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Development and quality assessment of handmade papers using underutilized agro based natural fibres

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Abstract
Management of crop residue for industrial application is an upcoming researchable issue for sustainable environment. Locally available eco-friendly renewable resources *viz.*, sugarcane bagasse, sisal fibre and maize husk have been used for development of handmade papers along with cotton rags and waste paper with different blend proportions. Among the papers, bagasse/cotton (60:40) handmade paper possessed significantly greater thickness, more uneven surface, low folding endurance with greater bursting and tears strength. Further, bursting, tear and tensile strength was found to be greater in bagasse/sisal/cotton (40:30:30) handmade paper followed by bagasse/ waste paper/ cotton paper which can be used as packaging materials to disposable paper plates. Effective management and utilization of agriculture crop residue with other cellulosic waste can be aptly suitable for production of eco friendly handmade papers which will provide sustainable enterprise for rural artisans.

Keywords: Handmade paper, burst factor, tear factor, tensile strength and elongation

1. Introduction

A large quantity of crop residue has been generated every year in India approximately 500 million tons (MNRE, 2016) and this may increased in future. Traditionally, most of this crop residue is burnt or thrown into landfill to rot which contributing to air pollution and climate change by releasing greenhouse gases such as carbon dioxide and methane which is 27 times more dangerous to the ozone than carbon dioxide, later cause environmental issues (Bagasse for Bioenergy, 2014) [4]. Very small amount of crop residue is used as animal feed, composting, thatching for rural homes and fuel for domestic and industrial use (Devi *et. al.* 2017) [11]. Therefore, there is a need to develop an alternative solution to overcome the problem to manage the agro waste.

In present era materials extracted from renewable sources are preferred by everyone to save earth from future hazardous problems. In this context, products developed from residue obtained directly from the agriculture bio waste will certainly occupy a relevant position in the field of technical textile sector. Natural fibres mainly composed of cellulose, hemicelluloses, lignin and minor contents of proteins, lipids and ash (Limayem and Rick, 2012) [19] which can replace the synthetic materials wherein major contributor for increasing in carbon footprint (Ho, M.P *et al.* 2012) [17]. The Indian government has taken up green initiatives to overcome the problem of environmental pollution. Hence, agro based fibres and crop residue management is an utmost important for sustainable green environment however the fibres extracted from crop residue possessed mechanical and physical properties which are aptly suitable for textile application.

Hence, many industries have been actively working on different kinds of natural fibers (Sathishkumar *et al.*, 2012) [27]. Annually renewable resources like corn, wheat, rice, sorghum, sugarcane, pineapple, banana and coconut, *etc*., are the by-products utilized as agro-based biofibres which are very much suitable for development of green products for multiple applications in the field of technical textiles.

Usage of plastic is one of the major problems for environmental pollution to overcome this; optimum utilization of green products by the consumers is a need of an hour. However, for production of paper, a lot of wood pulp is required which leads to deforestation. The handmade paper industry in India offers considerable potential to meet the increasing demand for paper products in an environmentally sound way. Handmade paper has enjoyed resurgence, both as a traditional craft and as an art-form over the automated paper making. Many industries and scientific community involved in utilization of various agro based fibres for different industrial application. Hence the present study has been designed to develop handmade papers from bagasse and other agro based fibres and their characterization.

2. Materials and Methods

2.1 Procurement of raw materials

The study is focused on effective management of locally available agro based fibres *viz.*, sugarcane bagasse (SNK 09293), sisal fibre (BAS -1) and maize husk (GPMH 1101) were the released varieties of UAS Dharwad. The office waste papers were procured in bulk from UAS campus and pulp of knitted cotton rags from paper industries, Tarihal, Hubli.

2.1.1 Sugarcane Bagasse

Sugarcane bagasse (SNK 09293) was procured from Agricultural Research Station, Sankeshwar, UAS, Dharwad. Sugarcane bagasse is a residue generated after juice extraction and mainly used for co-generation in sugar industry. The bagasse is valuable raw material for textile application which consists of water-insoluble basis, *i.e.*, "pith" from the center of the stalks (30%), "fiber bundles" (65%; 50% from the rind and 15% from the internal material) and the epidermis (5%) (Atchison 1971a, b, Rao 1997) [3, 25].

2.1.1.1 Depithing Process

To produce bagasse handmade paper, it is necessary to depith the bagasse. It has been unanimously agreed that removing 30% of the shortest bagasse fibers is essential for making pulp of acceptable quality (Atchison 1962, Giertz and Varma 1979, Paul and Kasi Viswanathan 1998, Covey *et al*. 2005, Rainey *et al*. 2010) [2, 15, 23, 9, 24]. The largest part of agriculture fibers requires some kind of pre-treatment application before pulping. Bagasse contains very high amount of pith, which is mostly parenchyma cells that originate from the vascular bundles must be separated first.

