CHAPTER IV

PREPARATION AND CHARACTERIZATION OF

PINE CELLULOSIC FIBER-ADHESIVE BASED

POLYMER COMPOSITES
The preparation of particle boards from naturally available materials i.e. the lignocellulosic fibers as the reinforcing agent and the various adhesives as the matrix is an artful task. It may be for a man to think that it is necessary only to take a certain amount of lignocellulosic material, a certain amount of resin, mix them together, and put them in press to produce the particle boards with desired characteristics. However, the things are entirely different. Numerous factors influence the formation of particle boards in achieving various properties of given standards. The quality of the product is dependent on strict control at all the stages of manufacturing and the regular testing of the finished product. Only by this close supervision can the quality of the finished product be maintained at a constant and uniform level and be relied upon to have the various physical and strength properties claimed for it. These values are determined by the type of the board, the type of the raw material and the variables inherent in the method of manufacturing.

Factors influencing the properties of the finished board depend upon its composition, but to an even greater degree upon the treatment of the components. The factors influencing the properties of the board are broadly divided into two sections:

(I) The Materials and (2) Treatment of the materials

1. THE MATERIALS

Whatever the process or the type of board, the first consideration is naturally the raw material, the wood, flax or other lignocellulosic substance which is main constituent of the boards and referred to as the "reinforcing agent", together with the resin binder referred to as the "matrix". Any other additive can be added to impart a specific property to the particle board. Different raw materials used as reinforcing agents and
resins used as binder for the production of the particle boards have been discussed in chapter-II (Section A and Section B respectively). In the present chapter we discuss other factors that may affect the physical and mechanical properties of the particle boards

(i) **Use of Resin**

Depending upon the nature of the resin i.e. the thermosetting or thermoplastic, selection of the resin and its formulation will depend on many factors. These may include the type of raw material and its moisture content, the interval of time required in various operations, the temperature applied to accelerate curing and the time cycle involved in pressing. The quality of the board can adversely be affected through divergence from the established routine dictated by resin formulation. During the production of particle board, only a relatively small quantity of resin is used, varying between 4 and 12 % of resin solids to particles based on dry weight. This small proportion however, may cost more than the wood or other raw materials and every effort is made to keep resin consumption minimal within the limits of the process and desirable board properties, and to ensure that the fullest use is made of the quality used in fulfilling its function of binding the particles together.

In this context a correct amount of adhesive, and uniformity in its distribution in the board is most important. Any agglomeration of chips containing excess of resin is likely to affect not only the uniformity of appearance and of substance, but even the thickness of the board is affected. The well-known phenomenon is caused by the natural tendency of the urea-formaldehyde adhesive to shrink; this action is progressive for a period of two to three years. This means that a furniture component,
sanded, veneered duly sanded again, during a period of years may develop an indentation on the surface corresponding to the agglomeration in the board.

(ii) Moisture Content

Optimum moisture content is considered to be of such importance that in some plants dealing with timber of low moisture content, ponds for soaking timber before cutting are considered essential. The mix should have adequate moisture content; it does not matter very much exactly where the moisture is, i.e. in the wood, in the adhesive, or in the emulsion, as long as total amount is adequate. In other words, lack of moisture in the wood chips can be corrected by an excess of water in the adhesive, and conversely, dry urea-formaldehyde powder can be used directly as an adhesive, instead of usual syrup, if the wood carries enough water. We must therefore, consider the amount of water contained by the chips or the raw material before transferring it for the mix preparation. Insufficient moisture results in a tendency of the chip to absorb the adhesive readily, thus diminishing the amount available in the chip surface for bonding purposes. Insufficient water in the surface chips affects adversely the degree of compression of the face layers and results in loose and weak board surfaces. On the other hand, too high a moisture content of the core chips may lead to blowing out of the board during or after the pressing operation. Thus, excess of the water may result in blistering unless the cycle is prolonged, while lack of water results in poor bond, and poor surface strength. There must be water in the adhesive since viscosity during spraying with conventional equipment at short temperature must be low, the importance of which has already been indicated.
Apart from having the water in the wood and in the adhesive, water can be applied separately on the surface of the mattress before pressing. This application shortens the pressing cycle, in some instances prevents pre-cure in the press and thus improves strength, appearance and structure of board faces, as well as contributes towards a desirable pattern of the classification throughout the thickness of the board. This in turn affects the surface quality and appearance and practically all the strength properties.

(iii) Additives

Various additives can be added to the mix for imparting and improving properties of the particle boards. Additives may include: hardeners, fortifiers, fillers, extenders, preservatives, insecticides, fungicides, wax emulsion and fire retardants etc. The additive has to be introduced into the mix in amount large enough to be efficient with respect to water absorption and swelling resistance and small enough not to adversely affect the bond between the chips and any subsequent gluing operation performed on the finished board.

The incorporation of additives usually presents no physical problems; adequate and equitable distribution must be ensured and care be taken that the chemicals used do not affect curing of the adhesive. The principle of additives, although well known, is only established to a limited degree and would appear to be a subject worthy of more attention.

2. TREATMENT OF RAW MATERIALS

Before transferring the reinforcing agent to the mix, to prepare the particle board, proper treatment of the raw materials is essential.
(i) Preparation of Raw Material

The wood or industrial residue can be broken down in several ways and the quality of resulting chips depends upon the nature of machinery used for conversion. The main aim of the manufacturer is to produce small particles related as closely as possible to a specified size and geometry within certain limits. The size of particles produced in this way can be controlled to fairly precise limits and it is generally conceded that the properties of the final board can be predetermined much more readily when engineered particles are used.

(ii) Drying and Screening

Whether the source is round wood or industrial residue, the moisture content of the particles will be high. The desired moisture content of the finished board will be around 10% and consequently some drying of the particles will be necessary. It is not, however, a case of drying down to the moisture level of the finished board since water in the resin must obviously be considered together with the condensation and drying which occur when the board mattress is in the hot press. To achieve the correct balance of moisture is extremely complicated, but again is a most important function of manufacture of the finished board of high quality.

Whatever the method used, the aim is to dry particles of varying sizes to uniform moisture content quickly and economically. For the manufacture of good quality particles the moisture content of timber should be fairly high, between 30% and 60% is common, since wet timber cuts more cleanly, there is less wear on the cutting edges and less fragmentation of the particles.
(iii) Glue Coating of Particles

The dried and screened particles are now ready to be mixed with the resin binder. The mixing or blending of the resin binder with the particles is aimed at applying a thin film of resin, though not necessarily a complete coating, to each and every particle so that the eventual close binding of the mass of each unit is effectively spot welded to its neighbour.

Preparation of the adhesive is carried out immediately, prior to the addition of the particles and other ingredients. The resin syrup, hardener and water together with any additive such as paraffin wax emulsion are carefully mixed in the correct proportions. Actual resin/particle blending may be a continuous process in which the particles are moved mechanically through a container in a continuous stream, resin being introduced as a fine spray by means of compressed air spray nozzles. While this method is an excellent one, it does call for accurate and reliable measurement of the relative proportions of particles and adhesive to avoid using too much expensive resin and upsetting the economics of production. Not enough, resin would result in a poor quality board. Modern method involves continuous weighing of the particles, which by electrical method, controls the flow of adhesive at the required level.

A common method is to feed the batch of particles into a drum alongwith necessary quantity of resin into it as in the continuous process. As the drum revolves contact of particles with each other helps to ensure even distribution of the resin. As an alternative, rotating arms or paddles inside the drum can maintain movement of the particles.
(iv) Board Forming

The resin-coated particles are now ready for the final process before actual consolidation in board form and indicate the pattern of particle arrangement that decides the type of board produced.

The particles after being coated with glue, are not as to be supposed a glutinous mass, but quite dry to the touch, actually in the region of 12 to 14 % moisture content, since the very dry particles readily absorb water in the proportionally small amount of added resin. It is thus a relatively simple matter to transport them mechanically or pneumatically to the forming station where they are spread or otherwise formed into a carpet or mat of predetermined thickness before final board pressing. It is at this point at which the various processes differ.

(v) Board Pressing

Pressing is carried out in what is essentially a conventional heated platen press similar in application to those used for plywood manufacture.

Press temperature is usually in the range 100º to 140°C or slightly higher according to UF or phenolic resin used. The heating of the mix during pressing has a triple effect on mattress and also on the board. Firstly, it consolidates by rendering the substrate plastic, secondly it cures the adhesive in a comparatively short time, and thirdly it evaporates moisture from the mattress. The pressure will be influenced by a number of factors and is generally between 10 to 20Kg/cm² but it must be understood that this is not exerted on the mattress to the limit of resistance. Metal stops or distance pieces are inserted between the platens, corresponding to the required board thickness and the press closes on to these stops, otherwise there would be complete
lack of control over the thickness of the finished board. Pressure is exerted from the bottom upward. This step by step operation takes time and can also give rise to variation in the physical and strength properties of boards according to their position in the press.

(vi) Board Conditioning

When the treated (pressed) board is withdrawn from the press, the board is still very hot since as far as it is known, no present day processes include press cooling in the cycle. Unless the board is permitted to lose this heat gradually, the moisture to equilibrate through the board, and a period of time allowed for the resin to completely cure, the board will tend to distort. Likewise unless the board is laid in true plane for this conditioning period the distortion shape will be permanent. This conditioning period of seven to ten day’s duration is as essential as any of the earlier precautions taken during actual manufacture.

