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Neutral Sodium Sulphite Pulping of Jute for Making Paper Bag for Packaging Application

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For a plant-based lignocellulosic substrate, pulping is an essential process for producing paper. This process requires a notable quantity of alkali-based chemicals as well as thermal energy. Mostly, sodium hydroxide and Kraft pulping processes are commonly practised to produce paper, where strong alkali is used to remove a substantial percentage of hemicellulose, and sodium sulphite is used to remove the major part of lignin, to accomplish a cellulose-rich pulp, although pulp yield is less. But for handmade paper making, the pulping process is expected to produce higher yield, with lower dosage of chemical involvement, enabling the process to be suitable for adoption by the cottage industries. In the present work, an effort was made to address the conventional lower-pulp-yield, high effluent generation and high chemical involvement pulping process, following an innovative Neutral-Sodium-Sulphite (NSS) pulping process, also known as semi-chemical pulping. Here, a mild alkali, i.e., sodium carbonate, was used in place of strong sodium hydroxide alkali, along with a lower dosage of sodium sulphite, which helped to achieve a higher pulp yield of 81.5% and a paper-specific tensile strength of 0.53 N/g/m^2. The concentration of sodium sulphite was varied in the range of 10– 25% on the weight of fibre to produce paper sheets of 115 ± 5 g/m^2 (gram per square meter, GSM) and its effect on paper's tensile, tearing, bursting, folding, colour and morphology properties was studied in detail. In the case of brown paper, the achievable folding endurance was about 1000, bursting index of 4.0 and tear index of 14. Many of these properties were found to enhance when the paper was produced from bleached pulp. The pH of process-discharge liquor, being near neutral, does not pose a severe impact on the environment. The developed paper sheets were also characterized in terms of printability, water absorbency and bag formability for its application as disposable packaging as an alternative to plastic.

Keywords: Handmade paper, Jute fibre, Lignocellulose, Natural fibre, Paper bag

Introduction

The pulp and paper industry is one of India's oldest and core industrial sectors with a high economic contribution in terms of employment generation and development of speciality paper products. The demand and consumption of paper are a relative measure of a society/ country, as far as their development is concerned in terms of finance, education, packaging, mass communication, advertising, excursion, and service sectors, where large amounts of paper are consumed. Both wood, non-wood and recycled paper resources are conventionally used to produce paper and boards that are mostly composed of cellulose, hemi-cellulose and lignin in varying proportions. India has about twenty-eight hundred small-scale paper units that largely rely on cotton-based secondary materials, viz., knitted and tailor remnants in addition to discarded paper.[1,2] The need for paper is projected to increase in the coming years due to rapid growth in education, hospitality, packaging, e-commerce, and developing products, as an alternative to plastic. The paper industry faces a shortage of raw materials, which is worsening as demand increases with societal development. So, searching for alternative sources of raw material, recycling of products and development of processes that result in higher productivity are some of the avenues that need to be adopted by the sector. The majority of the raw materials used in the handmade paper sector are wastepaper, paperboard, hosiery cuttings, cotton rags, wood pulp, and other materials. Hardwood, softwood, and jute-like lignocellulosic materials require a pulping process to produce handmade paper, after removing hemicellulose and lignin. To mitigate the demand - supply value chain of pulp, alternative raw materials like fibre crops and agri-biomass are also being explored.[3,4] In this context, jute fibre can play a vital role in the production of handmade paper. The cooking of lignocellulosic jute fibres is an important step before paper making, which

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requires a lot of thermal energy and alkali-based chemicals, with simultaneous production of pulping-liquor waste. Furthermore, sequential step-wise bleaching and bleaching in highly alkaline bath could also draw environmental challenges. Pulping and bleaching using fewer-chemicals or lower temperatures may lead to the development of an environmentally friendly process.[5–7]