Depithing is the process wherein the pith material is separated from the rest of the bagasse sheath through scooping out the central content called pith. Without depithing, it is virtually impossible to create a sheet of paper using normal industrial pulp washers and paper machines due to hydraulic holdup (*i.e.*, extremely poor pulp freeness). Depithing is used to improve pulp drainage in the pulp washers followed by paper machine, reduce chemical usage, reduce foaming, reduce costs for handling and storage, dirt count in the paper, improves tensile properties and black liquor quality (Rao 1997, Lois-Correa 2012) [25, 20]. In this study depithing was carried out by hand stapling, grinding with industrial blender followed by pith and fibre separation.

2.1.1.2 Delignification

Removal of surface impurities and improve the pulp quality, the bagasse fibre was soaked in luke warm water for about 2 hours. The softened bagasse was subjected to delignification wherein lignin content is removed. Sugarcane bagasse was immersed in 5% NaOH solution at room temperature with a liquor ratio of 1:15 for about 2 hours. The fibres were then washed several times with fresh water to remove the NaOH from the surface and neutralized with dilute acetic acid followed by final rinsing washed again with distilled water, (Acharya *et al.,* 2011) [1]. Delignified fibre was used for pulp making.

2.1.2 Maize/corn Husk

Corn husk, a lignocellulosic fibre generally discarded as waste is the potential of being explored as a renewable source for textile application. It is one of the major agricultural crops in the world and cultivation of corn generates valuable by-products (stalk, leaves and husks) that have been considered for a suitable raw material for various end uses.

Corn Stover typically consists of about 50 per cent stalks, 23 per cent leaves, 15 per cent cobs and 14 per cent husk. The leafy outer shell/ covering of an ear of maize is referred to as corn husk. Each husk is relatively thin and flat, unlike the adult and juvenile foliar leaves. The sheaths of husks are broader and thinner than the sheaths of the foliar or ordinary leaves. Corn husk have a high content of cellulose about 80-87 per cent and low content of lignin of about 6-8 per cent which is aptly suitable in the field of technical textile.

In this study, the husk was procured from UAS field and manually chopped into small pieces with the cut length of 2 inch. Finely chopped maize husk was soaked in hot water for 2 hours for softening and softened husk was used for pulp making.

2.1.3 Sisal Fibre

Traditionally, sisal has been the leading raw material for agricultural twine because of its strength, durability, ability to stretch, affinity for certain dyestuffs and resistance to deterioration in saltwater. A sisal plant can produce about 200-250 leaves before flowering, each of which contains 1000-1200 fibre bundles. The leaf is composed of 4% fibre, 0.75% cuticle, 8% dry matter and 87.25% water (Murherjee and Satyanarayana, 1984) [21]. It is currently found on embankments, bunds, roadsides serving the purpose of soil conservation and protection as hedge plantations. For the present study the Sisal (*Agave americana*) fibre variety BAS -1 was procured from the Regional Agricultural Research Station, Vijayapura, Karnataka State. The sisal fiber was extracted by using Raspador machine and the extracted fibre was subjected to washing and sun drying. The dried sisal fibre was cut into 2 inches in length, softened by required amount of softening agent and further used for paper making.

2.1.4 Waste Paper

The waste paper recycling is a need of an hour, it involves a number of steps, including collection, sorting, processing into usable raw materials and finally using that raw material to produce new paper production. All the recovered or collected paper waste was chopped into small pieces. The chopped paper was soaked in hot water for removal of dirt and ink. The deinked papers were used for paper making.

2.1.5 Pulps of cotton knits rags

The processed cotton knits pulp was procured from local paper mills for paper making. Garment and hosiery industries generate abundant waste of the cotton rags, trims and cuttings mainly during the manufacturing of garments. Cotton has highest percentages (87 to 96%) of cellulose; it can be used for manufacturing of value added products (Chauhan, *et. al.*, 2009) [8].

2.2 Blend Ratios

All the above explained fibres were blended in different ratios for the production of handmade paper.