(vii) Board Trimming

Platen pressed board emerging from the press are roughly two inch longer and two inch wider than their final size. This surplus may be trimmed off either immediately after pressing or after conditioning period.

EXPERIMENTAL

MATERIALS AND METHOD

Reinforcing Agent: - Pine needles were cut into a standard size between (0.5” to 1.0”) and treated with aqueous NaHSO₃ solution under pressure. The treated needles were thrashed with wooden hammer to separate cellulosic fibers, which were used as the reinforcing agent.
Matrix: - Following resins were used as matrix.

(i) Phenol-formaldehyde
(ii) Urea-formaldehyde
(iii) Phenol-resorcinol-formaldehyde
(iv) Phenol-lignin-formaldehyde

Additives: - No additives were used.

Preparation of Particle Board

Definite amount (1000g) of pine cellulosic fiber of known moisture content (6%) were intimately mixed with the specific amount of the resin in a glue mixer and allowed to stand in air for half an hour so that the moisture content of the mix is between 10%–25%. This depends upon the nature of the resin used i.e. PF, UF, PRF, or PLF, mole ratios of the resin components and the amount of the resin used. After thorough mixing of the cellulosic fibers and the resin, the mixture was placed in a wooden frame placed on aluminium sheet for mat formation. The wooden frame was replaced by another iron frame of 10 mm thickness and was covered with another aluminium sheet from above. The surfaces of the aluminium sheets were coated with oleic acid from inside to avoid adhesion of the mix to the sheets and to make an easy removal of the particle board after its production. The whole assembly was then placed inside the hot press for specific time, temperature and pressure depending upon the nature of the resin used. The details are given in Table 1. After removing from the press, the aluminium sheets and the iron frame were removed. The particle board were kept in the open for conditioning at room temperature. The sides of the boards were trimmed by D.D. saw to give smooth edges.
Each particle board, prepared by using different resins, was characterized with respect to water absorption and mechanical properties such as tensile strength both perpendicular and parallel to surface, modulus of elasticity and modulus of rupture. The methods used for the characterization of the particle board are given below:

**CONDITIONING OF THE SAMPLE**

All the test specimen were conditioned by freely exposing them for at least 48 hours immediately before testing to the atmosphere of a well-ventilated room, according to 2.2 of IS: 2380 (Part I) – 1977.

**DETERMINATION OF WATER ABSORPTION/MOISTURE ABSORPTION ACCORDING TO IS: 2380 (PART XVI) – 1977**

i. **Test specimen**

The size of the specimens should be 30cm x 30cm. However, in the present case 10cm x 10 cm. specimens were used. All the four edges were smoothly and squarely trimmed.

ii. **Procedure**

The specimens were sealed by cooling with wax or other suitable sealant material on all the four edges of the specimen and then submerged horizontally under 25mm fresh clean water. The test specimens were separated by at least 15mm from each other and from the bottom and sides of the container. After a 2 hour submersion, the specimens were suspended to drain for 10 minutes, at the end of which the excess surface water was removed and the specimens immediately weighed. The specimens were then submerged for an additional period of 22 hours and the above weighing procedure repeated.
DETERMINATION OF TENSILE STRENGTH PERPENDICULAR TO SURFACE ACCORDING TO IS: 2380 (PART V) – 1977

i. Test specimen

Each test specimen was 50mm² and the thickness of the finished board was measured. Loading blocks of steel or aluminium alloy 50mm² and 25mm in thickness were bonded with a suitable adhesive to the 50mm² face of the specimen. The adhesive were such that failure does not occur at or near the glue line. Any suitable adhesive and the corresponding technique of application may be employed for the blocks to be glued to the specimen.

ii. Procedure

Method of loading: Loading fixtures, attached to the heads of the testing machine, shall engage the blocks attached to the specimen. The specimen was stressed by separation of the heads of the testing machine until failure occurs. The direction of loading was as nearly perpendicular to the faces of the board as possible and the centre of load passed through the centre of the specimen.

Rate of loading: The load shall be applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine of 0.8mm/minutes.

iii. Calculation and Report

Maximum loads shall be determined from which the stress at failure shall be calculated for each specimen. Strength value shall be calculated in N/mm² for which the measured dimensions of the specimen shall be used.
DETERMINATION OF TENSILE STRENGTH PARALLEL TO SURFACE

ACCORDING TO IS:2380 (PART VI) – 1977

i. Test specimen

This test may be applied to material of 25mm or less in thickness. Each test specimen shall be prepared as shown in Fig. 1. The reduced section shall be cut with a handsaw, to the size shown. A sharp saw shall be used to ensure a smooth surface in the centre section. The thickness of the board and the minimum width of the reduced section shall be measured to an accuracy of not less than ± 0.3 percent. These two dimensions shall be used to determine the net cross section area for determining maximum stress.

ii. Procedure

Method of Loading: Self aligning, self-tightening grips with serrated gripping surface at least 50 mm in width and at least 50 mm in length shall be used to transmit the load from the testing machine to the specimen.

Rate of Loading: The load shall be applied continuously throughout the test at a uniform rate of motion of the movable crosshead of the testing machine of 4mm / minutes.

iii. Calculation and Report

The stress at failure shall be calculated from the maximum loads for each specimen and reported. If the failure is within 10mm of either grip, the test value shall be discarded.
Fig. 1 Details of Specimen for Tension Test Parallel to Surface

$T =$ Thickness of material 25 mm, Max.
All dimensions in millimetres.
DETERMINATION OF STATIC BENDING STRENGTH (MODULUS OF RUPTURE AND MODULUS OF ELASTICITY IN BENDING). ACCORDING TO IS 2380 (PART IV) – 1977.

i. Test Specimen

Test specimen of 75 mm in width of 10 mm thick particle board was taken. The length of each specimen shall be \(50 + 24t\), where \(t\) is nominal thickness of the board in millimeters. Here long span specimens are desired for tests in bending so that the effects of deflections due to shear deformations will be minimized and the value of modulii of elasticity obtained from the bending test will approximate the true modulii of the materials. The width, length and thickness of each specimen shall be measured to an accuracy of not less than \(\pm 0.3\) percent.

ii. Procedure

Method of Loading

The specimens were loaded at the center of the span with the load applied to the finished face at uniform rate of 4mm/min through a rounded loading block. The bearing blocks shall be at least 75 mm in width and shall have a thickness (in a direction parallel to the span) equal to twice the radius of curvature of the rounded portion of the loading block. The radius of the rounded portion shall be approximately equal to one-and-a-half times the thickness of the specimen.

iii. Calculation and Report

The readings of the deflection and the loads were recorded and a load-deflection curve was drawn. While drawing a load-deflection curve, the straight line of proportionality at the initial part of the curve shall be drawn in such a way that...
maximum number of points lie on the straight line or nearest to it. No consideration needs be given to the initial two or three points. When straight line does not pass through the origin, a parallel line shall be drawn through the origin and the deflection and load at the limit of proportionality shall be measured on this line. The points beyond the elastic limit and up to maximum load may be corrected by smooth curve but the points beyond the maximum load shall be joined from point to point. Load and deflection at first failure and maximum load shall also be noted.

Modulus of Rupture

The modulus of rupture shall be calculated for each specimen by the following formula, and the values are reported.

$$ R = \frac{3PL}{2bd^2} $$

Where

- $R =$ Modulus of rupture in N/mm$^2$
- $P =$ Maximum load in Newton
- $L =$ Length of the span in mm.
- $b =$ Width of specimen in mm, and
- $d =$ Depth of specimen in mm

Stress at the Limit of Proportionality

The stress at the limit of proportionality shall be calculated for each specimen by the following formula and the values will be reported.
\[ SP_i = \frac{3P_i L}{2bd^2} \]

Where

\( SP_i = \) Stress at proportional limit in N/mm\(^2\)

\( P_i = \) Load in Newton at the limit of proportionality, which shall be taken as the point on the load-deflection curve at which the graph deviates from the straight line

\( L = \) Length of span in mm

\( b = \) Width of specimen in mm and

\( d = \) Depth of specimen in mm

**Modulus of Elasticity**

The modulus of elasticity (MOE) shall be calculated for each specimen by the following formula.

\[ E = \frac{P_i L^3}{4bd^2y_1} \]

Where

\( E = \) Apparent modulus of elasticity in N/mm\(^2\)

\( y_1 = \) Central deflection at limit of proportionality load in mm

\( P_i = \) Load in Newton at the limit of proportionality, which shall be taken as the point on the load-deflection curve at which the graph deviates from straight line

\( b = \) Width of specimen in mm and

\( d = \) Depth of specimen in mm
RESULTS AND DISCUSSION

The particle boards prepared under different conditions using different resins have been characterized with respect to water absorption and other mechanical properties according to the procedure adopted by Bureau of Indian Standards. The various results obtained for different particle boards are discussed and the results are presented as bar diagrams for each of the property studied.