The pulping is an important essential process prior to formation of paper-sheet from any raw materials including wood.[8] This process needs to remove the non-cellulosic components (hemicellulose and lignin) from the raw material, which are mostly carried out by (a) chemical pulping; (b) mechanical pulping; (c) chemo-mechanical pulping; (d) biological pulping; (e) semi-chemical pulping.[9,10] All such processes produce a distinct quality pulp, appropriate for certain category of paper production. For instance, chemical pulping mostly lowers the pulp realization, while ensuring adequate disintegration of wood-fibres to develop a requisite grade of paper. In the process wood-fibres possess with higher length that leads to development of paper with appropriate tensile and physical properties.[11] Originally, paper was made from non-wood materials such as papyrus, hemp and textile rags. With the development of technologies for isolating pulp from wood, abandoning non-wood sources and their cost-effectiveness make them a preferred choice. However, the trend is now being reversed, and pulp making from non-wood sources, viz., agricultural fibre crops, grasses, shed tree leaves, fibrous fruit shells, and others, is once again gaining importance for commercial ventures. It is also meaningful in the context of deforestation and abundance of such non-wood materials at lower cost, while ensuring post-harvest management of such crop residues in the context of circular economy.[12]

Neutral-Sodium Sulphite Semichemical (NSSS) pulping is an innovative semi-chemical process of pulp making, consisting mechanical and chemical processes. The NSSC is generally caried out in three stages namely., impregnation of wood chips in sulphite chemicals, raising the temperature to 100°C for better penetration of the cooking liquor for woody substrates, then digestion of pre-treated substance at 160–190°C, and lastly, the material undergoes beating/ refining mechanical action.[13,14] Here, the digested liquid mostly composed of sodium sulphite for lignin solubilization in the presence of sodium carbonate, sodium hydroxide, or sodium bicarbonate buffer to address the liberated wood-acid. Processes generally produce higher pulp yield owing to high residual lignin (15–20%).[15]

Jute is a plant-based bast fibre that is largely produced in India, Bangladesh, Nepal, Mynamar, mainly used for making hessian and sacking bags for storage of food grains and sugar. Jute fibre has also been explored in the area of technical textiles viz., agro-textile, geo-textile, composite, and acoustic & thermal insulation. Jute is annually renewable plant, and its production is about 1.5 million tons per annum, excluding the stick and leaves. Currently, good quality of jute fibre is also being used for making lifestyle products, apparel & home textiles in pure or blends, utility bags, ornaments and upholstery items, after the requisite chemical treatment like bleaching, dyeing, printing and finishing. Though this fibre or whole biomass has a huge potential to be used as an alternative raw material in the pulp and paper industry, it has not been explored properly, and scanty work has been reported in this field. Jute mill-processed waste fibre and jute root-cuttings could also be judiciously used to manufacture paper products. Jute fibre is rich in cellulose content (60%–65%), as compared to many other paper-making raw materials like hardwood, softwood, bagasse, etc. Thus, in the recent past, jute fibre as well as sticks were utilised for making paper of different g/m^2, attempting different pulping methods.[4,7] In the conventional pulping process of jute and other biomasses, pulp yield is very low, resulting in low raw material realization.

In the present study, an effort was made to use lower-grade jute fibre to produce handmade paper using semi-automatic paper-making machinery in a batch process. Such intervention would also show a pathway for conversion of waste into wealth, while highlighting an alternative raw material to the commonly used wood/ forest resources for paper making. This can also reduce the gap between demand and supply of raw materials for handmade paper making and establish new applications for jute fibre beyond its traditional use as an agricultural packaging bag.[16] The novelty of the work is that, as the pulp yield from the lignocellulosic material/ fibre in the conventional alkaline pulping process is less, a new neutral-sodium-sulphite semi-chemical (NSSS) pulping process was attempted for achieving higher pulp yield. The NSSC is an innovative semi-chemical pulping process that has been explored for wood

substrates in the past, however, a similar study is not reported for jute fibre. Pulp was also bleached using an environment-friendly single-stage hydrogen-peroxide bleaching agent. The concentration of sodium sulphite was varied from 10–25% with an increment of 5% in the experiment. The effect of sodium sulphite pulping followed by oxidative bleaching action on the paper's tensile and optical properties was studied in detail. Considering the application of the developed paper in this pulping process as a packaging material, quality as well as performance of paper in terms of printability, bag formability, water absorbency, tensile load and structural morphology were evaluated in detail.

Materials & Methods

Materials

Good quality jute fibre is mainly used for making textile products. In this study, jute fibre of lower quality (grade TD5-TD6) was used for paper making. The following laboratory-grade pulping- chemicals were utilized for developing paper: caustic soda (sodium hydroxide), sodium sulphite, Hydrogen Peroxide (H_2O_2), Trisodium Phosphate (TSP), sodium carbonate and sodium silicate.