Blend Ratios

Blending	Ratio
T1 – Pure Cotton (Control)	100%
T2 – Bagasse + Cotton	50 : 50
T3 – Bagasse + Maize husk + Cotton	40 : 30 : 30
T4– Bagasse + Sisal fibre + Cotton	40 : 30 : 30
T5 – Bagasse + Waste paper + Cotton	40 : 30 : 30

2.3 Development of blended handmade paper

Softened and delignified bagasse fibres were subjected to beating in a Hollander beater in which fibres were cut into very short staple length. Softening treatment makes the pulping process easier and reduces the time of pulping. According to required GSM, the pulp was blended and poured manually on the nylon mesh with wooden frame. The frame is immersed in the water and transferred the paper onto padding stand. The developed paper needs to be pressed by screw pressing machine in order to remove the excess water and air bubbles completely. The pressed paper is flat dried and hanged over the ropes around 6-7 hours. After drying, ironing process was carried out to achieve even surface of paper. The dried sheet was subjected to cutting or trimming process, Plate 1 and 2.

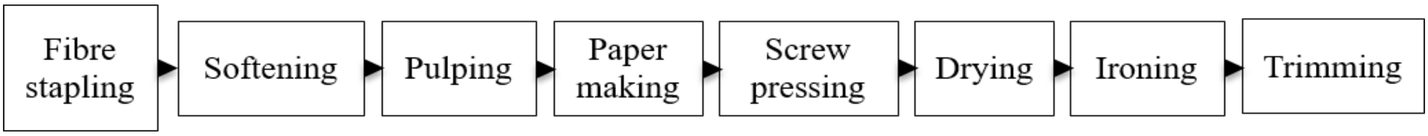

Plate 1. Manufacturing process of blended handmade paper

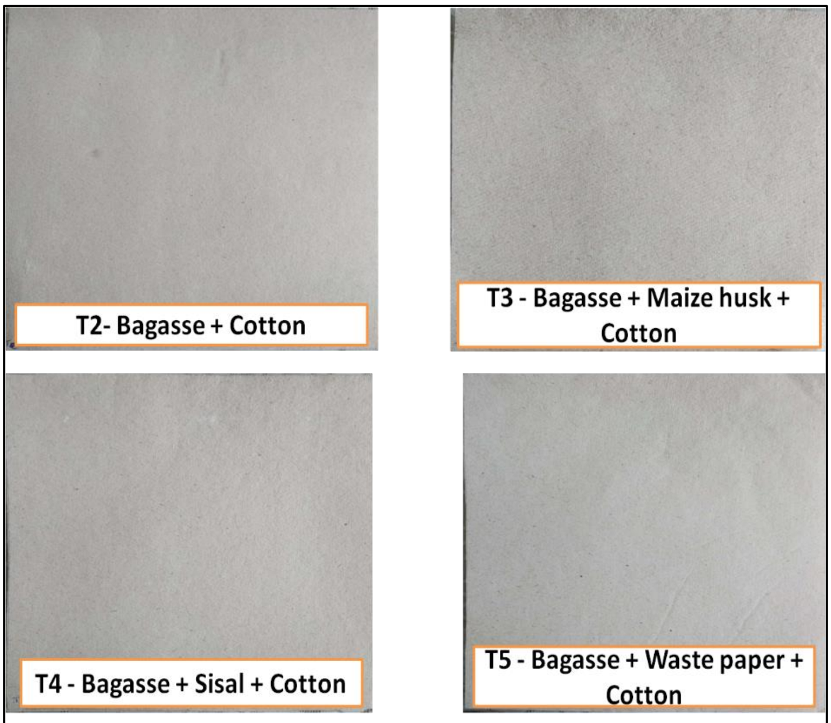

Plate 2. Bagasse Blended Handmade Paper

Assessment of physical properties of handmade papers

Developed composite handmade papers were subjected to physical properties using TAPPI standards.

Physical Parameters	Tests
GSM	Weighing Balance
Thickness	TAPPI 411
Cobb	TAPPI 432
Folding Endurance	TAPPI 402, 511
Tear Factor	TAPPI 470
Burst Factor	TAPPI 403
Tensile Strength	TAPPI 494

3. Results and Discussion

3.1 Chemical properties of Baggase, Maize husk and Sisal fibre

Chemical composition is an important element that influences the physical, mechanical and thermal properties of the natural fibres (Table 1). Most of the plant fibres except for cotton are composed of cellulose, hemicelluloses, lignin, fat & waxes and some water soluble compounds as major constituents. However, the chemical contents are different according to the variety, location of plantation, climate, irrigation and environment aspects. The cellulose content noticed was slightly at higher per cent in sisal and maize husk compared to bagasse (69.43%, 53.00% & 39.70%) respectively. Cellulose is a semi crystalline polysaccharide made up of D-glucopyranose units linked together by β-(1-4)-glucosidic bonds and has strong mechanical properties (Rowell, *et. al.*, 1997) [26] and the large amount of hydroxyl group in cellulose gives natural fibre hydrophilic properties to the fibre enhancing its uses in non-woven's and composites.