1. PROPERTIES OF THE PARTICLE BOARDS PREPARED BY USING PHENOL-FORMALDEHYDE RESIN

Water Absorption

Water absorption for the particle boards prepared using phenol-formaldehyde resin with different F/P ratio and with varying amount of resin w.r.t. the weight of the pine cellulosic fibers has been studied. The results of water absorption as a function of mole ratio of F/P and amount of resin are presented respectively in Fig. 4.1.1.1 and 4.1.1.2 for 2h. treatment and in Fig. 4.1.2.1 and 4.1.2.2 for 24 h. water treatment. It is observed from Figs. 4.1.1.1 and 4.1.1.2 that the water absorption decreases as the mole ratio of formaldehyde to phenol increases in the resin. The same trend is observed for the particle boards, prepared from the PF resin with increasing amount of the resin w.r.t. the amount of pine cellulosic fibers (Figs. 4.1.2.1 and 4.1.2.2). The decrease in water absorption may be due to of restrictions occasioned by gluing multidirectional particles to one another. However, at 2.44 F/P ratio for all boards, water absorption increases both after 2h. and 24h. This may be due to the excess free methylol groups present in the resin, which bind the excess water. On comparison
Fig: 4.1.1.1 Percent water absorption after 2h as a function of mole ratio of HCHO : PhOH

Fig: 4.1.1.2 Percent water absorption after 2h as a function of amount of PF resin
Fig: 4.1.2.1 Percent water absorption after 24h as a function of mole ratio of HCHO : PhOH

Fig: 4.1.2.2 Percent water absorption after 24h as a function of amount of PF resin
with the standard values (IS:3087-1985), the water absorption values are within the limits of 25 % and 50 % respectively for 2h. and 24h.

**Dimensional Stability**

Dimensional Stability of the particle boards after treatment with water for 24h w.r.t. percent thickness expansion and length expansion as function of mole ratio of F/P and amount of resin are shown in Tables 2 and 3 and Figs. 4.1.9.1, 4.1.9.2, 4.1.10.1 and 4.1.10.2 respectively.

It is observed from the tables that both percent thickness and percent length expansion do not show a particular order with increasing mole ratio of F/P or increasing amount of resin in the particle board. However, percent thickness expansion is found to decrease with increasing amount of resin of 2.2 F/P and probably shows the best result. Percent length expansion varies between minimum of 0.48 % to maximum of 1.45 %.

**Moisture Absorption Behaviour Of Particle Boards As A Function Of Temperature And Relative Humidity (RH)**

The conditions generally specified as per B.S. (1811) for moisture absorption studies are temperature of 25°C and RH of 65 % for normal condition, 90 % RH for wet conditions and 40 % RH for dry conditions. In the present studies, however, moisture absorption has been carried out at RH varying between 60% - 90% i.e. from normal conditions to wet conditions as a function of temperature. Moisture absorption behaviour of particle boards prepared from phenol-formaldehyde resin using different F/P mole ratio of formaldehyde to phenol and different amount of resin was studied at different temperatures such as 25°C, 35°C and 45°C. For each temperature the studies were made at different level of percent relative humidity (%RH) varying
Fig.- 4.1.9.1 Percent Thickness expansion after 24h water absorption as a function of mole ratio of HCHO : PhOH

Fig :- 4.2.9.2 Percent Thickness expansion after 24h as a function of amount of PF resin
Fig: - 4.1.10.1 Percent length expansion after 24h water absorption as a function of mole ratio of HCHO : PhOH

Fig: - 4.2.10.2 Percent length expansion after 24h as a function of amount of PF resin
between 60% to 90%. The results are presented in Figs. 4.1.3.1 - 4.1.3.12. for 24h and Figs. 4.1.3.13 - 4.1.3.24 for 48h humidity cabinet treatment.

Figs. 4.1.3.1–4.1.3.4 represent the percent moisture absorption studies as a function of F/P ratios of the particle boards prepared using different amounts of the resin at 60%, 70%, 80%, 90% relative humidity at a temperature of 25°C. It is observed from the figures that the particle boards prepared from phenol-formaldehyde resin with different F/P mole ratio show increase in percent moisture absorption with increase in the relative humidity from 60% to 90%. It is further observed that the percent moisture absorption decreases with increase in the mole ratio of formaldehyde to phenol i.e. from F/P 1.74 to 2.44 and increases with amount of the resin from 300gm. to 450gm. at every relative humidity level. Maximum percent moisture absorption (4.87%) is observed in the particle boards prepared with F/P mole ratio of 1.74 with 350gm of resin and minimum percent moisture absorption is observed in the particle boards prepared with higher F/P mole ratio (2.44) and at higher amount (450gm.) of the resin.

Figs. 4.1.3.5–4.1.3.8 represent the results of percent moisture absorption as a function of F/P ratios of the particle boards prepared using different amounts of the resin at 35°C for relative humidity varying between 60% to 90%. It is observed from the Figs. that the particle boards prepared from phenol-formaldehyde resins of different F/P mole ratio did not show much change with increase in the relative humidity from 60% to 90%. However, decrease in percent moisture absorption is observed for the particle boards prepared with increasing F/P mole ratio (1.74 to 2.44) and the amount of resin (300gm. to 450gm.). However, higher percent moisture absorption at RH
Fig.- 4.1.3.1 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 24h at 25°C temperature.

Fig.- 4.1.3.2 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 24h at 25°C temperature.
Fig. 4.1.3.3 Percent moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (400g) after 24h at 25°C temperature.

Fig. 4.1.3.4 Percent moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (450g) after 24h at 25°C temperature.
Fig: 4.1.3.5 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 24h at 35°C temperature.

Fig: 4.1.3.6 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 24h at 35°C temperature.
Fig. 13.7 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (400g) after 24h at 35°C temperature.

Fig. 13.8 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (450g) after 24h at 35°C temperature.
90% for particle boards made using higher mole ratio (F/P 2.44) and higher amount of resin (450gm.) is due to higher methylol concentration which binds excess water.

The results of percent moisture absorption at 45°C for relative humidity varying between the 60% to 90% RH are presented in figs. 4.1.3.9–4.1.3.12. Percent moisture absorption of the particle boards remain almost same with increasing F/P mole ratio at increasing RH level. However, it decreases with increase in the amount of resin. Maximum percent moisture absorption is observed for the samples with low F/P mole ratio and with lesser amount of resin and minimum percent moisture absorption is observed for the samples prepared with higher F/P mole ratio (2.44) and high amount of resin (450 gm.). Thus particle boards prepared using higher F/P mole ratio of phenol-formaldehyde resin and higher amount of resin shows better results w.r.t. percent moisture absorption. This may be due to excessive crosslinking between the reinforcing agent and the matrix leaving little space for water absorption. Similar trends were observed for percent moisture absorption by the particle boards after 48h. (Figs. 4.1.3.13 – 4.1.3.24)

Tensile Strength

This property is useful in determining the propensity of the particle boards to split or delaminate through the core and is also an excellent quality control test. Tensile strength (T.S.) is measured both perpendicular and parallel to the surface as a function of F/P ratio and amount of resin in accordance with (IS: 2380 (Part V & VI – 1977) and the results are presented in Figs. 4.1.4.1–4.1.4.2 and 4.1.5.1–4.1.5.2, respectively. It is observed from Fig.4.1 4.1 that the T.S. increases with increase in the mole ratio of F/P and the maximum (0.050 N/mm²) is observed at F/P = 2.44. T.S. perpendicular to the surface measured for the particle boards with increasing
Fig.: 4.1.3.9 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 24h at 45°C temperature.

Fig.: 4.1.3.10 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 24h at 45°C temperature.
Fig: 4.1.3.11 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (400g) after 24h at 45°C temperature.

Fig: 4.1.3.12 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (450g) after 24h at 45°C temperature.
Fig.- 4.1.3.13 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 24h at 25°C temperature.

Fig.- 4.1.3.14 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 48h at 25°C temperature.
Fig: 4.1.3.15 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (400g) after 48h at 25°C temperature.

Fig: 4.1.3.16 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (450g) after 48h at 25°C temperature.
Fig. 4.1.3.17 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 48h at 35°C temperature.

Fig. 4.1.3.18 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 48h at 35°C temperature.
Fig.- 4.1.3.19 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (400g) after 48h at 35°C temperature.

Fig.- 4.1.3.20 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (450g) after 48h at 35°C temperature.
Fig:- 4.13.21 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (300g) after 48h at 45°C temperature.

Fig:- 4.13.22 Percent Moisture absorption of particle boards prepared as a function of different F/P ratio of PF resin (350g) after 48h at 45°C temperature.
Fig: 4.1.3.23 Percent Moisture absorption of particle boards prepared as a function of different F/P mole ratio of PF resin (400 g) after 48 h at 45°C temperature.