Pulping of Jute

Prior to neutral-sodium-sulphite (NSS) pulping jute, the fibre was cut into 2.5 to 5 cm in length in the fibre cutting machine. Pulping was carried out in a rotary digester machine in the presence of sodium sulphite and sodium carbonate with a 1:10 fibre-to-water ratio at 160°C for 3 hours. Prior to raising the temperature to 160°C, it was increased stepwise initially to 100°C and held for 60 min for better chemical penetration. The sodium sulphite-to-sodium carbonate ratio was kept at 3:1, based on the weight ratio calculated from the oven-dry weight of fibre. Four different concentrations of sodium sulphite were varied, namely, 10, 15, 20 and 25% on the weight of jute fibre. For each digestion batch, the size was kept at 5 kg jute fibre.

Bleaching of Jute Pulp

To produce a brown-coloured paper sheet, bleaching of pulp is not required. However, to produce white paper for its versatile applications, the digested pulp was subjected to bleaching action with hydrogen peroxide (H_2O_2) of 20 ml/L at 80–85°C for a duration of 90 min, maintaining the pulp-to-water ratio at 1:15 and pH of 10 using sodium silicate (10 g/L), sodium hydroxide (1 g/L), and trisodium phosphate (5 g/L). After the process, the bleached pulp was washed in fresh water, then neutralised in acetic acid solution (2 ml/L), rewashed in fresh water and air-dried.

Paper Sheet Formation

Digensted pulps were subjected to beating operation in a pilot-scale beater for different durations to produce pulp of 40° SR freeness value. Paper sheets of 115 ± 5 g/m^2 were produced using a semi-automatic sheet former machine from both the unbleached and bleached pulps. Finally, all the paper sheets were squeezed in a hydraulic press to remove excess water and then air-dried. Such paper sheets were subjected to hot-pressing for 3 min at 110°C, and the final dimensions of the paper sheet were 74 cm × 59 cm.

Evaluation of Paper Sheet

Whiteness Properties: The developed paper sheet was stored in a specified environment before the measurement of whiteness properties. Colour parameters, viz., Whiteness Index, Yellowness Index and Brightness Index of the brown as well as bleached handmade papers, produced by the different pulping processes, were determined in a Premier Colour-scan SS-6200 machine coupled with a Spectrascan-5100 computerized colour matching system. Canon 5D Mark III SLR camera (Japan-made) was used to capture the image of various samples.

Physical and Tensile Properties: Jute paper sheets were conditioned in 65% relative humidity at 27°C for 48 h in a conditioning chamber following the BIS recommendation (IS: 6359–1971) before any physical and mechanical test. Different properties of papers were measured by following different standards like tensile properties by TAPPI Test Method – T404 om-85 in tensile strength tester Veb Thuringer Industriewerk, Raunstein (Germany) keeping the gauge length of 100 mm, bursting Index by TAPPI Test Method – T403 om-85 using digital bursting strength tester (UEC-2010D, UEC India), tearing strength as per TAPPI – T414 om-88 in tearing strength tester by UEC, Saharanpur and folding endurance as per TAPPI T423 om-89 standard – using a fold endurance tester (UEC-1007B, Universal Engineering Corporation (UEC), Saharanpur, India).[1]

SEM Surface Morphology: Surface morphology of paper sheets was examined under the Scanning

Electron Microscope (SEM, Model: SNE-3200M, SEC Co. Ltd., Korea, supplied by Alfa Tech. Services, New Delhi) by typifying the surface at 100-700X. Prior to imaging of paper samples to typify the surface features, samples were coated with a conductive metal to eliminate the surface charging.

Water Absorbency Time and Contact Angle: Water absorbency is an important parameter to understand behaviour of a paper sheet in contact of liquid, particularly for their application in packaging. Liquid absorbency (water) of the paper-sheet was evaluated following AATCC 79-2007 standard, putting a 35 µL water droplet on the paper sheet. Time required by the droplet for its complete absorption in the paper was measured as water-absorbency-time and the average of five such measurements is reported. Water-contact-angle was measured by sessile drop principle on the paper samples, keeping the water droplet volume at 3.4 µl and taking the photograph of water droplet in Canon 5D Mark III SLR camera (Japan-made), as reported in our earlier work .[18]

Printability: For the application of paper sheets as a packaging bag, its printability in terms of colour reality, print sharpness and colour stability to rubbing was performed. The paper was subjected to printing using the screen-print process with synthetic colour. The synthetic colour Calmatt Vivid Green C-318 printing colour, supplied by Calcutta Inks, Kolkata 700 053, was used to print the paper.