Hemi-cellulose content in all the fibres were on par with each other *i.e.*, sisal fibre (21.17%), maize husk (22.00%) and bagasse (23.11%). Hemi-cellulosic polymers are branched, fully amorphous and have a significantly lower molecular weight than cellulose. Because of its open structure containing many hydroxyl and acetyl groups, hemi-cellulose is partly soluble in water and hygroscopic (Frederick and Norman, 2004) [3]. Lignin content of sisal and maize husk (5.37% & 5.00%) were found to be same as indicated in Table 1. However, bagasse fibre contain notably high amount of lignin *i.e.*, 23.32% due to complex macro structure. Generally lignin is amorphous, highly complex, mainly aromatic, polymers of phenyl propane units (Rowell, *et. al.*, 1997) [26] but have the least water absorption of the natural fibre components (Frederick and Norman, 2004) [3]. Fat and wax was found to be high in maize husk (6.50%) compared to bagasse and sisal fibres. The ash content is comparative higher in sisal fibre (13.52%) than bagasse and maize husk. The major crystalline phases found in sugarcane bagasse ash are quartz (SiO_2) and cristobalite (SiO_2), in turn its hydrophilic properties promote its use in multiple paper bags production (Ganesan, *et. al*., 2007) [14].

Table 1: Chemical properties of Baggase, Maize husk and Sisal fibre

Fibre	Composition				
	Cellulose (%)	Hemi – cellulose (%)	Lignin (%)	Fat and waxes (%)	Ash (%)
Bagasse	39.70	23.11	23.32	01.59	0.34
Sisal	69.43	21.17	05.37	01.71	13.52
Maize/ corn Husk	53.00	22.00	05.00	06.50	04.50

3.2 Physical properties of bagasse, sisal and maize husk fibres

Among the processed fibres bagasse fibre was found to be finer (31.00 tex) than the maize husk (31.90tex) and sisal (76.96tex). However, sisal fibre possessed greater strength and elongation (563.68gf/tex) followed by bagasse fibres (329.00gf/tex) and maize (234.70gf/tex). This may be due to more number of single cell fibres cemented together by the naturally occurring gums in the sisal fibre as compared to bagasse and maize husk. It can be clear that, maize husk fibre possessed more finely, less strong and elongation at break than bagasse and sisal. This may be due to molecular orientation and crystallinity of the maize fibre (Table 2).

Table 2: Physical properties of Baggasse, Maize husk and Sisal fibre

Fibre	Fineness (tex)	Strength (gf/tex)	Elongation (%)
Bagasse (SNK 09293)	31.00	329.0	02.62
Sisal (BAS 1)	76.96	563.68	03.21
Maize/ corn Husk (GPMH 1101)	31.90	234.7	02.18

3.3 Effect of fibre blending on thickness (mm) of handmade paper

Handmade papers made up of various natural fibres with different ratios were found to be greater thickness (Table 3 and Fig.1) and it is indicating that these papers can be used for rough and sophisticated usages. Among all the papers the highest thickness was found in T3 - Bagasse + Maize husk + Cotton compared to pure cotton paper due to the thicker cell wall of bagasse fibre *i.e.*, 20µm compared than eucalypt, making it stiffer. This attribute makes it ideal for applications such as corrugating medium and folded paper towelling (Thomas, 2016) [9]. Apart the combination of different fibre with varied ratio and fibre properties also influence the strength and thickness of papers. The highest thickness was found in T3-bagasse + maize husk + cotton paper *i.e.*, 692 followed by T5-bagasse + waste paper + cotton (668), T2-Bagasse + Cotton (630), T4-Bagasse + Sisal fibre + Cotton (610) and T1-Pure Cotton composite paper (320).

Table 3: Effect of fibre blending on thickness (mm) of handmade paper

Parameters	Thickness (mm)
T1 - Pure Cotton	320
T2 - Bagasse + Cotton	630
T3 - Bagasse + Maize husk + Cotton	692
T4 - Bagasse + Sisal + Cotton	610
T5 - Bagasse + Waste Paper + Cotton	668
S.Em.±	0.707
CD (5%)	2.085
CV%	0.065

