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APPLICATION OF LIGNIN AS FILLER FOR THE MIDDLE LAYER OF CARTON BOARD


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Abstract

Lignin is second most abundant renewable raw material available on earth. Despite its unique characteristics as natural product most lignin obtained by pulping is burnt for its fuel value and only 2% separated lignin from wood biomass is used for other purposes. This ignores the fact that many modern kraft mills could get benefits from lignin recovery in terms of both product capacity and process economy.

In the present study, it was proposed that lignin particles as filler added in middle layer can improve specific volume and ultimately the bending stiffness. This can result in replacing some pulp amount with lignin particles and can help in product economy of carton board. Thus major goal of this project is to find suitability of lignin particles as filler for the middle layer of carton board.

Results of laboratory forming symmetrical tri-layer carton board having lignin particles as filler in middle layer shows improved bending stiffness and drainage time at the cost of decreased Z Span strength and Short Compression Test (SCT) for both the pulps, i.e. mechanical and recycled. Results also show that by adding lignin particles in middle layer having recycled pulp, costly mechanical pulp that gives a high specific volume can be replaced by recycled pulp with improved strength properties and bending stiffness.

Keywords : *Lignin, Filler, Bending Stiffness, Carton Board, Mechanical Pulp, Recycled Pulp, Short Compression Test, Z Span Strength.*

1. Introduction & Literature Review

Lignin is one of the most abundant natural available raw materials on earth, second to cellulose if mass is considered (1, 2). It is generated when plant biomass is fractionated into its molecular components, mostly cellulose, hemicelluloses and lignin. It is the side product of the kraft pulping process. It is estimated that most of the lignin obtained during kraft puling process is usually burnt for its fuel value and only 2% of this extracted lignin is used for other purposes (1, 3, 4). Two percent utilization of lignin particles in industry is also limited to R&D department only. In these applications either modified lignin particles were used (5, 6) or used as hydrophobic compound to impart specific property in a paper (7). Many potential industrial applications of lignin have been reported in literature (8, 9). But none of the applications has been implemented for industrial use with expected gain in economy. It simply ignores that most of the modern integrated pulp and paper industries can get benefits from lignin recovery in terms of both product capacity and process economy (8).

One of the immediate potential applications of lignin as adhesive in pulp and paper industry may be in the carton board manufacture. Carton board must be dimensionally stable for which it must have high bending stiffness. Bending stiffness is basically the ability of a structure to resist the forces that are acting out of its axis or planer direction (10-11). It is one of the most critical properties of carton board as it affects the ability of board to run smoothly through the machine that erects, fills and closes the carton board (10).

It is well known that Carton board is usually made in at least three layers: top, bottom and middle layer. The top layer is important for the optical appearance of the carton board. The bottom layer should have some optical homogeneity and hide the middle layer from the costumer. Carton board can be compared to an I-beam: The middle layer is the web and sets the distance between the flanges, e.g. top and bottom layer (12-16).

Recently a new model for maximizing the bending stiffness of a symmetric three-ply paper or board has been proposed (16). However, for the simplicity, the simple model of bending stiffness of tri-layer symmetric carton board can be given as below (13, 16):

$$S_b = \frac{E_1 d_1^3}{12} + \frac{E_2 (d^3 - d_1^3)}{12} \quad \text{.........(1)}$$

where, E_1 and E_2 are the elastic modulus of the middle layer and the surface layers respectively and d_1 and d are the thickness of the middle layer and the whole sheet. The above equation will further be used to determine the bending stiffness of the board.

From the equation 1, it is apparent that middle layer thickness mainly determines the bending stiffness of carton board. For high bending stiffness carton board must have high elastic modulus of top and bottom layer and higher thickness of middle layer. The middle layer has by far the highest basis weight of these three layers (at least 68%). Currently there are two strategies to design the middle layer: one is to use expensive mechanical pulp that is giving a high specific volume or to use cheap recovered paper grades and increase the basis weight. The best method will be one that gives higher specific volume.

In pre-trials, lignin particles were used as filler in middle layer of carton board. These lignin particles as filler created a very voluminous, open structured paper. This can help in generating carton boards having lignin particles in middle layer replacing some of the pulp. Thus in this way lignin particles can be used in integrated pulp and paper industry to produce economical carton board with desired bending stiffness.