Development of Paper Bag: Bags were designed and developed for their application as a gift bag, and the dimensions were kept at height of 18 cm × width of 13 cm × depth of 7 cm.

Results and Discussion

Pulping and Paper Sheet Formation

In the present study, the potential of jute fibre has been explored for making paper and paper bags, beyond its conventional applications in fabric packaging bags and other textile products. An effort was made to use the lower-grade jute fibre to produce handmade paper using a series of semi-automatic paper-making machineries. This intervention may underscore the gap between the demand and supply of raw materials for handmade paper manufacturing, while suggesting an alternative raw material to the frequently used wood/forest based raw materials for the pulp & paper industry.[16] As far as raw materials in the paper industry are concerned, the presence of cellulose in a material plays an important role. Jute fibre contains a higher percentage of cellulose (60–65%), as compared to hardwood (35–45%), softwood (40–45%), bagasse (35–40%) and rice straw (35%), thus having potential for paper making with higher yield.[19] Initially, the temperature was raised to 100°C for better penetration of the cooking liquor in the jute fibre structure, as reported for non-fibrous material.[20,21] The yield of pulp was calculated with the change of sodium-sulphite (SS) dosage and found to be 81.5%, 79.1%, 77.1% and 74.9% for the sodium sulphite concentration of 10%, 15%, 20%, and 25%, respectively. The yield is much higher compared to well-known other pulping processes like Kraft, Alkaline Sulphite Anthraquinone and Methanol (ASAM) and alkaline sulphite.[5] This is because the reaction of sodium sulphite on cellulose, hemicellulose, lignin and other macromolecules is less drastic than that of the acid sulphite, sulphate, or caustic soda used in the conventional pulping processes. The role of sodium sulphite is to accomplish this by dissolving and softening the ligno-cellulosic fibre, which bonds the ligno-cellulosic fibre with other fibrous tissues.[20,21] Sodium carbonate acts as a neutralizing agent towards the wood acids to maintain the pH value of the cooking liquor at 7–8, formed as the digestion progresses, ensuring minimum hydrolytic degradation of hemicelluloses, celluloses, and other fibrous components. Sodium sulphite, during pulping, reacts with lignin through sulfonation, converting the hydrophobic lignin into water-soluble lignosulfonates along with the release of acidic by-products, viz., sulfurous acid–like species and organic acids from wood (acetic acid from hemicellulose acetyl groups, and other low-molecular-weight organic acids). Sodium carbonate is added specifically to counteract this acidification. It reacts with the liberated acids and neutralises them. As acid is produced, carbonate converts to bicarbonate (and sulphite to bisulphite), which resists sharp pH swings and acts as a buffer system. As Neutral-Sodium-Sulphite Semi-chemical (NSSS) pulping is an innovative semi-chemical process of pulp making, consisting of chemical (digestion) and mechanical (beating) processes. It leads to higher pulp yield due to presence of a higher percentage of residual lignin that provides additional mechanical properties.[15] Furthermore, the pH value of the initial bath was 10.6, and after pulping, the discharge liquor was near neutral (6.4), thus does not

pose a severe impact on the environment. Indeed, it also reduces the corrosive tendency of the digestion vessel. One set of pulp was further subjected to environment-friendly bleaching using hydrogen peroxide as an oxidative bleaching agent to produce white paper. Unlike the commonly practised multi-step bleaching of wood pulp using chlorine-based compounds along with hydrogen peroxide carried out for a longer duration, here the bleaching of jute pulp was carried out in a single stage for a shorter duration of 90 min.[21] From unbleached and bleached pulps, paper sheets of 115 ± 5 g/m^2 were produced using semi-automatic sheet former machinery with a size of 74 cm × 59 cm, as shown in Fig. 1. The concentration of chemicals in the pulping process has a direct effect on the pulp yield, which gradually decreases with a progressive increase in sodium sulphite percentages.

