CSF

The mechanical properties of the paper gradually increased with the increasing portion of virgin pulp which are shown in Fig. 1 to Fig. 4). R^2 value of strength factor of different pulp ratio is shown in Fig. 5.

The following TAPPI test methods (Anon 1992) were used for sheets analysis:tear index (T 414 om-88), tensile index (T 404 om-87), burst index (T 403 om-91) and folding endurance (T 423 om-89). Paper properties are shown in Table 4 where papers made from different ratios are graded following Akhtaruzzaman *et al*. (1997).

Table 4. Properties of paper were made from mixed recycled (newsprint book and whiteprint book) and new (jute) pulp.

Recycled: New Pulp	Excellent (A grade) ≥ 700	Properties (Strength Factor) (Tear Index × Tensile Index)		
		Good (B grade) 700-600	Fair (C grade) 600-500	Poor (D grade) ≤500
100:00	–	–	–	245.33
90:10	–	–	–	406.29
80:20	–	–	–	482.05
70:30	–	–	588.15	–
65:35	701.55	–	–	–
60:40	757.26	–	–	–
55:45	745.53	–	–	–
50:40	820.83	–	–	–

Discussion

Recycled fibres had a poor quality due to the paper forming and drying process and have much lower freeness rates compared to virgin fibres. During refining of the newsprint book and white paper book some features were upgraded but it forms more fines that lead to lower dewatering rate. Drainage of recycled fibres are improved through addition of virgin jute pulp. The important charge groups in fibres are carboxylic acids found in the hemicellulose components (Sjostrom 1989). In this respect, the total charge on virgin pulp is much higher than recycled pulp due to the removal of the hemicelluloses during the recycling process (Rosli *et al.* 2001), contributing to the increase in wetness upon addition of virgin jute fibres. Which is probably due to the increase of pulp's wetness. High yielding long fibre pulp was one of the choices to blend with recycled pulp. The high yield (69.71%) of jute pulp could be the result of high value of cellulose and low lignin content in jute fibre and the NS-AQ method (Akhtaruzzaman *et al.* 1988). A noticeable effect of beating is observed by blending recycled pulp with jute pulp for the drain ability of pulp suspension. It is observed that pulp freeness value of recycled pulp is very low, which signifies a pulp difficult to de-water (Ek *et al.* 2009) at the time of paper making. The tensile index of paper depends on the bonding ability, flexibility, strength, and length of the individual fibres (Nazhad 2005; Fiserova *et al.* 2010). Although beating may decrease both the average length and strength of the fibre, the dominating effect on tensile strength is the increased bonding. (Ek *et al.* 2009).That's why, it is noticeable that the tensile index is increased up to 35% addition of virgin jute pulp. After that, it remained constant or was slightly increased with further addition of jute pulp. The effect of blending virgin jute pulp with recycled fibres on the tensile index appears that the virgin fibres could restore the tensile strength of the recycled papers after 35% addition, which could be due to the substitution of the passive recycled fibres with the more active fibres of the virgin jute pulp. Virgin jute fibres were able to absorb water and swelled to a higher degree than the recycled fibres. Swelling is an important factor in the development of paper strength by virtue of increasing fibre flexibility; the more flexible the fibres, the more their conformation can be altered that could enhance inter fibre bonding between themselves and the recycled fibres, thus increasing the tensile strength. The inactivity of the recycled fibres is a consequence and drying, which reduces the capabilities of the fibres to swell because of hornification. Szwarcsztajn and Przybysz (1974) reported a similar finding and they attributed it to the presence of more active fibres in virgin jute pulp. Blending with virgin jute fibres had a more pronounced effect where even at a low addition of 10%, the restoration is already completed. This enhancement is ascribed to increase in the bonded area of the sheet resulting from internal and external fibrillation that occurs during beating.

It is clearly noticed from the tear index versus pulp ratio at 250 CSF that the tear index was sharply increased with the addition of new pulp. It has happened for jute fibres of long fibre length, since longer fibres naturally provide more points of bonding and are pulled a longer average distance from within the network (Ek *et al.* 2009). However, it is interesting to note that the effect of addition of virgin jute pulp is negligible. It is possible that the amount of new active sites generated is not sufficient to increase new inter fibre bonding needed to further increase the tear index. Tear strength is found 12 mNm^2/g after adding 35% virgin jute pulp. Burst Index and folding endurance were also linearly increased with the addition of new pulp. Standard strength properties value of prepared paper samples were found at the mixture of virgin pulp 35% and recycled pulp were 65%. The tearing resistance of paper hand sheets, considered in conjunction with the tensile strength, is probably the most commonly used direct measurement of paper strength potential, as others have suggested (Allison 1992). Tearing resistance is a function of both fibre strength and fibre bonding, though limited by fibre strength. It is evident that both tearing resistance and tensile strength increase with pulp blending irrespective of whether the pulp is unbeaten or beaten. This has been explained as a result of replacement of the passive recycled fibres with active virgin jute fibres, which has generated new sites for inter fibre linking. The addition of virgin fibres has, as expected, further enhanced the development of both indices. It is however of significance to note that at high tear strength, the improvement of tensile strength effectively ceases at about 59.91 Nm/g high, suggesting that no further bonding is occurring (tear continue to rise due to the continuing substitution of poor bonding material with virgin fibres). When product of tear and tensile strength value is greater than 700 then that paper is A-grade paper according to Akhtaruzzaman *et al.* (1997). Hence, A-grade paper at the ratio of 35% virgin and recycled pulp was produced where R square value is highly significant.

Conclusion

The study result shows that, it is possible to produce good quality paper from recycled paper upon addition of certain proportion of new pulp. Jute pulp could be commercially used as a new pulp with recycled pulp. NS-AQ process produced good quality pulp from jute fibre (Tossa) with 69.71% (w/w) yield. At a minimum of 35% addition of jute pulp, high quality A-Grade paper could be produced. However, further research is recommended on blending the recycled pulps with other long fibrous virgin pulp to improve recycled papers strength.

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