Fig: 4.1.3.24 Percent Moisture absorption of particle boards prepared as a function of different F/P mole ratio of PF resin (450 g) after 48 h at 45°C temperature.
weight of the resin for each mole ratio is presented in the Fig. 4.1.4.2. It is observed from the Fig. that the T.S. perpendicular to the surface, increases as the amount of resin in the particle board is increased with respect to the pine cellulosic fibers. It is further clear from Fig. 4.1.4.1 that the use of 400gm or 450gm of resin does not have much effect on T.S. for all the ratio of the resins. T.S. parallel to the surface as a function of mole ratio of F/P (Fig.4.1 5.1) shows that at lower F/P ratio of the resin (1.74 and 1.97), an irregular increase and decrease of T.S. is observed. At F/P = 2.2, T.S. values are same for the resin above 300gm. and for the resin with 2.44 F/P ratio, a slight increase is observed in the T.S. when the amount of resin is increased from 300gm to 400gm but at 450gm a much higher value (0.10 N/mm²) of T.S. is observed. The T.S. parallel to the surface as a function of amount of resin shows that the T.S. does not vary much with the increase in the amount of resin. Amount of resin and the increase in the mole ratio of F/P, increases the T.S. except for the resin amount of 400gm. where a decrease in T.S. is observed when F/P increase from 1.74 to 1.97. Maximum value for T.S. perpendicular to the surface (0.050 N/mm²) and parallel to surface (0.10 N/mm²) is obtained for the resin using higher mole ratio of F/P (2.44) and higher amount of resin (450gm.). The T.S. perpendicular to the surface for 20mm thick board as presented by Indian standards is 0.8 N/mm². However, the boards prepared in our laboratory are only 10mm thick with T.S. perpendicular to the surface is (0.050 N/mm²). The lower value of T.S. may primarily be due to 50% less thickness of the board and may also be due to experimental variations during the preparation of the particle boards.
Fig:- 4.1.4.1 Tensile strength perpendicular to the surface as a function of mole ratio of HCHO : PhOH

Fig :- 4.1.4.2 Tensile strength perpendicular to the surface as a function of amount of PF resin
Fig: 4.1.5.1 Tensile strength parallel to the surface as a function of mole ratio of HCHO : PhOH

Fig: 4.1.5.2 Tensile strength parallel to the surface as a function of amount of PF resin
Modulus Of Rupture (MOR), Modulus Of Elasticity (MOE) And Stress At The Limit Of Proportionality

Figs. 4.1.6.1– 4.1.6.2 represent the MOR for particle boards as a function of mole ratio of F/P of the resin and amount of resin respectively. It is observed from Figs. that for each mole ratio, the increase in the amount of resin (Fig. 4.1.6.1) and for each weight, increase in the F/P ratio (Fig. 4.1.6.2) shows irregular pattern of MOR values. However, with increase in the F/P ratio or increasing the amount of resin, MOR value increases and the maximum value of (5.10 N/mm²) is observed for the resin with higher amount (450gm.) and higher F/P mole ratio (2.44). The standard value of MOR reported for the particle boards up to 20mm thickness is (11 N/mm²). Thus, the particle boards of 10mm thickness prepared in our laboratory (with 50% less thickness) show 50% of the standard value of 20mm thick boards suggesting that two have equivalent value of MOR.

Modulus of elasticity (MOE) is studied as a function of F/P ratio of the resin and the amount of resin used for the preparation of the particle boards. The results are presented in Figs. 4.1.7.1 and 4.1.7.2 respectively. As observed for MOR, MOE also does not show a regular pattern for each F/P ratio of the resin against increase in the amount of resin and for each amount of resin against increase in F/P ratio. However, MOE for the particle boards prepared using higher amount of resin i.e. 450gm show an increase with increase in F/P mole ratio giving maximum value (693.82 N/mm²) at F/P 2.44.

Stress at the limit of proportionality as a function of mole ratio of F/P and amount of resin are presented in Figs. 4.1.8.1 and 4.1.8.2 respectively. Both these figs. show
Fig: 4.1.6.1 Modulus of rupture as a function of mole ratio of HCHO : PhOH

Fig: 4.1.6.2 Modulus of rupture as a function of amount of PF resin
Fig: - 4.1.7.1 Modulus of elasticity as a function of mole ratio of HCHO : PhOH

Fig: - 4.1.7.2 Modulus of elasticity as a function of amount of PF resin
Fig. 4.1.8.1 Stress at limit of proportionality as a function of mole ratio of HCHO : PhOH

Fig. 4.1.8.2 Stress at limit of proportionality as a function of amount of PF resin
irregular pattern of stress at the limit of proportionality and maximum (3.73 N/mm²) and minimum (1.85 N/mm²) values obtained for 2.44 F/P ratio (450gm. resin) and 1.74 F/P ratio 300gm. respectively. Irregular value of stress at limit of proportionality is the reason for the irregular pattern of MOR and MOE values for different F/P ratios of the resin and different weights of the resin used.

2. PROPERTIES OF THE PARTICLE BOARDS PREPARED BY USING UREA-FORMALDEHYDE RESIN

Water Absorption

The results of percent water absorption of the particle boards prepared from UF resin as a function of mole ratio of F/U and amount of resin are presented respectively in Figs. 4.2.1.1 – 4.2.1.2 and 4.2.2.1 – 4.2.2.2 respectively for 2h. and 24h. treatment. It is observed from the Figs. that overall percent water absorption after 2h. decreases with increasing F/U ratio and also with the increasing amount of resin. However, the pattern within the particle boards prepared from same F/U ratio using different amount of resin (Fig. 4.2.1.1) or with same amount of resin with different F/U ratios, the percent water absorption pattern is irregular, maximum percent water absorption 72.66% has been observed for the mole ratio F/U=1.41 when 350 gm. of resin was used and minimum percent water absorption 27.74 % has been observed for 1.74 F/U ratio when 425gm of resin was used. It is further observed that for 425gm of the resin percent water absorption remains almost constant around 30% with increasing F/U ratio. Percent water absorption for the particle boards after 24h. shows that percent water absorption decreases both with increasing mole ratio (fig 4.2.2.1) and the
Fig.- 4.2.1.1 Percent water absorption after 2h as a function of mole ratio of HCHO : Urea

Fig :- 4.2.1.2 Percent water absorption after 2h as a function of amount of UF resin
Fig: 4.2.2.1 Percent water absorption after 24h as a function of mole ratio of HCHO : Urea

Fig: 4.2.2.2 Percent water absorption after 24h as a function of amount of UF resin
amount of resin (fig. 4.2.2.2). Maximum percent water absorption 97% for 350gm. of resin with mole ratio F/U 1.41 and minimum 35.48% for 425gm. of resin with 1.74 mole ratio have been observed. For 1.74 F/U ratio increasing amount of resin has no effect on percent water absorption. On comparison with standard values (IS: 3087–1985), the percent water absorption values are within the limits of 25% and 50% respectively for 2h. and 24h.

**Dimensional Stability**

Dimensional Stability of the particle boards after treatment with water for 24h w.r.t. percent thickness expansion and length expansion as function of mole ratio of F/U and amount of resin are shown in Figs. 4.2.9.1 – 4.2.9.2 and 4.2.10.1 – 4.2.10.2 and Tables 4 and 5 respectively. Figs. 4.2.9.1 – 4.2.9.2 show that thickness expansion decreases with increase in the mole ratio (F/U) of UF for each amount of the resin used and the amount of resin with different ratios of F/U except for the 400gm of resin used, where increase in percent thickness is observed for F/U values ranging from 1.55 to 1.74. Maximum percent of thickness expansion (45.32 %) and minimum percent of thickness expansion (16.15 %) has been observed for the boards prepared with 350gm. of resin (1.41 F/U ratio) and 425gm. of resin (1.74 F/U ratio). Figs. 4.2.10.1 and 4.2.10.2 show percent length expansion after 24h. water treatment and show that % length expansion varies between maximum 2.5% for the particle boards prepared from UF resin with F/U 1.44 mole ratio using 350gm of resin to the lowest value 0.48 % for UF resin with 1.74 mole ratio and 425gm of resin. No particular order is observed with varying mole ratio of F/U or varying amount of resin used.
Fig:- 4.2.9.1 Percent thickness expansion after 24h water absorption as a function of mole ratio of HCHO : Urea

Fig :- 4.2.9.2 Percent Thickness expansion after 24h as a function of amount of UF resin
Fig. 4.2.10.1 Percent length expansion after 24h
water absorption as a function of mole ratio of HCHO : Urea

Fig. 4.2.10.2 Percent length expansion after 24h as a function of amount of UF resin
Moisture Absorption Behavior Of Particle Boards As A Function Of Temperature And Relative Humidity

Moisture absorption behavior of particle boards, prepared using UF resin of different F/U mole ratios and different amounts of resin, was studied as a function of temperature at different humidity levels. The temperature varies between 25°C to 45°C and for each temperature the studies were made at different levels of relative humidity varying between 60% - 90%. The results are presented in figs. 4.2.3.1 – 4.2.3.12 for 24h. and 4.2.3.13 – 4.2.3.24 for 48h. humidity cabinet treatment. Figs. (4.2.3.1 – 4.2.3.4 and 4.2.3.13 – 4.2.3.16) respectively represent the percent moisture absorption studies at 25°C and 60%, 70%, 80%, 90% relative humidity for 24h. and 48h. respectively. It is observed from the Figs. that the particle boards prepared using UF resin with different F/U mole ratio show an increase in the percent moisture absorption with increase in relative humidity from 60% to 90% both for 24h. and 48h. However, percent water absorption decrease with increasing F/U ratio from 1.41 to 1.74. The maximum percent water absorption for each F/U ratio of the resin is higher at 90% RH. Percent water absorption studies after 24h. for the particle boards with varying amount of the resin (Fig 4.2.3.1 – 4.2.3.2), show that maximum percent moisture absorption (4.9%) and minimum percent moisture absorption (2.3%) respectively with resin of 1.55 F/U ratio and 1.74 F/U ratio at 90% RH when 375gm. of the UF resin is used. It is further observed from the Figs. that for the particle boards prepared with 350gm.of resin, percent water absorption studied as a function of relative humidity shows that percent water absorption at RH 60%, 70% and 90% decreases with increasing F/U ratio while for 80% RH, it remains constant at lower
Fig: 4.2.3.1 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (350g) after 24h at 25°C temperature.