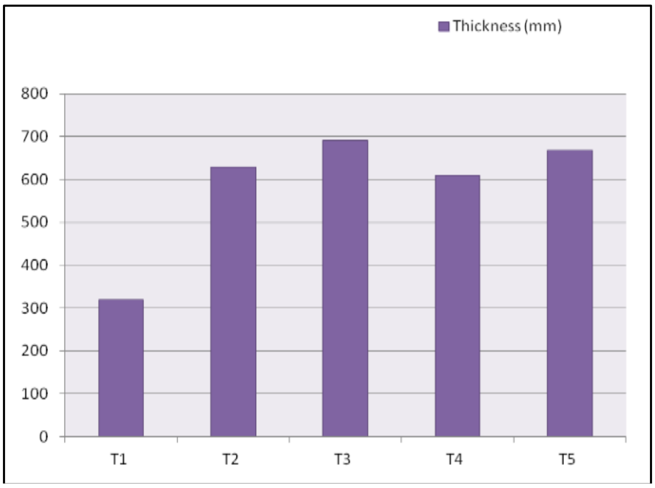

Fig 1: Effect of fibre blending on Thickness of handmade composite paper

3.4 Effect of fibre blending on cobb (g/m^2) of handmade paper

Cobb test describes the procedure for determining the water absorption property of paper in a specified time under standardized conditions. The bagasse combined papers showed good cobb value as bagasse fibre absorbs water very easily due to the presence of hydroxide group in their fibre cellulose (Hoque, *et. al.*, 2019) [18]. The T3 - bagasse + maize husk + cotton paper (79 g/m^2) exhibited high water absorption because of absorption capacity of bagasse, maize husk and cotton, wherein, cellulose content of these fibre absorbs at least two times its weight of water and has comparable hydration capacity (Bakre, 2013) [5].

Table 4 Fig. 2 showed the effect of fibre blend ratio on cob value of handmade papers and explained that, among the papers pure cotton handmade paper exhibited greater reduction in the cob value *i.e.* (16 g/m^2) indicating less water absorption property than the other blended paper. This may have resulted from reduction in gaps or empty spaces within the fibrous network of the sheet structure due to extensive and effective bonding between the fibres (Behero *et.al* 2015) [6]. Further, blending of bagasse with other fibres has been found to influence on cob value *i.e.* a combination of bagasse: maize husk: cotton handmade paper showed greater cob value resulted into higher water absorption properties due to lack of effective fibre bonding between the fibres during pulping process. And also may be presence of 30 percent maize husk fibres was found to be more soft and pliable than the other fibres which leads greater affinity for water than the bagasse and cotton. However similar results were noticed in T4 (Bagasse + sisal +cotton) and T5 (Bagasse+waste paper+ cotton) *i.e.* (43 g/m^2) and (47g/cm) respectively due to effective inter-fibre bonding lead to reduction in pore gaps in the sheet structure.

Table 4: Effect of fibre blending on cobb (g/m^2) of handmade paper

Parameters	Cobb (g/m^2)
T1 - Pure Cotton	16
T2 - Bagasse + Cotton	25
T3 - Bagasse + Maize husk + Cotton	79
T4 - Bagasse + Sisal + Cotton	43
T5 - Bagasse + Waste Paper + Cotton	47
S.Em.±	0.707
CD (5%)	2.085
CV%	0.174

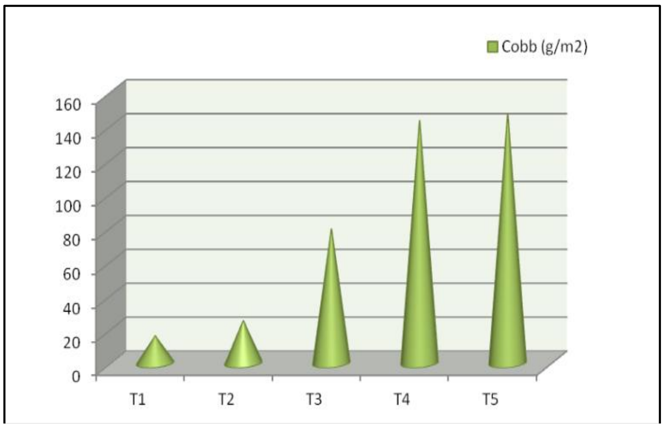

Fig 2: Effect of fibre blending on Cobb (g/m2) of handmade composite paper

3.5 Effect of fibre blending on folding endurance of handmade paper

Table 5 and Fig. 3 indicate the effect of fibre blending on folding endurance of handmade paper. The highest folding endurance was found in control *i.e.*, T1-Pure Cotton paper (57) than other blended papers, because, of very smooth texture which adds more in folding. However, bagasse blended papers showed less folding endurance as bagasse fibre is typically around 20µm in thickness and has a thicker cell wall which makes the paper stiffer (Thomas, 2016) [9]. Among the blends the T4-bagasse + sisal fibre + cotton has highest folding endurance (28) because of fibre length (sisal & bagasse) that in turn increase sheet density, particularly the longer the fibres and the higher the density (Seth, 1990) [28]. Folding endurance of T2-bagasse + cotton was found to be (14) because of stiffness of bagasse and fold endurance of T3 - bagasse + maize husk + cotton (20) decreased rapidly with decreasing fibre strength of maize husk (234.7 gf/tex).