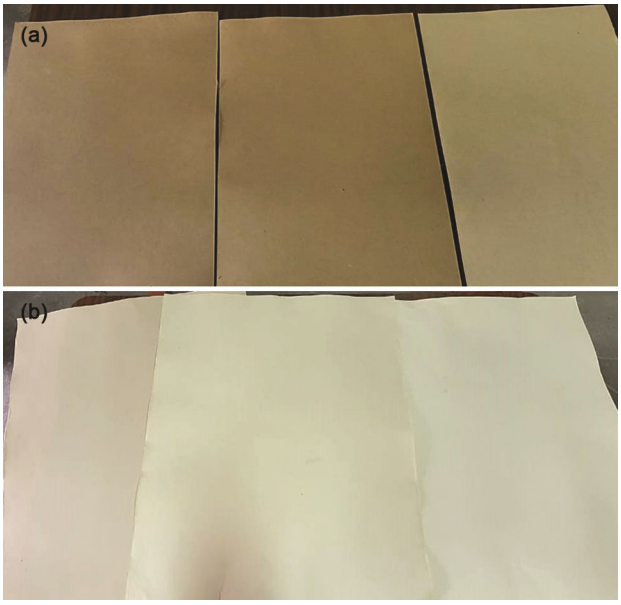

Fig. 1 — Pictures of handmade papers from the (a) unbleached and (b) bleached pulps with different concentrations of sodium sulphite (left to right: 10, 15 and 20% on weight of jute)

Physical and Tensile Properties

All eight papers, consisting of four unbleached and four bleached, were subject to measurement of physical and mechanical properties in terms of tear index, bursting index, folding endurance, specific tensile load and elongation, as tabulated in Table 1. It can be seen that, due to bleaching of the pulp, its bursting, tensile load, and elongation properties improved. Folding properties were slightly reduced after bleaching, which might be due to the removal of hemicellulose macromolecules that provide structural integrity.

It can also be seen from Table 1 that the major properties of paper-sheet increased during the enhancement of sodium-sulphite from 10% to 15%. After the sodium-sulphite with a dosage of 15% or higher, physico-mechanical properties either remained unaltered or decreased. Because bleaching is carried out in alkaline conditions at elevated temperatures, it can further remove some hemicellulose and lignin, ultimately increasing the relative cellulose percentage. Due to an increase in the cellulose component, bursting and tensile properties are also higher in the case of bleached papers. Elongation length is also higher in the case of all the bleached papers (5.5 to 7.4 mm); the elongation percentage also remains the same (4.5% – 7.4%). The combined effect of an increase in elongation length and tensile strength increases the bursting strength. The strength characteristics of the bleached pulp-based are considerably higher than those of the unbleached pulps, as reported in literature.[20,21] Due to shorter fibre length with higher lignin content, tear and folding are

Table 1 — Effect of sodium sulphite as well as bleaching agent on the physical and mechanical properties of jute papers

Sample details	Folding (number)	Tear index (mN·m^2/g)	Bursting index (KPa·m^2/g)	Specific tensile load (N/g/m^2)	Elongation length (mm)
			Unbleached paper		
Unbleached paper (10%)	1120	7.44	2.27	0.51	6.9
Unbleached paper (15%)	1023	13.9	3.99	0.49	4.5
Unbleached paper (20%)	612	12.5	3.56	0.53	5.7
Unbleached paper (25%)	497	8.1	3.54	0.65	5.4
			Bleached paper		
Bleached paper (10%)	736	6.88	3.78	0.50	7.4
Bleached paper (15%)	913	12.1	6.60	0.76	6.4
Bleached paper (20%)	458	10.2	5.16	0.65	6.1
Bleached paper (25%)	360	6.4	4.95	0.52	5.5

lower in the sodium sulphite pulping, where the value initially increases up to 15%, possibly indicating the requirement for such dosage for proper pulping. Further increase of sodium sulphite dosage leads to more damage to the composite fibre structure of jute fibre, which reduces the fold and tear properties. In the bleached samples, these values are still lower. From analysis of physical and mechanical properties, it is evident that 15% sodium sulphite is appropriate for achieving satisfactory paper properties. So, the semichemical process requires lower dosage of chemicals to produce paper with superior quality, while generating less effluent.