Fig: 4.2.3.2 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 24h at 25°C temperature.
Fig: 4.2.3.3 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 24h at 25°C temperature.

Fig: 4.2.3.4 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 24h at 25°C temperature.
Fig.- 4.2.3.13 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (350g) after 48h at 25°C temperature.

Fig.- 4.2.3.14 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 48h at 25°C temperature.
Fig. 4.2.3.15 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 48h at 25°C temperature.

Fig. 4.2.3.16 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 48h at 25°C temperature.
F/U ratio i.e. 1.41 and 1.55 but decreases thereafter. For the particle board prepared by using 350gm. of resin, a very interesting result is observed. Moving from 60% to 90% RH, decrease in percent moisture absorption is observed with increasing F/U but at all humidity levels, maximum is observed where resin F/U ratio of 1.55 is used. For 400gm. of the resin used, percent moisture absorption decreases with increasing F/U ratio i.e. for 60% and 70% RH. For 80% and 90% of relative humidity, percent moisture absorption increases up to F/U 1.55 resin ratios, and becomes constant in case of 80% RH and for 90% RH.

On further increasing the amount of resin to 450gm percent moisture absorption remains constant at 60% RH with increasing F/U ratio. At higher humidity levels i.e. 70%, 80%, percent moisture absorption decreases up to 1.63 F/U resin ratio, and then increases at higher ratio of F/U i.e. 1.74. However, at 90% RH, percent moisture absorption is slightly higher at lower level of F/U i.e. 1.41 but then remains constant at all F/U ratios.

Similar trends were observed for percent moisture absorption by the particle boards after 48 hrs. Maximum percent moisture absorption 4.91% occurred in the particle boards prepared from resin with F/U ratio 1.41 at 90% RH after 48h immersion. and minimum percent moisture absorption 0.55% occurred in the particle boards prepared from higher F/U mole ratio i.e. 1.74 with 425gm. of resin after 24h immersion. Figs. 4.2.3.5 - 4.2.3.8 and 4.2.3.17 - 4.2.3.20 represent the results of moisture absorption at 35°C with relative humidity levels varying between 60%-90% for the particle boards kept in humidity cabinet for 24h. and 48h. respectively. It is observed from Figs. 4.2.3.5 - 4.2.3.6 and 4.2.3.17 - 4.2.3.18 that particle boards prepared from UF
Fig: 4.2.3.5 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (350g) after 24h at 35°C temperature.

Fig: 4.2.3.6 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 24h at 35°C temperature.
Fig.- 4.2.3.7 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 24h at 35°C temperature.

Fig:- 4.2.3.8 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 24h at 35°C temperature.
Fig: 4.2.3.17 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (350g) after 48h at 35°C temperature.

Fig: 4.2.3.18 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 48h at 35°C temperature.
Fig: 4.2.3.19 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 48h at 35°C temperature.

Fig: 4.2.3.20 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 48h at 35°C temperature.
resin of different F/U mole ratio do not show much change with increase in relative humidity from 60% – 80% but increase at 90% RH. The percent moisture absorption, however, decreases with increase in the mole ratio. Fig. 4.2.3.7 and 4.2.3.19 show that when 400gm. of resin was used, percent moisture absorption remained almost same for F/U (1.55 to 1.74) and for all the relative humidity levels. Figs. 4.2.3.8 and 4.2.3.20 show dramatically changed pattern, when 425 gm. of resin was used to prepare the particle boards. Percent moisture absorption increases with increase in RH from 60% to 90% but it remains almost constant for each mole ratio after 24 hrs. But the percent moisture absorption after 48h. is higher at 90% RH and remains almost same between 60% – 80% RH for UF resin with F/U ratio varying between 1.55 to 1.74. At 35°C, minimum value of percent moisture absorption is 2.38% for F/U 1.74 with 425gm. of resin (RH 80%) and maximum 7.78% for F/U 1.41 with 350gm. of resin (RH 90%).

The results of percent moisture absorption at 45°C for RH varying between 60% to 90% are presented in figs. 4.2.3.9 – 4.3.9.12 and 4.2.3.21 – 4.2.3.24 for 24 hrs. and 48 hrs. respectively. Figs. 4.2.3.9 – 4.2.3.12 show that the percent moisture absorption of particle boards prepared from 350gm. of UF resin decreases with increase in mole ratio of F/U in the resin. However, percent moisture absorption with increase in % RH for UF resin of particular F/U ratio shows irregular trends. The percent moisture absorption decreases with increasing amount of the resin in the particle boards. Figs. 4.2.3.21 – 4.2.3.24 represent the percent moisture absorption of particle boards prepared from UF w.r.t. the amount of the pine cellulosic fibers at 45°C after 48h immersion. The mole ratio of F/U is also varied for every amount of
Fig.- 4.2.3.9 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of VF resin (350g) after 24h at 45°C temperature.

Fig.- 4.2.3.10 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 24h at 45°C temperature.
Fig: 4.2.3.11 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 24h at 45°C temperature.

Fig: 4.2.3.12 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 24h at 45°C temperature.
Fig: 4.2.3.21 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (350g) after 48h at 45°C temperature.

Fig: 4.2.3.22 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (375g) after 48h at 45°C temperature.
Fig.- 4.2.3.23 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (400g) after 48h at 45°C temperature.

Fig.- 4.2.3.24 Percent Moisture absorption of particle boards prepared as a function of different F/U ratio of UF resin (425g) after 48h at 45°C temperature.
the resin. Percent moisture absorption is found to decrease with increasing amount of
the resin in the particle board and also decreases while moving from low F/U mole
ratio to high F/U mole ratio. The percent moisture absorption also increases with
increasing F/U mole ratio in the UF resin for each weight of UF resin used.
Comparison of the data of percent moisture absorption after 24h. and 48h., Figs
4.2.3.10 and 4.2.3.22 show that percent moisture absorption has not changed with
change in the mole ratio and RH. Figs. 4.2.3.11 and 4.2.3.23 show that 1.41 mole
ratio of UF resin shows highest percent moisture absorption and 1.74 F/U shows
minimum for 400gm. of resin used to prepare particle boards but change in F/U mole
ratio from 1.55 to 1.63 shows almost same value. For 425gm. of resin percent
moisture absorption remains same for 1.55 and 1.63 F/U ratio. (Fig. 4.2.3.12) and
irregular pattern has been observed for varying RH when particle boards were kept is
humidity cabinet at 45°C. Maximum percent moisture absorbed by the particle boards
is 8.66% for 1.41 F/U ratio (375gm. resin) at 90% RH and minimum value of percent
moisture absorption is 0.60% for 1.74 F/U. Thus particle boards prepared by using
higher F/U mole ratio of UF resin and high amount of resin show better results w.r.t.
percent moisture absorption. This may be due to the excessive cross-linking between
the reinforcing agent and the matrix leaving little space for water absorption.

Tensile Strength

Tensile strength (T.S.) is measured both perpendicular and parallel to the surface as a
function on F/U ratio and amount of resin in accordance with (IS: 2380 ,Part V and
VI – 1977) and the results are presented in Figs. 4.2.4.1 – 4.2.4.2 and 4.2.5.1 –
4.2.5.2 respectively. It is observed from the Fig. 4.2.4.2 that the tensile strength
Fig.- 4.2.4.1 Tensile strength perpendicular to the surface as a function of mole ratio of HCHO : Urea

Fig.- 4.2.4.2 Tensile strength perpendicular to the surface as a function of amount of UF resin
Fig: 4.2.5.1 Tensile strength parallel to the surface as a function of mole ratio of HCHO : Urea

Fig: 4.2.6.2 Tensile strength parallel to the surface as a function of amount of UF resin
perpendicular to the surface for each mole ratio increases with increase in the amount of resin and Fig. 4.2.4.1 shows that for each fixed amount of resin it increases with increase in the mole ratio of F/U in the resin. Maximum value of T.S. perpendicular to the surface (0.046 N/mm²) is observed for 425gm of resin with 1.74 F/U ratio while its minimum value is (0.016 N/mm²) is observed for 350gm of resin with 1.41 F/U ratio. Fig. 4.2.5.1 shows that T.S. parallel to surface increases with increase in the mole ratio but for increase in the amount for each ratio, drop in T.S. is observed when 400gm of resin with 1.41 F/U and 1.63 F/U resin is used. However, T.S. increases with increase in amount of resin (Fig. 4.2.5.2) and also increases with increase in F/U for that amount of resin except when 400gm of UF resin was used. Maximum T.S. parallel to the surface of board (0.076 N/mm²) has been observed for particle boards prepared with 425gm of resin of 1.74 F/U ratio and minimum (0.035 N/mm²) for the boards prepared with 350gm of resin of 1.41 F/U ratio.