The aim of the present investigation is to examine the suitability of lignin particles as filler for the middle layer of carton board.

2. Materials and Methods

In the present study, the major equipments required to perform the experiments were:

Coulter counter LS200, Rapid Coulter sheet former, Disperser, Schopper Reigler Freeness tester, PFI mill Beater and Bending stiffness tester.

The methodology of the experiments consisted of preparation of lignin particles, characterization of lignin particles for particle size distribution and mechanical stability, preparation of top and bottom layer of carton board of various patterns, formation of middle layer with mechanical pulp/ recycled pulp, and lignin particles, and measurement of matrix sheet properties by ISO test procedures. Properties included thickness of different layers, apparent density, Young's modulus of elasticity, tensile strength, Z span strength values, and bending strength.

Sheets of different lignin contents for both raw materials, namely mechanical and recycled pulps were made and tested. In addition to specific volume, following other quality and process parameters were also investigated: tensile strength, SCT for paper quality, Z span strength and dewatering as process parameters Promising recipes were selected and three layer symmetric carton board was prepared on Rapid-Kothen sheet former and subsequently tested.

Firstly lignin particles were characterized in terms of particle size and size distribution with Coulter counter LS200. 120 grams of lignin particles were mixed in water to make final volume 240 ml. Mixing of lignin particles was done by glass rod manually with hand until uniform suspension was formed. Five ml of sample from this was collected and kept in a vial and marked as 0 min. Rest of the sample was dispersed in dissolving tank at 4000 rpm. During dispersion in dissolving tank, 5 ml sample was taken at 5, 10 and 15 minutes, kept in a vial and marked as 5 min, 10 min and 15 min respectively. After 15 min, dispersion process was stopped and rest of the lignin sample was stored in vessel for later use. For each of these samples, size distribution was tested by Coulter counter LS200. After particle size analysis of lignin particles, suitable distribution was selected for further use as filler in middle layer. For the trial experiments lignin filler sheets were made as shown in figure 1.