Whiteness Properties

The effect of Neutral-Sodium-Sulphite (NSS) pulping of jute as well as H_2O_2 oxidative bleaching on Whiteness Index (WI), Yellowness Index (YI), Brightness Index (BI), lightness-darkness (L*), red-green (a*) and yellow-blue (b*) colour attributes of developed papers are presented in Fig. 2 and Table 2. From Fig. 2, it can be seen that WI increase from 42.9 to 63.3 in the 10 to 25% sodium sulphite treated samples. After treatment of jute fibre in the presence of alkali at higher temperature, the WI was observed to reduce from 48.3 in the raw jute to 42.9 in the 10% SS treated jute pulp; a similar observation is also reported for alkali treatment of jute fibre for scouring action.[22] Subsequent improvement in colour parameters in terms of WI is possibly due to removal of lignin, hemicellulose, and natural colour material in the presence of pulping chemicals at a higher temperature of 160°C. As whiteness and yellowness indices follow opposite trends, YI value gradually reduced from 57.1 for jute fibre to 30.6, 29.3, 22.4 and 21.1, where WI value increases from 42.9 to 63.3 in the different sodium sulphite-treated samples. As expected, due to bleaching of pulp using hydrogen peroxide, whiteness value improved profoundly from 42.9–63.3 to 61.3–80.5. This occurs due to oxidizing of colour compounds present in the jute pulp as well as lignin macromolecules, through the action of perhydroxyl ions (HO_2^-) formed from hydrogen peroxide, which break down the double bonds in colour (chromophore) molecules. In aqueous solution, hydrogen peroxide dissociates in the presence of water to form perhydroxyl ions (HO_2^-) and hydronium ions (H_3O^+), and the latter acts as a nucleophilic bleaching agent by attacking and breaking the double bonds of colour compounds present in different ligno-cellulosic fibres.[23] The improvement in WI is clearly visible for up to 20% sodium sulphite-treated samples. Due to the improvement in WI value, the yellowness indices (YI) in the bleached samples reduced from 24.5 to 15.4.

The other colour parameters, viz., L* (lightness-darkness of a sample), gradually increased from 53.1 to 69.9 for unbleached samples with increasing concentration of SS from 10% to 20%. The L* values in all the bleached papers were much higher (71.5 – 86.6) than their corresponding unbleached samples (53.1 – 72.3). The red-green (a*) value was

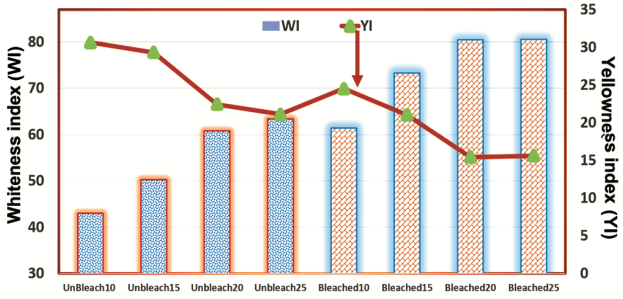

Fig. 2 — Effect of concentration of sodium sulphite and H_2O_2 bleaching on whiteness and yellowness indices of jute papers

Table 2 — Effect of sodium sulphite and H_2O_2 bleaching agent on colour attributes of jute papers

Sample	L*	a*	b*	Brightness Index
		Unbleached paper		
Jute fibre	60.7	6.68	21.1	17.9
Unbleached paper (10%)	53.1	5.04	13.4	15.2
Unbleached paper (15%)	60.6	4.94	14.2	21.1
Unbleached paper (20%)	69.9	4.83	12.3	31.7
Unbleached paper (25%)	72.3	4.31	12.2	35.5
		Bleached paper		
Bleached paper (10%)	71.5	4.39	12.9	34.9
Bleached paper (15%)	82.0	1.47	12.5	47.8
Bleached paper (20%)	86.5	0.84	9.5	59.7
Bleached paper (25%)	86.6	0.52	9.7	59.9

reduced, and it was lowest (4.31) in the case of 25% sodium sulphite-treated sample, signifying a lower degree of red tone in the sample, which further reduced to 0.52 in the bleached paper. The positive value of b* denotes the yellowness of a sample, and it mostly follows a similar trend of YI. As far as brightness indices are concerned, they indicate shininess of a sample. BI values are much higher in all bleached papers, and BI increased with increasing sodium sulphite concentration up to 20%. Therefore, based on the results, when a white-to-brown paper with acceptable colour properties is desired, 20% sodium sulphite may be considered.