It determines the durability of paper when repeatedly folded under constant load, determining how many times the paper can be folded until it breaks. The control sample *i.e*, pure cotton rags handmade paper exhibited greater folding endurance (57) than the blended fibres handmade papers. This may be due to fibre inherent microstructure and effective fibre bonding during pulping leads to even soft and pliable structure contributed better folding endurance property. Among the blended fibre papers, T2 sample possessed lesser folding endurance due to presence of greater 60 percent bagasse fibres. However, bagasse fibre has 20 µm thickness, thicker cellwall and comparatively inelastic which makes the paper more stiffer and crispier (Rainey) than the others. However, the improvement in folding endurance value of the blended sheets was appreciable in T4- Bagasse + Sisal + Cotton (28) followed by T5 - Bagasse + Waste Paper + Cotton (22) and T3 - Bagasse + Maize husk + Cotton (20) respectively. This may be owing to individual fibre properties and their bonding potential. Endurance durability was found to be fairly least in blended sheet of T3 due to 30 percent loss of maize husk fibres as low reinforced potential with bagasse and cotton fibres.

Table 5: Effect of fibre blending on folding endurance of handmade paper

Parameters	Folding endurance
T1 - Pure Cotton	57
T2 - Bagasse + Cotton	14
T3 - Bagasse + Maize husk + Cotton	20
T4 - Bagasse + Sisal + Cotton	28
T5 - Bagasse + Waste Paper + Cotton	22
S.Em.±	0.707
CD (5%)	2.085
CV%	0.362

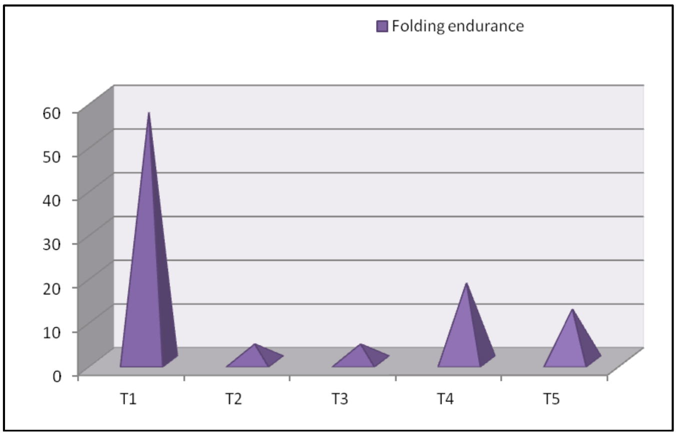

Fig 3: Effect of fibre blending on folding endurance of handmade paper

3.6 Effect of fibre blending on tear factor (kgf/cm) of handmade paper

Tear factor of handmade paper showed in Table 6 and Fig 4. According to Hinterstoisser *et al.*, (2001) [16] the carbon-oxygen-carbon bonds in addition to hydrogen bonds are the ones deformed when cellulose molecules are mechanically loaded and tears. The greater tear factor was found in control *i.e.*, pure cotton paper (207.6) compared to blended papers. This is attributed to cellulose which is major load bearing component in fibres. It is a linear polymer composed of glucose units joined together by β-1,4 glycosidic bonds. The extents of inter-fibre bonding is considered the most important factor contributing to tensile and tear properties (Fagbemi, 2014) [12]. Among the blended papers greater tear strength was found in T5-bagasse + waste paper + cotton (181.2) this may be due to presence of cellulose, it has a strong tendency for intra and inter-molecular hydrogen bonding, which leads to the formation of microfibrils with excellent mechanical properties. However, tear factor was slightly on far in T4 - Bagasse + Sisal + Cotton (179.6) handmade paper. This may be explained by the predominance of stiff and hard sisal fibres would have better reinforcing property in paper making. Whereas, T3-bagasse + maize husk + cotton (97.6) possessed low levels of bonding which leads to lesser tear strength due to presence of maize husk.