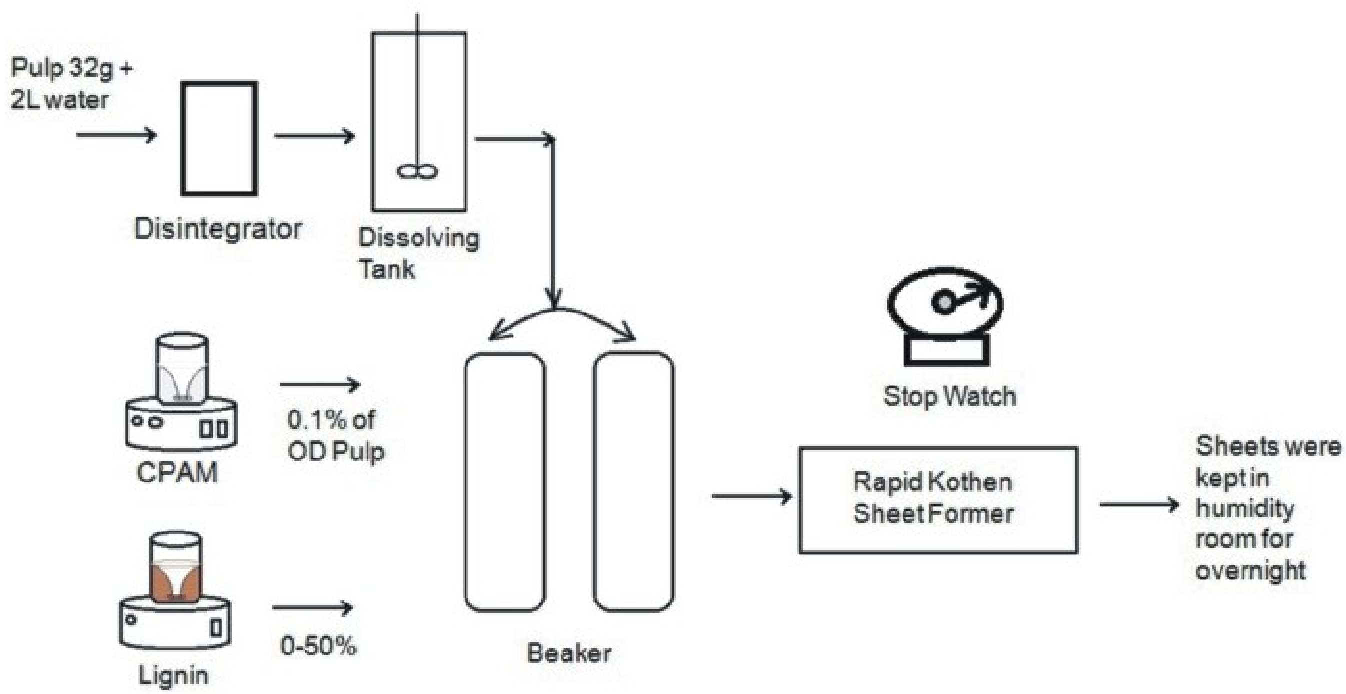

Figure 1: Procedure of lignin filler sheet formation

Experiments were performed with two types of pulp samples for the formation of middle layer of carton board i.e. mechanical and recycled pulp. The effect of lignin as filler on sheet properties for both the pulp samples was examined. For this purpose, pulp sheets of 80 gsm were made separately with both the samples,

The composition of recycled pulp (obtained from German industries) from various types of papers employed in this study is as under:

Table : Composition of different grades of papers in recycled pulp

Papers	Percentage (%)
Carton Board	15
Corrugated Board	70
Magazines	10
Newsprints	5

Unbeaten mechanical and recycled pulps used were of 15 ^{0}SR and 17 ^{0}SR freeness respectively. Lignin particles were added in the sheet ranging from 0 to 50% of sheet weight. Lignin particles used were previously disintegrated at 4000 rpm for 10 minutes. Sheets were made using Rapid Coulter sheet former and subsequently tested.

Later tri-layer sheets were formed with pattern shown below:

For top and bottom layer of symmetrical tri-layer paper 60 gsm kraft pulp was used. It was first beaten to get desired °SR value using PFI mill.

For middle layer, recycled pulp or mechanical pulp was used having different gsm and different lignin concentrations. It was formed in 3 different patterns as shown below:

Pattern 1: In this pattern, grammage of the middle layer was kept constant at 160 gsm and lignin particles of **160 gsm** were added 0-50% by replacing middle layer pulp. Tri-layer sheets were made with this pattern for both the pulp samples i.e. mechanical pulp and recycled pulp separately in middle layer. The ultimate form of pattern for middle layer is:

[Mechanical or Recycled pulp + 0-50% lignin of 160gsm] = 160 gsm

With this pattern, sheets were made to show the effect whether one can replace the fibers with the lignin particles.

Pattern 2: In this pattern, pulp in the middle layer was kept constant at 112 gsm and grammage 30% of pulp from 160 gsm of the pulp can be reduced In this, grammage of the middle layer was increased from 112 gsm to 224 gsm by adding 0-50% lignin particles. Tri-layer sheets were made with this pattern for both the pulp samples i.e. mechanical pulp and recycled pulp separately in middle layer. The ultimate form of pattern for middle layer is:

Mechanical or Recycled Pulp = 112 gsm + 0-50% lignin

With this pattern, sheets were made to check how much lignin addition can achieve same bending stiffness if one removes specific amount of middle layer fibers.

Pattern 3: In this pattern also, pulp in the middle layer was kept constant at 160 gsm and grammage of the middle layer was increased by adding 0-50% lignin particles. Tri-layer sheets were made with this pattern for only recycled pulp in middle layer. The ultimate form of pattern for middle layer is:

Recycled Pulp = 160gsm + 0-50% Lignin

With this pattern, sheets were made to check whether one can replace mechanical pulp with recycle pulp.

After forming tri-layer papers, these were tested for finding bending stiffness by ISO5628 standard (10) and SCT by ISO9895 standard (12).

3. Results and Discussion

The laboratory experimental data were analyzed. Stiffness values were estimated from equation 1. These are interpreted in various figures. The relationships among various parameters are enumerated below:

3.1 Characterization of lignin particles

Dispersion of lignin particles at 4000 rpm and 50% consistency for 0-15 minutes at time interval of 5 minutes was done. d_{90} values of lignin particles are plotted as a function of time of dispersion (fig.2).