**Modulus Of Rupture (MOR), Modulus Of Elasticity (MOE) And Stress At The Limit Of Proportionality.**

Figs. 4.2.6.1 and 4.2.6.2 represent the MOR of the particle boards as a function of mole ratio of F/U and the amount of UF resin respectively. Fig. 4.2.6.1 shows that MOR increases with increasing mole ratio of F/U. But a decrease is observed when 425gm of resin with 1.41 and 1.55 F/U ratio was used and also when 400gm of UF resin of 1.63 and 1.74 F/U ratio was used for the particle board preparation. Fig. 4.2.6.1 indicates that MOR increases with increase in amount of resin with some exceptions such as for UF resin with F/U 1.55 mole ratio shows decrease with 350gm and 375gm of resin. Particle boards prepared from resin (425gm) with 1.74 F/U
mole ratio shows maximum (3.6 N/mm²) MOR and minimum MOR (2.34 N/mm²) for particle boards prepared from UF resin (350 gm) with 1.41 F/U mole ratio.

Modulus of elasticity (MOE) studied as a function of mole ratio of F/U in UF resin and amount of resin respectively is presented as bar diagram in Figs. 4.2.7.1 and 4.2.7.2. It is observed from the Fig. 4.2.7.1 that MOE for each F/U ratio of the UF resin increases with increasing amount of resin from 350gm to 400gm but decreases at 425gm weight of the resin used. For UF resin with 1.41 F/U ratio, the decrease is also observed for 400gm of resin used. However, for 1.74F/U mole ratio the MOE values almost lie in the same range for each weight of the UF resin used except for 400gm where a small decrease is observed. Fig. 4.2.7.2 shows irregular pattern for MOE with increasing mole ratio of F/U for each amount of the resin used. The MOE increases from moving from 350gm to 375gm but decreases at higher weights of the resin used. Maximum MOE (409.98 N/mm²) has been observed for the boards prepared with 425gm of resin (1.74 F/U) while its minimum value (200.44 N/mm²) has been observed for 425gm of resin (1.63 F/U ratio). Figs. 4.2.8.1 and 4.2.8.2 show stress at the limit of proportionality as a function of F/U mole ratio and the amount of resin. Both these Figs. show irregular pattern of stress at the limit of proportionality. Maximum value for stress at the limit of proportionality is 2.8 N/mm² and minimum 1.24 N/mm² has been observed respectively for boards prepared from 425gm resin of 1.74 F/U ratio and 350gm resin 1.55 F/U ratio.
Fig: 4.2.6.1 Modulus of rupture as a function of mole ratio of HCHO : Urea

Fig: 4.2.6.2 Modulus of rupture as a function of amount of UF resin
Fig: 4.2.7.1 Modulus of elasticity as a function of mole ratio of HCHO : Urea

Fig: 4.2.7.2 Modulus of elasticity as a function of amount of UF resin
Fig: 4.2.8.1 Stress at limit of proportionality as a function of mole ratio of HCHO : Urea

Fig: 4.2.8.2 Stress at limit of proportionality as a function of amount of UF resin
3. PROPERTIES OF THE PARTICLE BOARDS PREPARED BY USING PHENOL-RESORCINOL-FORMALDEHYDE RESIN

Water Absorption

Water absorption studies as a function of percent PRF resin for particle boards prepared by hot press and cold press method were made and the results are presented in Figs. 4.3.1 and 4.3.2 respectively for 2h and 24h immersion. It is observed from the Figs. that percent water absorption shows an initial decrease and then increases with increasing percent of PRF resin. Maximum and minimum percent water absorption (39.85%) and (26.21%) have been observed for the cold press boards of 15% and 20% PRF resin after 2h water treatment. Particle board treated for 24h shows maximum and minimum percent water absorptions values at 58.77 % and 33.78 % respectively for the cold press boards of 25% and 20% PRF resin. Maximum and minimum percent water absorption (42.30%) and (30.43%) have been observed for the hot press boards of 25% and 20% PRF resin after 2h water treatment and particle board treated for 24h shows maximum and minimum percent water absorptions values at 45.16 % and 37.68 % respectively for the hot press boards of 15% and 20% PRF resin.

Dimensional Stability

Figs. 4.3.9 and 4.3.10 show percent thickness expansion and percent length expansion after 24h water absorption respectively. From Fig. 4.3.9, it is observed that thickness expansion first decreases and then increases with increase in the percentage of PRF resin both for hot press and cold press particle boards. Maximum percent thickness expansion is 28.37 % for 25% PRF resin boards and minimum percent
Fig: 4.3.1 Percent water absorption after 2 h as a function of percent of PRF resin.

Fig: 4.3.2 Percent water absorption after 24 h as a function of percent of PRF resin.
Fig. 4.3.9 Percent thickness expansion after 24 h water absorption as a function of percent of PRF resin.

Fig. 4.3.10 Percent length expansion after 24 h water absorption as a function of percent of PRF resin.
thickness expansion of 15.54 % for 20 % PRF resin has been obtained for cold press boards (Table 6). Fig. 4.3.10 shows that length expansion remain same up to 20 % PRF resin and then increases for hot press boards while for cold press it first decreases and then increases with increase in percent of PRF resin. Minimum of 0.5% length expansion has been observed for 20 % PRF resin of cold press boards.

Moisture Absorption Behaviour Of Particle Boards As A Function Of Temperature And Relative Humidity

Moisture absorption behaviour of particle boards prepared using different percent of PRF resin was studied at temperature range of 25°C, 35°C, 45°C. For each temperature, the studies were made at different levels of RH varying between 60% to 90%. The results are presented in the Figs. 4.3.3.1 and 4.3.3.12.

Figs. 4.3.3.1, 4.3.3.4 and 4.3.3.7, 4.3.3.10 represent respectively the percent moisture absorption of particle boards in 24h and 48h water treatment for hot press and cold press at 25°C. Percent moisture absorption increased with increase in relative humidity in all the cases. However, percent moisture absorption decreases with increasing percent of PRF resin for hot press particle boards. Maximum percent moisture absorption (5.34%) and (5.5.%) was observed for hot press boards with 15% PRF resin after 24h and 48h percent water treatment respectively. For cold press particle boards, percent moisture absorption increases while moving from 15 % to 20% PRF resin giving maximum percent moisture absorption 6.25 % at 90 % RH after 24hwater treatment. Similar behaviour is observed for moisture absorption after 48h, where maximum absorption (6.39%) is observed for 20% PRF resin. Minimum percent moisture absorption of 1.35 % for 20 % PRF resin is observed at 60 % RH
Fig: 4.3.3.1 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 24h at 25°C temperature.

Fig: 4.3.3.4 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 48h at 25°C temperature.
Fig: 4.3.3.7 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 24h at 25°C temperature.

Fig: 4.3.3.10 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 48h at 25°C temperature.
after 24h treatment for hot press boards and 1.51 % for 15 PRF resin for cold press boards.

Figs. 4.3.3.2, 4.3.3.5 and 4.3.3.8, 4.3.3.11 represent the percent moisture absorption of particle boards as a function of percent PRF resin after 24h and 48h water treatment for hot press and cold press respectively at 35°C and different humidity levels. It is observed from the Figs. that percent moisture increases with increase in the humidity level except for cold press particle boards prepared from 300gm of 10 % PRF resin where maximum absorption is observed at 70 % RH, decreases at 80 % RH and again increases at 90 % RH. Percent moisture absorption however, decreases with increase in PRF percentage in all the cases. Maximum percent moisture absorption (8.12 % and 8.17 %) and minimum (5.35 % and 6.74 %) has been observed for the hot press and cold press boards prepared with 25 % PRF resin at 90% RH and 60% RH respectively. Figs. 4.3.3.3, 4.3.3.6 and 4.3.3.9, 4.3.3.12 represent the percent moisture absorption of particle boards after 24h and 48h water treatment for hot press particle boards and cold press boards respectively at 45°C. Figs. 4.3.3.3 and 4.3.3.6, for hot press boards, show that percent moisture absorption decreases with increase in percent PRF resin and increases with increasing percent relative humidity while cold press particle boards (Figs. 4.3.3.9 and 4.3.3.12) show not much change in percent moisture absorption with increasing RH and percent PRF resin. Minimum percent moisture absorption 3.83 % is observed for the boards prepared with 25 % PRF resin (hot press) at 70 % RH after 48h treatment of boards in humidity cabinet and maximum percent moisture absorption (7.94 %) has been observed at 90 % RH with 25 % PRF resin particle boards in cold press.
Fig.- 4.3.3.2 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 24h at 35°C temperature.

Fig.- 4.3.3.5 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 48h at 35°C temperature.
Fig: 4.3.3.8 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 24h at 35°C temperature.

Fig: 4.3.3.11 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 48h at 35°C temperature.
Fig. 4.3.3.3 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 24h at 45°C temperature.

Fig. 4.3.3.6 Percent moisture absorption of particle boards (hot press) prepared as a function of different percent of PRF resin (300g) after 48h at 45°C temperature.
Fig.:- 4.3.3.9 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 24h at 45°C temperature.

Fig.: 4.3.3.12 Percent moisture absorption of particle boards (cold press) prepared as a function of different percent of PRF resin (300g) after 48h at 45°C temperature.
Tensile Strength

Tensile strength (T.S.) was measured both perpendicular and parallel to the surface as a function of percent of PRF resin in accordance with (IS: 2380, Part V and VI – 1977) and the results are presented in Figs. 4.3.4 and 4.3.5 respectively. It is observed from the Fig. 4.3.4 that T.S. perpendicular to surface increases with increase in %PRF, both for hot press and cold press boards. Maximum (0.027 N/mm²) and minimum (0.018 N/mm²) T.S. perpendicular to surface has been observed for 25% PRF and 15% PRF resin respectively for hot press boards. On the other hand, T.S. parallel to surface for cold press particle boards increases with increase in percent PRF and its maximum value of 0.046 N/mm² has been obtained for 25% PRF whereas minimum value (0.03 N/mm²) for 15% PRF resin particle boards is observed.