Table 6: Effect of fibre blending on tear factor (kgf/cm) of handmade paper

Parameters	Tear factor (kgf/cm)
T1 - Pure Cotton	207.6
T2 - Bagasse + Cotton	101.8
T3 - Bagasse + Maize husk + Cotton	97.6
T4 - Bagasse + Sisal + Cotton	179.6
T5 - Bagasse + Waste Paper + Cotton	181.2
S.Em.±	0.070
CD (5%)	0.208
CV%	0.013

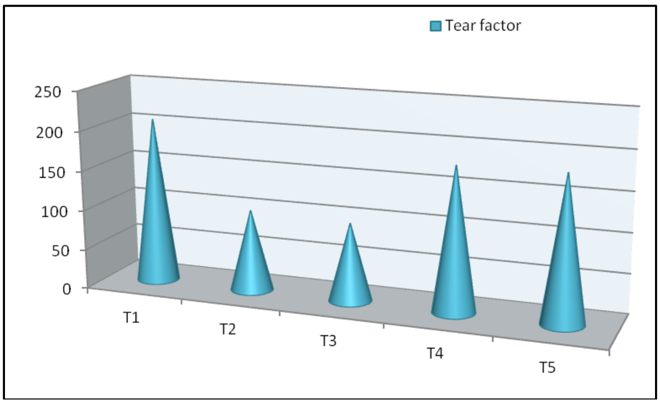

Fig 4: Effect of fibre blending on Tear factor of handmade composite paper

3.7 Effect of fibre blending on burst factor (kg/cm^2) of blended handmade paper

The bursting strength of all the paper samples was found to be significantly varied. It is reported to be dependent on lumen width, fiber diameter, specific gravity, runkel ratio, percentage of fines, coarseness *etc* (Dayal, *et. al.*, 1994, Wertz, *et. al.*, 2010 & Canakei, *et. al.*, 2012) [10, 30]. The T1-pure cotton (15.3 kg/cm^2) handmade paper possessed greater bursting strength mainly by the way in which individual fibres are bonded together in paper sheet. The burst factor of handmade paper has been reported to be dependent on various morphological characteristics of pulp fibres *viz.*, thick/thin walls of fibres, fibre length, strength, intra & inter fibre bonding *etc* (Nieminen, *et. al.*, 1994, Wertz, *et. al.*, 2010 & Canakei, *et. al.*, 2012) [22, 30]. Among the combination fibre sheets T4- Bagasse + Sisal fibre +Cotton sample possessed greater bursting strength compared to T5- bagasse + waste paper + cotton (9.98 kg/cm^2), T3- bagasse + maize husk + cotton (6.00 kg/cm^2) respectively. This may be due to presence of adequate number of strong and flexible sisal microfibrils possessing greater ability to form effective bonding than the fibres from maize husk wherein, it has soft and pliable structure leads to least bursting strength (Table 7 and Fig.5).

Table 7: Effect of fibre blending on burst factor (kg/cm^2) of handmade paper

Parameters	Burst factor (kg/cm^2)
T1 - Pure Cotton	15.3
T2 - Bagasse + Cotton	7.17
T3 - Bagasse + Maize husk + Cotton	6.00
T4 - Bagasse + Sisal + Cotton	13.9
T5 - Bagasse + Waste Paper + Cotton	9.98
S.Em.±	0.449
CD (5%)	1.325
CV%	0.081