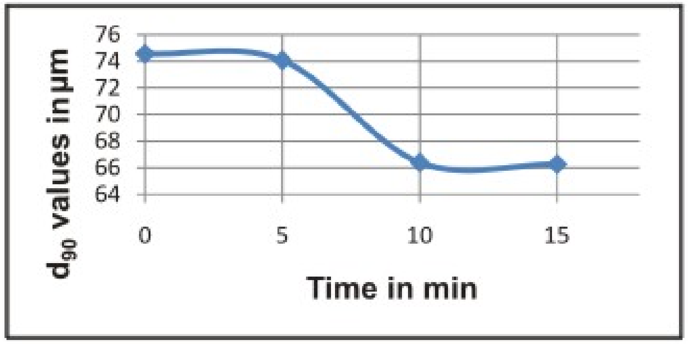

Figure 2 : d_{90} values of lignin particles with respect to time of dispersion

It is clear from the figure that after 10 sec of dispersion at 4000 rpm, there was no further effect on the size distribution and d_{90} value. Thus lignin particles dispersed at 4000 rpm is sufficient. Therefore, 10 min of dispersion at 4000 rpm at 50% consistency of lignin particles was kept constant in further experimentation.

3.2 Effect of lignin particles on sheet properties

Figure 3 compares the effect of lignin particles addition on thickness of both pulp samples (mechanical, recycled).

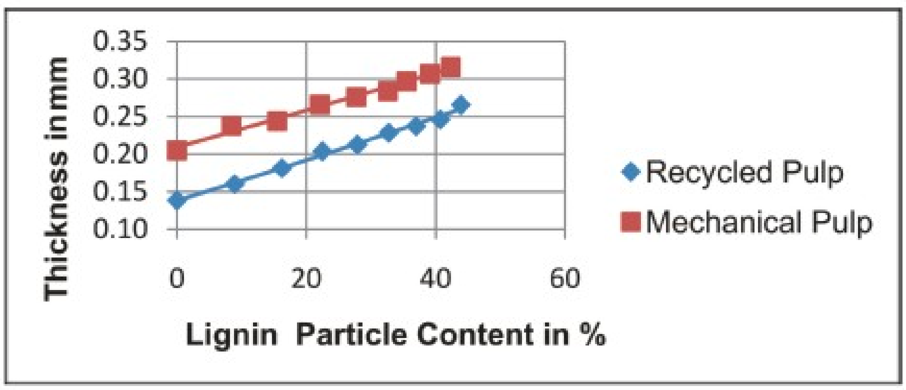

Figure 3: Comparison of thickness variation with lignin particles addition on mechanical and recycled papers

It is evident from the figures that with the addition of lignin particles the thickness of sheet for both the pulp samples is increasing.

Changes in apparent density of sheet with the addition of lignin particles on mechanical and recycled pulp are shown in figure 4. It is clearly reflected the difference between the behaviors of two different pulp samples on addition of lignin particles

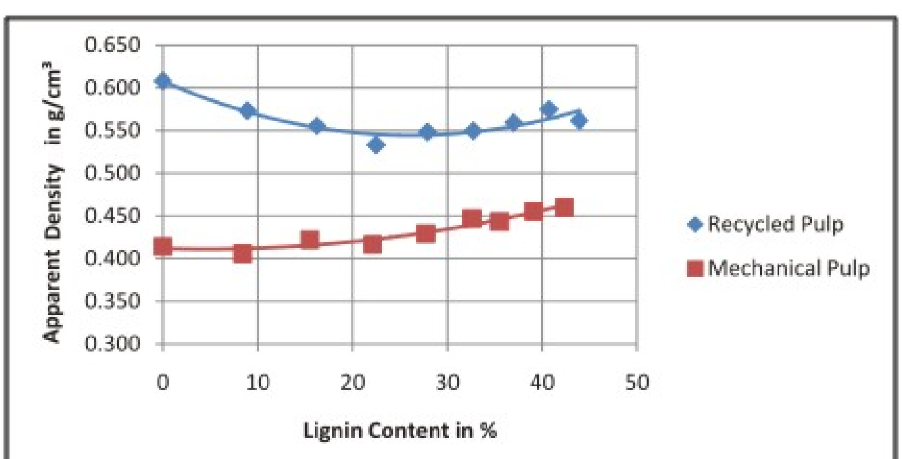

Figure 4: Comparison apparent density with lignin particles addition on mechanical and recycled papers