Water Absorbency

Sodium sulphite pulp from jute fibre and its successive bleaching using hydrogen peroxide on hydrophilic and hydrophobic properties of the developed papers was evaluated in terms of water droplet absorbency time. The shape of water droplet in both unbleached and bleached paper can be observed from Fig. 3. It can also give an idea about the degree of hydrophilic/hydrophobic attributes in terms of water contact angle. In an unbleached cellulosic paper, a water droplet of 35 µL took 66 min for its complete absorption in the paper (Fig. 3a). On the other hand, the water absorbency time was found to increase to more than 99 min in the case of bleached paper (Fig. 3b). The water contact angle was determined keeping the water droplet volume at 3.4 µl, as shown in Fig. 3(b). The water contact angle was 93° for unbleached paper, indicating hydrophilic properties. In the case of bleached paper, the contact angle increased to 134°, i.e., less hydrophilic properties or, to some extent, hydrophobic properties.

Paper Surface Morphology

Surface morphology of the developed handmade paper sheets was analysed in detail under the scanning electron microscope (SEM) at different magnifications to typify the fibre morphology at the surface. It can be seen from Fig. 4 (a & b) that both the paper sheets look like a fibrous mat/ felt, where several tiny fibres are randomly placed throughout the structure. It signifies the uniformity of the prepared paper sheet. Several fibres are fused together in the sheet, indicating the micro-fibrillation of macro-size jute fibre by shearing action during the beating operation. Both unbleached and bleached samples show a compact sheet-like structure, contributing to good mechanical properties. The morphology of the paper sheet also shows a

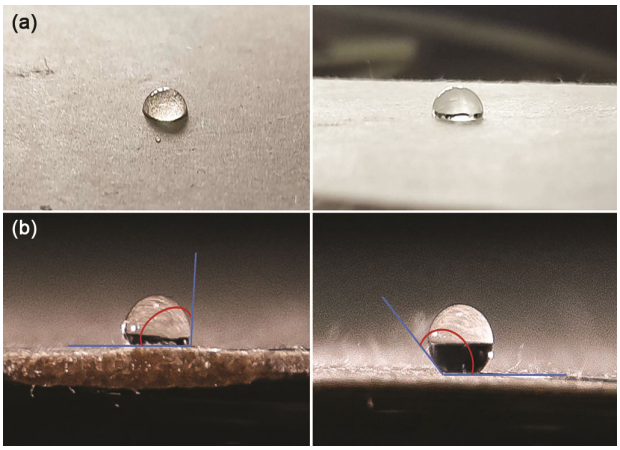

Fig. 3 — Shape of water droplets (a) and water contact angle (b) in the unbleached and bleached papers

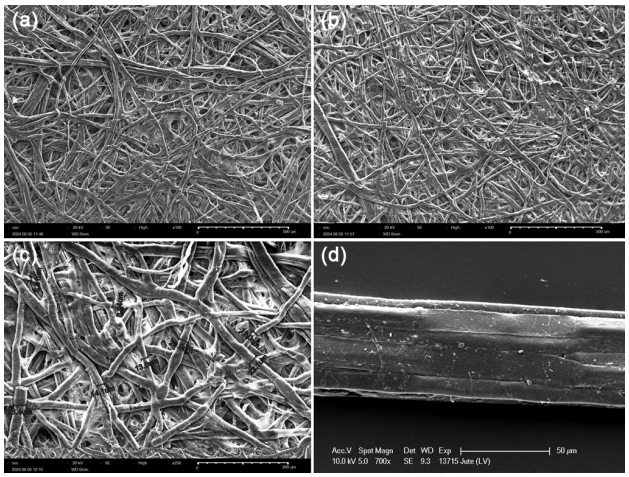

Fig. 4 — SEM micrographs of unbleached paper-sheet (a), bleached paper-sheet (b), unbleached paper-sheet at higher magnification (c), and (d) jute fibre

porous structure of the sample, resulting in adequate water absorbency through capillary action. From Fig. 4(c), the diameter of the fibrillated jute fibre after pulping & beating was measured to be in the range of 6.9–23.4 µm, as compared to 55–110 µm, i.e., the diameter of the raw jute fibre, considering fibre-to-fibre and within-the-fibre variation. This indicates a tentative 5.5-fold reduction in fibre diameter, which ensures good bonding between the fibrillated cellulosic fibres and, along with the possibility of hydrogen bonding between the cellulose macromolecular polymer chains.