Modulus Of Rupture (MOR), Modulus Of Elasticity (MOE) And Stress At The Limit Of Proportionality

Figs. 4.3.6, 4.3.7 and 4.3.8 represent the MOR, MOE and stress at the limit of proportionality for particle boards as a function of percent PRF resin both for hot press and cold press. Fig. 4.3.6 shows that MOR for hot press decreases with increasing %PRF whereas it increases with increasing percentage of PRF for cold press boards. Maximum (2.8 N/mm²) and minimum (2.6 N/mm²) MOR has been observed for hot press boards prepared with 15% and 25% PRF resin respectively and maximum (2.95 N/mm²) and minimum (2.23 N/mm²) MOR has been observed for cold press boards prepared with 25% and 15% PRF resin respectively. Fig. 4.3.7 shows that MOE remains almost constant for hot press boards but for cold press
Fig: 4.3.4 Tensile strength perpendicular to the surface as a function of percent of PRF resin.

Fig: 4.3.5 Tensile strength parallel to the surface as a function of percent of PRF resin.
**Fig:** 4.3.6 Modulus of rupture as a function of percent of PRF resin.

**Fig:** 4.3.7 Modulus of elasticity as a function of percent of PRF resin.
Fig. 4.3.8 Stress at the limit of proportionality as a function of percent of PRF resin.
boards initial increase and then decrease is observed with increasing % PRF resin. Its maximum value (305 N/mm$^2$) is obtained at 20 % and 30 % PRF and minimum (292.3 N/mm$^2$) at 15 % PRF resin for hot press boards whereas maximum value is 429.15 N/mm$^2$ at 20 % PRF and minimum 300.7 N/mm$^2$ at 25 % PRF resin for cold press boards. Fig. 4.3.8 indicates that the stress at the limit of proportionality is 2.17 N/mm$^2$ at 15 % and 20 % for hot press boards and 1.55 N/mm$^2$ at 15 %, 20 % and 25% for cold press boards.

4. PROPERTIES OF THE PARTICLE BOARDS PREPARED BY USING PHENOL-LIGNIN-FORMALDEHYDE RESIN

Water Absorption

For water absorption studies of the boards prepared from PLF resin, same procedure has been adopted as in case for the boards of PF, UF & PRF resins. Results of water absorption by the samples after 2h & 24 h treatment are presented in Figs. 4.4.1 and 4.4.2 respectively. Both these figures indicate that percent water absorption increases as the percent of PLF resin increase except for the 40 % PLF resin where it decreases. Minimum values of percent water absorption after 2h & 24h water treatment are 26.92 % and 34.61 % respectively which indicate that maximum percent water absorption occurs within 2h and only about 8% of water absorption takes place within next 22h water treatment. Increase in percent water absorption with increase in percent PLF is due to decrease in PF amount, which causes less cross-linking and therefore offer more space for water absorption.
fig.- 4.4.1 Percent water absorption after 2h as a function of percent of PLF resin.

fig.- 4.4.2 Percent water absorption after 24 h as a function of percent of PLF resin.
Dimensional Stability

Figs 4.4.9 and 4.4.10 represent respectively the percent thickness and percent length expansion for particle boards using PLF resin. Both the parameters i.e. percent thickness and percent length expansion, increases with increase in percent PLF expect for 40 % composition where decrease is observed for both the properties. Minimum values of percent thickness and percent length expansion are 15.06 % and 0.49 % (Table 7) respectively obtained for 10 % PLF. Overall dimensional stability is found to decrease with increase in the percent water absorption.

Moisture Absorption Behaviour Of Particle Boards As A Function Of Temperature And Relative Humidity

Moisture absorption for particle boards prepared from varying percent PLF resin was studied as a function of temperature at different humidity levels. The studies were made at 25°C, 35°C and 45°C and % RH, at each temperature, varied between 60% to 90% for 24h and 48h treatment. The results are presented respectively in Figs. 4.4.3.1-4.4.3.6. It is observed from Figs. 4.4.3.1- 4.4.3.3 that when the boards are treated for 24 h at 25°C, 35°C and 45°C and varying the % RH, percent moisture absorption is found to increase with increasing relative humidity levels from 60% to 90% and is also found to increase with increasing percent of PLF resin i.e. from 10 % to 50 % PLF. The increase in percent moisture absorption with increasing % RH is appreciably visible at 25°C whereas at 35°C and 45°C, this increase is very small. It is further observed that the increase in percent of PLF resin also does not show too much of change in percent moisture absorption. However with 50 % PLF and 45°C, percent water absorption is found to show much higher value than observed at lower
fig: 4.4.9 Percent thickness expansion after 24 h water absorption as a function of percent of PLF resin.

fig: 4.4.10 Percent length expansion after 24 h water absorption as a function of percent of PLF resin.
Fig: 4.4.3.1 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 24h at 25°C temperature.

Fig: 4.4.3.2 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 24h at 35°C temperature.
Fig: 4.4.3.3 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 24h at 45°C temperature.

Fig: 4.4.3.4 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 48h at 25°C temperature.
Fig: 4.4.3.5 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 48h at 35°C temperature.

Fig: 4.4.3.6 Percent moisture absorption of particle boards prepared as a function of different percent of PLF resin (450g) after 48h at 45°C temperature.
temperature and lower % PLF resin. The percent moisture absorption at 45°C for all
the samples is lower than that observed at 35°C. Maximum percent water absorption
(10.45 %) was observed for particle boards using 50 % PLF resin at 35°C and 90 %
RH. Minimum percent water absorption (1.15 %) was observed for particle boards
from 40 % PLF resin at 25°C and 60 % RH.

When moisture absorption studies were made for 48 h treatment, not much variation
is observed in percent water absorption except for the samples treated at 25°C where
little higher percent moisture absorption is observed than observed for 24h treatment.
Maximum percent water absorption (10.40 %), is observed for the boards from 50 %
PLF resin at 35°C and 90 % RH where as minimum value of percent water absorption
2.47 % is observed for boards from 40 % PLF resin at 25°C and 60 % RH.

Tensile Strength

Tensile strength, both perpendicular and parallel to the surface, of the particle boards
prepared using different percent PLF has been measured and the results are presented
in Figs. 4.4.4 and 4.4.5 respectively. It is observed from the Figs. that both the
properties show a decrease with increase in percent PLF resin from 10 % to 50 %.
Maximum value of T. S. perpendicular to the surface is 0.022 N/mm² and T.S.
parallel to the surface is 0.033 N/mm² is observed for particle boards prepared using
10 % PLF resin. These values are much lower than those for particle boards prepared
using PF resin. The decrease in the strength of the particle boards from PLF resin
must be due to the reason that not much of the resinification must have occurred in
the presence of lignin thus decreasing the adhesive properties of the resin. It may also
be because of the fact that crude mother extract of the pine needles was used as the
fig:- 4.4.4 Tensile strength perpendicular to the surface as a function of percent of PLF resin.

fig:- 4.4.5 Tensile strength parallel to the surface as a function of percent of PLF resin.
The other components in the mother liquor must also have inhibited the condensation reactions to give resin with good adhesive properties.

**Modulus Of Rupture (MOR), Modulus Of Elasticity (MOE), Stress At The Limit Of Proportionality**

MOR, MOE, and Stress at the limit of proportionality of the particle boards prepared using different percent PLF have been measured and the results are presented in Figs. 4.4.6, 4.4.7 and 4.4.8 respectively. It is observed from the figures that all these properties show a decrease with increase in percent PLF resin from 10 % to 50 %. Maximum values of MOR, MOE and stress at the limit of proportionality have been obtained for the boards prepared with 10 % PLF resin and the values are 3.35 N/mm², 381.7 N/mm² and 2.4 N/mm² respectively.

**PREPARATION OF PARTICLE BOARDS OF 5mm THICKNESS FROM PINE CELLULOSIC FIBERS AND PINE CELLULOSIC FIBERS GRAFTED WITH METHYLACRYLATE AND ETHYLACRYLATE**

As discussed earlier for the PF resin based particle boards, the T.S. of the boards of 10mm thickness is much less than the standard values given for 20mm thick boards. Therefore, in order to ascertain the effect of thickness on the mechanical properties of particle boards, particle boards of 5mm thickness were prepared using 500gm of pine cellulotic fibers and 225gm of PF resin of 2.44 F/P mole ratio. The amount of the fibers and the resin were half the amount used for preparing 10mm thick particle boards. Similar boards of 5mm thickness were also prepared from grafted pine
Fig. 4.4.6 Modulus of rupture as a function of percent of PLF resin.

Fig. 4.4.7 Modulus of elasticity as a function of percent of PLF resin.
fig: 4.4.8 Stress at the limit of proportionality as a function of percent of PLF resin.
cellulosic fibers. Water absorption and mechanical properties of these boards were studied and the results are presented in Table 9.