For mechanical pulp, increase in thickness is just because of increase in basis weight but for recycled pulp, increase in thickness is not just because of increase in basis weight but also because it creates spacious structure in the pulp. As a result, apparent density in the case of recycled pulp decreased. Therefore it can be concluded that the two pulp samples behave differently in terms of increase in thickness of sheet.

3.3 Effect of beating on kraft pulp for top and bottom layer

As the top and bottom layers of carton board must have high Young's modulus and tensile strength, these layers were made from kraft pulp which were beaten in PFI mill beater.

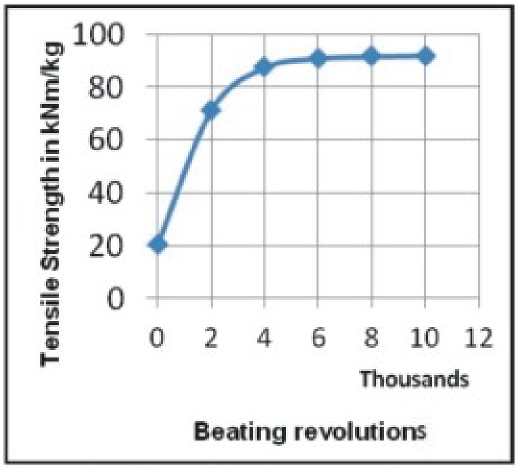

Figure 5 : Effect of beating on tensile strength of kraft pulp.

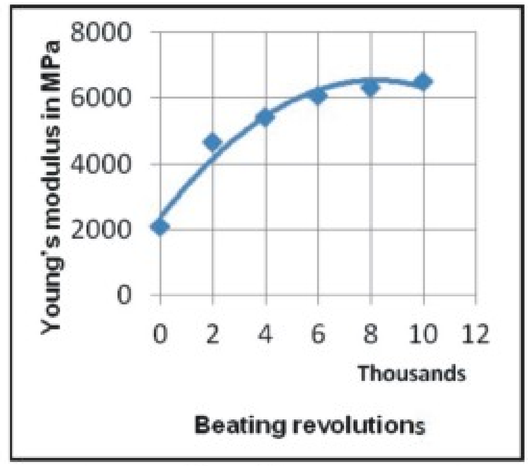

Figure 6 : Effect of beating on Young's modulus of kraft pulp.

Figure 5 shows the effect of beating on the tensile strength of sheet whereas figure 6 shows the effect of beating on the Young's modulus of elasticity.

It is reflected from the figures that 4000 beating revolutions gave best tensile strength and Young's modulus of elasticity. Further increase in beating increases energy consumption during beating and the effect on tensile strength and Young's modulus of elasticity is not appreciable.

3.4 Comparison of results of pattern 1 and pattern 2 of mechanical pulp

Bending stiffnesss is most desirable property for carton board, it is important to examine the effect of bending force as a function of addition of lignin particles for the various experiments.