Printability, Formability and Product Development

Keeping in mind the application of the developed paper sheet in bio-packaging, the areal density of the sheet was kept 115 ± 5 g/m^2 for suitable formability. Both the unbleached and bleached paper sheets were



Fig. 5 — Printing on unbleached and bleached jute paper sheets (top one: bleached and bottom one: unbleached)

printed by the screen-printing process, and the printability, print sharpness and colour prominence were evaluated. It can be seen that the visual appearance of print quality is better in the case of bleached paper, due to its white background. As far as print sharpness is considered, all the written texts are clearly visible on both papers (Fig. 5).

The paper could be easily printed without any difficulties. Higher water absorbency time in both papers, as discussed in the earlier section, is beneficial so that ink cannot readily absorb and spread by the paper, which commonly leads to the formation of a blurred image. Printed colour and sharpness remain stable even after the rubbing action of paper with a cotton cloth. A paper bag of size 18 cm × 13 cm × 7 cm (height × width × depth) was prepared from the unbleached and bleached papers (Fig. 6), and it could maintain its shape, which was possible due to adequate folding properties of the paper. Such bags can be used as a gift bag and as secondary packaging for selling high-value products in retail stores. Developed paper sheets, being a flexible structure, the formability and bendability of such paper sheets were found to be acceptable for making products, and it could also retain its final shape. The thread used in the handle of the bag is made of cotton; thus, the bag is biodegradable, and such a bag can be used as an alternative of similar plastic bag. With growing awareness of biodegradable and sustainable

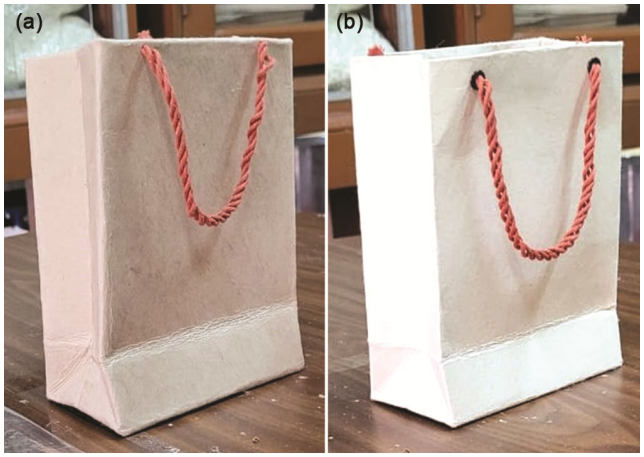

Fig. 6 — Development of paper bags from the unbleached (a) and bleached (b) jute papers

packaging materials, cloth bags and paper bags made from natural fibre/fibre crops are becoming popular. The developed neutral-sulphite jute-pulping route with higher yield and requiring mild alkali is well suited to small/cottage handmade-paper manufacturing units. This will also support rural entrepreneur development and artisan livelihoods around jute cultivation and processing units for handmade paper production.

Conclusions

The present study describes the usage of lower-grade jute fibre, as an alternative to forest wood

resources, to produce handmade paper using an innovative neutral-sodium-sulphite pulping process, with the usage of mild alkali (sodium carbonate) in place of strong NaOH. The process could lead to achieving a high pulp yield of 81.5%, which allows the production of paper sheets of 115 ± 5 GSM with desirable specific tensile strength (0.53 N/g/m^2), folding endurance (1000), bursting index (4.0), tear index (14), treatment dependent variable tensile and colour properties. The SEM micrographs show the fibrillation and a compact and porous structure of fibres that adds to paper's surface smoothness, good structural integrity and adequate water absorbency. This process facilitates the use of low-grade jute fibre as well as jute mill wastes like fibre, yarns, fabrics and product cuttings. The study also suggests that jute fibre can be used for making paper bags, over its conventional use as gunny bags for packaging of agricultural crops and commodities. This process can lower the cost of chemical treatment and effluent management, hence a lower environmental impact.

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