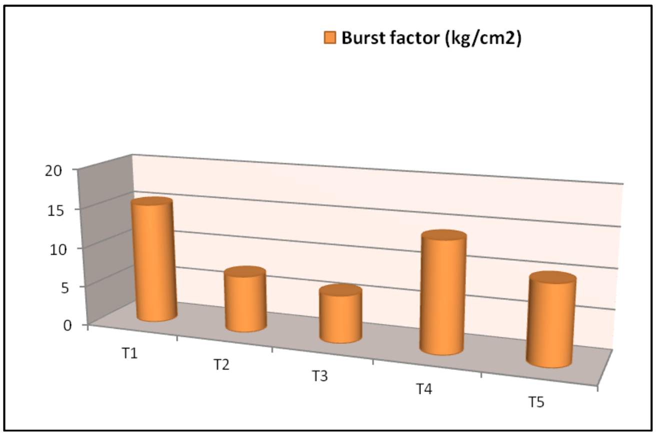

Fig 5: Effect of fibre blending on Burst factor of handmade composite paper

3.8 Effect of fibre blending on tensile strength (N/m) of handmade paper

Table 8 and Fig. 6 shows tensile strength of blended handmade papers. Among all the blended papers greater strength was found in T4- Bagasse + Sisal fibre + Cotton (2.28) followed by T5- bagasse + waste paper + cotton (1.88), T1- pure cotton (1.66), T2- Bagasse + Cotton (1.45) and T3- bagasse + maize husk + cotton (1.06) papers. T4 handmade paper showed greater strength due to the high fibre strength of sisal fibre (563.68 gf/tex) and bagasse fibre strength (329 gf/tex). Blending of sisal with bagasse and cotton pulp has been found to influence the sheet properties like burst factor, tear factor and tensile strength. The overall improvement in the strength characters of T4 blended sheet may be ascribed to the presence of virgin sisal pulp fibres in the blend mixture, which increases fibre swelling during pulping. Fibre swelling is an important phenomenon in pulping which is dependent on the water uptake of the fibres, which depends on the number of ions trapped in the fibres since swelling is driven by osmosis. The presence of sufficient amount of sisal fibres in the pulp furnish with a higher composition of hemicelluloses contributes adequately to the increase in pulp swelling, as proper swelling of the fibres would reduce the inter fibrilar bond distances. Thus it enhances the possibility of inter-fibrilar bond formations between both the types of fibre, due to the hydroxyl groups (-OH) residing in the cellulosic chains of the microfibrils generated from both the fibre types during pulping. Improvement in the tensile strength (in terms of breaking length), as well as the burst strength of the blended sheets points towards the increase in number of inter febrile hydrogen bonding within the sheet structure that may have resulted from the extensive defibrillation and effective swelling of the sisal pulp fibre. The presence of an adequate number of highly fibrillated sisal fibrils possessing sufficient pliability in the weaker pulp furnish increases the interaction between the two types of fibre as well as the interactions within the sisal fibrils themselves. Increase in strength due to intensive interactions between the sisal fibre and the other fibre points towards the compatibility and conformability of sisal fibres when mixed with the other weak and/or highly recycled content fibres. Further, T3 blended paper possessed least tensile strength (6.00) compared to other sheets. This may be due to finer and soft fibre structure leads to lower strength. Sisal with bagasse and waste cotton pulp could be considered as an alternative raw material for paper making by mixing with other minor natural fibres or recycled paper pulps to produce paper with improved mechanical strength.

Table 8: Effect of fibre blending on tensile strength (N/m) of handmade paper

Parameters	Tensile strength N/m
T1 - Pure Cotton	1.66
T2 - Bagasse + Cotton	1.45
T3 - Bagasse + Maize husk + Cotton	1.06
T4 - Bagasse + Sisal + Cotton	2.28
T5 - Bagasse + Waste Paper + Cotton	1.88
S.Em.±	0.007
CD (5%)	0.021
CV%	0.012

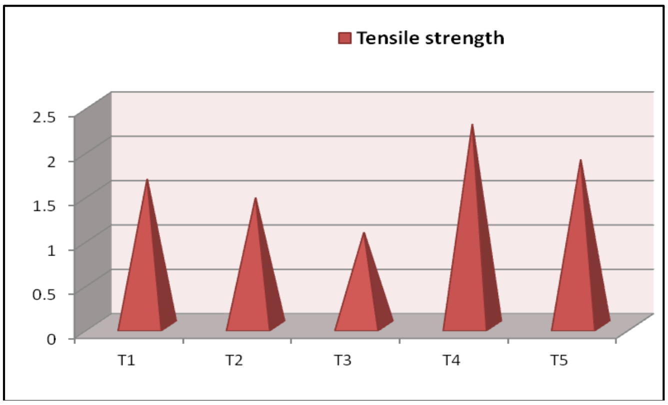

Fig 6: Effect of fibre blending on tensile strength of handmade composite paper

4. Conclusion

Management of underutilised natural fibres with other cellulosic waste for production of handmade papers is a better avenue for eco products diversification. Cotton rags and waste paper are chiefly available raw material with greater percentage of cellulose that can be effectively blended with locally available agro based fibres with optimised blend ratio for production of handmade papers with optimum physical properties. Among the papers, bagasse/cotton (60:40) handmade paper possessed significantly greater thickness, more uneven surface and low folding endurance with greater bursting and tears strength than the handmade papers. Further, bursting, tear and tensile strength was found to be greater in bagasse/ sisal/ cotton (40:30:30) blended handmade paper followed by bagasse/ maize husk/ cotton handmade paper. The folding endurance was found to be good in three fraction blend ratio than the two fraction blending. Among the blend ratios 40:30:30 (bagasse/ sisal and waste paper/ cotton rags) was found to be more suitable for production of handmade paper with optimum physical properties which can be suitable for production of various applications ranging from packaging materials to disposable paper plates. Thus, production of blended handmade paper is eco-friendly, bio-degradable, recyclable, the best in quality as well as utility with an affordable cost and above all it provides sustainable enterprise for rural artisans.

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