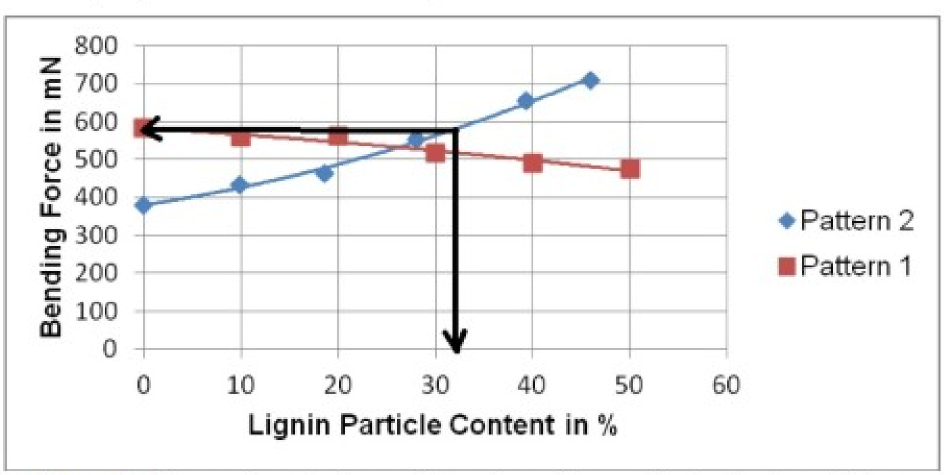

Figure 7 : Comparison of change in bending stiffness with the lignin particles addition in middle layer of carton board for pattern 1 & pattern 2 of mechanial pulp

Figure 7 shows the comparison of results that were obtained in case of the pattern 1 and pattern 2 of mechanical pulp. At roughly 33% of lignin particles concentration in pattern 2, one can achieve same bending stiffness as is given by origional mechanical pulp without lignin paricles addition in pattern 1.

Z span strength is another desirable property of triplex board which needs to be examined for its variation. Figure 8 shows the comparison of the Z span strength of the tri-layer sheet of pattern 1 and pattern 2 of mechanical sheets. It shows that at 33% lignin particles addition in pattern 2, Z span strength reduced to 30 N which is 80 N for original mechanical pulp without lignin paricles addition in pattern 1. It indicates that if in a tri-layer paper one replaces 30% of middle layer mechanical pulp fiber out of 160 gsm with 33 % of lignin particles, one can achieve the same bending stiffness as is given by tri-layer paper having 160 gsm of mechanical pulp without addition of lignin particles but at the cost of reduction in the Z span strength of the tri-layer sheet.

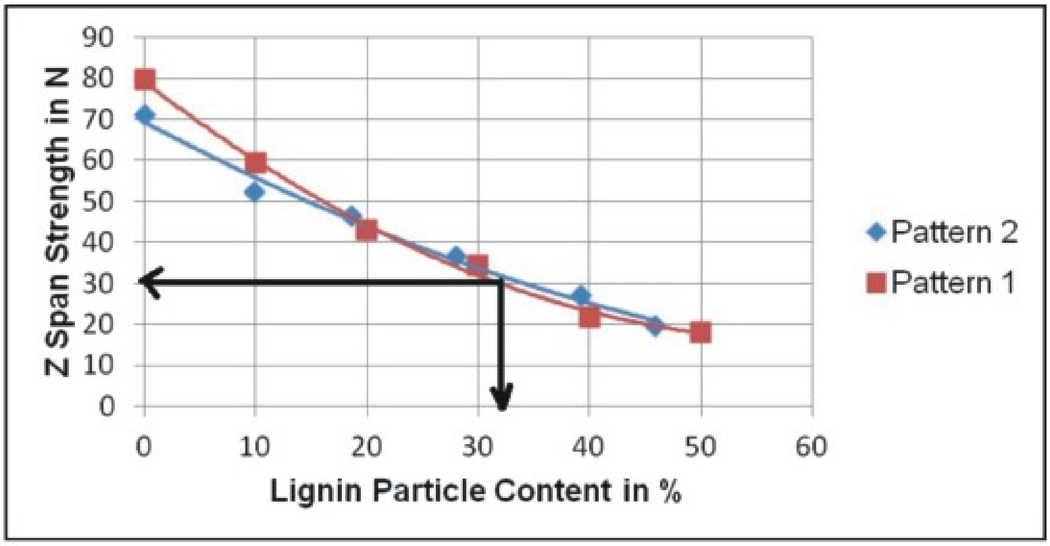

Figure 8 : Comparison of change in Z Span strength with the lignin particles addition in middle layer of carton board for pattern 1 and pattern 2 of mechanial pulp

Figure 9 shows the comparison of results that are obtained during the pattern 1 and pattern 2 of recycled pulp.

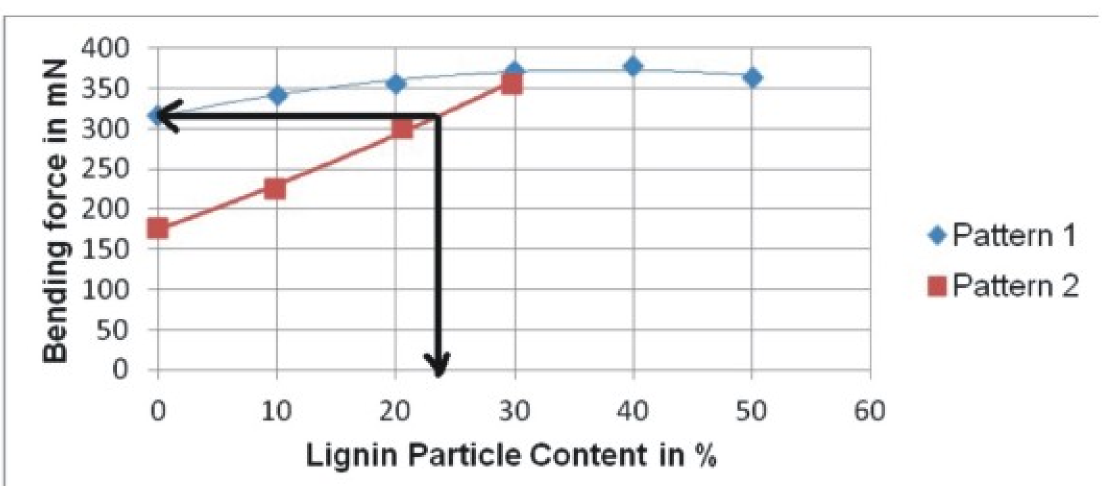

Figure 9 : Comparison of bending stiffness of tri-layer carton having recycled paper in middle layer of Patter 1 with Pattern 2

It shows that at around 24% of lignin particles concentration in pattern 2, one can achieve same bending stiffness as is given by origional mechanical pulp without lignin paricles addition in pattern 1. It indicates that if in a tri-layer paper one replaces 30% of middle layer recycled pulp fiber out of 160 gsm with just 24 % of lignin particles, one can achieve same bending stiffness as is given by tri-layer paper having 160 gsm of mechanical pulp without lignin particles but at the cost of reduction in the Z span strength of the tri-layer sheet.

3.5 Tri-layer carton having recycled pulp in middle layer with pattern 3 and comparison with pattern 1 of mechanical pulp

The tri-layer papers with pattern 3 of recycled pulp were made in which middle layer pulp was kept constant i.e. 160 gsm and lignin particles were added in it from 0 to 50% to check whether it is possible to replace mechanical pulp with recycled pulp with addition of lignin particles in it.

Comparison of effect of lignin particles addition in middle layer of carton board on bending stiffness of pattern 3 of recycled pulp with pattern 1 of mechanical pulp is shown in figure 10.

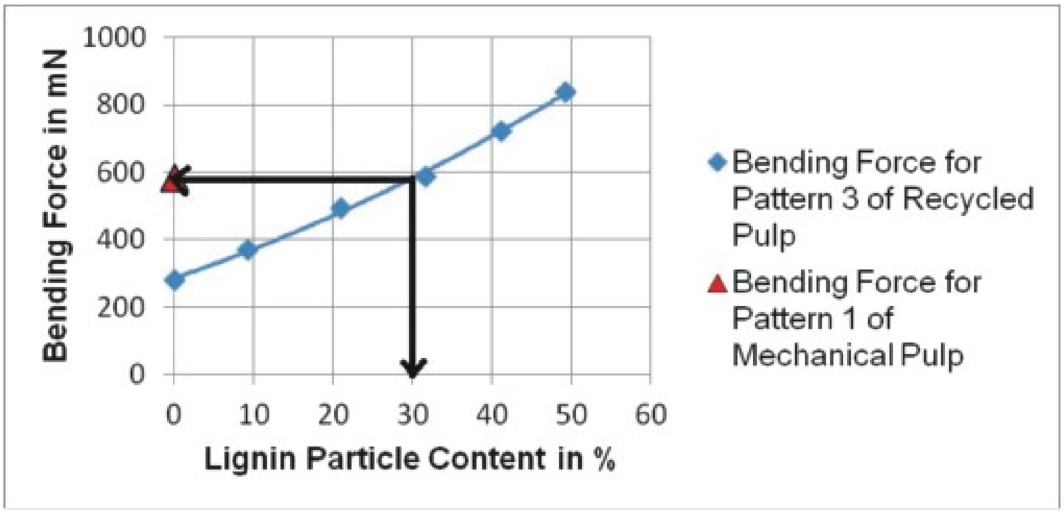

Figure 10 : Comparison of effect of lignin particles addition in middle layer of carton board on bending stiffness of pattern 3 of recycled pulp with patter 1 of mechanical pulp.

It is evident that if one adds 30% of lignin particles in the160 gsm middle layer of recycled pulp for pattern 3, one will get same bending stiffness as is given by 160 gsm mechanical pulp in middle layer for pattern 1 without lignin. In this way, one can see that there is a possibility to replace mechanical pulp with the lignin added recycled pulp in the middle layer of carton board.

Figure 11 shows the comparison of strength properties of pattern 3 of reccycled pulp with pattern 1 of mechanical pulp.

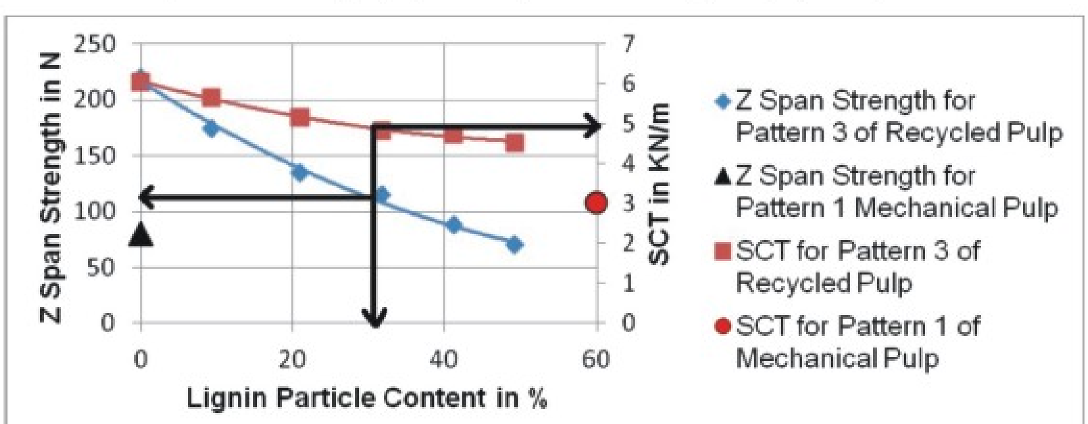

Figure 11 : Comparison of effect of lignin particles addition in middle layer of carton board on Z Span strength and SCT of pattern 3 of recycled pulp with patter 1 of mechanial pulp

From the figure one can see that at 30% lignin concentration in pattern 3 of recycled pulp, Z span strength is roughly 120 N which is just 80N for pattern 1 of mechanical pulp. Similarly, short compression strengh (SCT) for pattern 3 of recycled pulp is roughly 4.9 kN/m which is 3 kN/m for pattern 1 of mechanical pulp.

From all the above results, one can conclude that for tri-layer carton in the middle layer costly mechanical pulp can be replaced by the economic recycled pulp by adding some additional amount of lignin particles in it and can obtain same bending stiffness with improved Z span strength and SCT of the trilayer board. However, there is only one drawback of this method i,e the drainage time of the recycled pulp will be more as compared to that of the mechanical pulp.

4. Conclusions

In the present study lignin particles as filler in the middle layer of carton board was tested. Experimental results show that:

1. Mechanical pulp and recycled pulp behave differently with the addition of lignin particles.
2. Results of laboratory forming tri-layer paper having lignin as additive in middle layer shows improved bending stiffness and drainage time at the cost of decreased Z span strength and SCT for both the pulps, i.e. mechanical and recycled.
3. It is possible to replace some amount of pulp with lignin particles both for recycled and mechanical pulps in middle layer of carton board.
4. It is also possible to replace recycled pulp with mechanical pulp in middle layer of carton board because recycled pulp having lignin particles in middle layer of tri-layer paper shows same bending stiffness as obtained by tri-layer paper having mechanical pulp in middle layer with improved SCT and Z span strength as compared to mechanical paper.

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