**Water Absorption**

It observed from Table 9 that the percent water absorption of 5mm thick particle boards both after 2h and 24h water treatment is higher than that observed for 10mm thick particle boards. Percent water absorption (22.35 % and 32.07 %) after 2h and 24h treatment is higher than the percent water absorption values (19.20 % and 31.12%) of 10mm particle boards after 2h and 24h water treatment respectively. This may be due to the reason that penetration of water to the bulk of 10mm thick particle board will be lesser and therefore these boards show lower percent water absorption values. The particle boards of 5mm thickness from pine needles grafted with methylacrylate and ethylacrylate, however show lower percent water absorption both after 2h (18.12 % and 17.35 %) and 24h treatment (28.26 % and 28.61 %) respectively than 5mm and 10mm thick particle boards from the ungrafted pine cellulosic fibers. The thickness parameter has also not affected the water absorption in these boards. Hydrophobic nature of poly(methylacrylate) and poly(ethylacrylate) chains that are grafted onto pine needles leads to lower water absorption.

**Tensile Strength**

The results of T.S., both parallel and perpendicular to the surface, are given in Table 9. It is observed from the table that T.S. parallel and perpendicular to the surface of 5mm particle boards is much lower (0.037 N/mm² and 0.021 N/mm²) as compared to 10mm thickness particle boards (0.10 N/mm² and 0.059 N/mm²) suggesting that an optimum thickness of the board is an important factor for T.S. properties.
Modulus Of Elasticity (MOE) Modulus Of Rupture (MOR)

The MOE (590.54 N/mm²) of particle boards of 5mm thickness is also lower than that of 10mm thick particle boards (693.82 N/mm²). However, the MOR of 5mm thick particle boards is little higher (5.65 N/mm²) than that of 10mm thick board (5.10 N/mm²). All these properties suggest that the thickness of the particle board is an important factor for achieving the product of high quality with respect standard properties. A change in the ingredient ratios i.e. amount of the reinforcing agent to resin, the quality of the resin, addition of additives, and thickness etc. is likely to give particle boards which can match the standards laid by Bureau of Indian Standards.

MINIMUM WATER ABSORPTION AND MAXIMUM MECHANICAL PROPERTIES OF PARTICLE BOARDS PREPARED FROM PF, UF, PRF AND PLF RESINS

Table 8 represents the best values obtained for the particle boards prepared from PF, UF, PRF and PLF resins with respect to water absorption and mechanical properties. It is observed from the table that the water absorption and mechanical properties are best for the boards prepared by using 450g PF resin with F/P mole ratio of 2.44. Percent water absorption 11.25 % and 25.82 % after 2h and 24h water treatment is minimum as compared to all other boards Minimum values of percent thickness expansion and percent length expansion have been observed for the minimum value of percent water absorption suggesting that dimensional stability is directly linked with the water absorption property. Boards prepared with the PF resin show better mechanical properties than boards prepared from other resins. Maximum T.S. perpendicular to the surface (0.059 N/mm²) and T.S. parallel to the surface
(0.095N/mm²) and maximum MOR (5.1N/mm²) and MOE (693.8N/mm²) are obtained for PF treated boards. UF resin of 1.74 mole ratio using 425gm of resin shows good results among different ratios of UF but is dimensionally and mechanically less stable than that prepared by using PF resin. On comparing the properties of particle boards prepared from modified PF resin (i.e. PRF and PLF) with particle boards prepared from PF resin, it is clear from the table that the boards prepared using PLF resin are mechanically and dimensionally less stable than particle boards prepared using PF resins.

On the basis of the results and comparison of the properties of the particle boards, the following order for resins to give particle boards of best quality is observed

\[ \text{PF} > \text{UF} > \text{PLF} > \text{PRF} \]

PRF resin bonded boards should have better water resistance and strength properties than those of UF and PLF bonded material. Lower amount of PRF resin used as binder to produce the boards may be responsible for the relatively lower value of above properties.
TABLE 1: - TEMPERATURE, PRESSURE AND TIME OF PRESSING FOR THE PARTICLE BOARDS PREPARED BY USING DIFFERENT RESINS.

<table>
<thead>
<tr>
<th>Nature of the resin used</th>
<th>Temperature (°C)</th>
<th>Pressure (Kg/cm²)</th>
<th>Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF</td>
<td>145</td>
<td>120</td>
<td>15</td>
</tr>
<tr>
<td>UF</td>
<td>120</td>
<td>70</td>
<td>12</td>
</tr>
<tr>
<td>PRF hot press</td>
<td>145</td>
<td>120</td>
<td>15</td>
</tr>
<tr>
<td>PRF cold press</td>
<td>30</td>
<td>120</td>
<td>17hrs</td>
</tr>
<tr>
<td>PLF</td>
<td>150</td>
<td>120</td>
<td>15</td>
</tr>
</tbody>
</table>

TABLE 2: - PERCENT THICKNESS EXPANSION (AFTER 24H WATER TREATMENT) OF PARTICLE BOARDS PREPARED USING PF RESIN

<table>
<thead>
<tr>
<th>S.No.</th>
<th>F/P mole ratio</th>
<th>Amount of resin (gm)</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% conversion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.74</td>
<td>20.41</td>
<td>10.45</td>
<td>20.71</td>
<td>13.67</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.97</td>
<td>25.56</td>
<td>25.56</td>
<td>14.22</td>
<td>13.53</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.2</td>
<td>24.03</td>
<td>23.92</td>
<td>14.86</td>
<td>13.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.44</td>
<td>20.14</td>
<td>18.17</td>
<td>17.6</td>
<td>10.08</td>
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</tr>
</tbody>
</table>

TABLE 3: - PERCENT LENGTH EXPANSION (AFTER 24H WATER TREATMENT) OF PARTICLE BOARDS PREPARED USING PF RESIN

<table>
<thead>
<tr>
<th>S.No.</th>
<th>F/P mole ratio</th>
<th>Amount of resin (gm)</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% conversion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.74</td>
<td>1.02</td>
<td>0.49</td>
<td>0.99</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.97</td>
<td>1</td>
<td>0.99</td>
<td>0.48</td>
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<tr>
<td>3</td>
<td>2.2</td>
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<td>1</td>
<td>0.49</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.44</td>
<td>1</td>
<td>1.45</td>
<td>0.5</td>
<td>0.51</td>
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### Table 4: Percent Thickness Expansion (After 24H Water Treatment) of Particle Boards Prepared Using UF Resin

<table>
<thead>
<tr>
<th>S.No.</th>
<th>F/U mole ratio</th>
<th>Amount of resin (gm)</th>
<th>% conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>350</td>
<td>375</td>
</tr>
<tr>
<td>1</td>
<td>1.41</td>
<td>45.32</td>
<td>25.09</td>
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<td>2</td>
<td>1.55</td>
<td>33.66</td>
<td>30.29</td>
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<tr>
<td>3</td>
<td>1.63</td>
<td>28.84</td>
<td>23.63</td>
</tr>
<tr>
<td>4</td>
<td>1.74</td>
<td>20.19</td>
<td>17.53</td>
</tr>
</tbody>
</table>

### Table 5: Percent Length Expansion (After 24H Water Treatment) of Particle Boards Prepared Using UF Resin

<table>
<thead>
<tr>
<th>S.No.</th>
<th>F/U mole ratio</th>
<th>Amount of resin (gm)</th>
<th>% conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>350</td>
<td>375</td>
</tr>
<tr>
<td>1</td>
<td>1.41</td>
<td>2.5</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>1.55</td>
<td>1.48</td>
<td>1.47</td>
</tr>
<tr>
<td>3</td>
<td>1.63</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1.74</td>
<td>0.97</td>
<td>1</td>
</tr>
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</table>

### Table 6: Percent Thickness and Length Expansion (After 24H Water Treatment) of Particle Boards Prepared Using PRF Resin

<table>
<thead>
<tr>
<th>S.No.</th>
<th>% of PRF</th>
<th>Thickness expansion</th>
<th>Length expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
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<tr>
<td></td>
<td>Hot press</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>24.4</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>21.3</td>
<td>0.98</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>22.37</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Cold press</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>23.56</td>
<td>1.01</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>15.54</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>28.37</td>
<td>1.5</td>
</tr>
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TABLE 7: PERCENT THICKNESS AND LENGTH EXPANSION (AFTER 24H WATER TREATMENT) OF PARTICLE BOARDS PREPARED USING PLF RESIN

<table>
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<tr>
<th>S.No.</th>
<th>% of PLF</th>
<th>Thickness expansion (%)</th>
<th>Length expansion (%)</th>
</tr>
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<tr>
<td>1</td>
<td>10</td>
<td>15.06</td>
<td>0.49</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>16.07</td>
<td>0.49</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>31.78</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>24.65</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>37.53</td>
<td>1.96</td>
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TABLE 8: - MINIMUM WATER ABSORPTION AND MAXIMUM MECHANICAL PROPERTIES OF PARTICLE BOARDS PREPARED FROM PF, UF, PRF AND PLF RESIN.

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>Property</th>
<th>PF resin</th>
<th>UF resin</th>
<th>PRF resin</th>
<th>PLF resin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>Amount</td>
<td>Value</td>
<td>Amount</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(gm)</td>
<td>(gm)</td>
<td>(gm)</td>
<td>(gm)</td>
</tr>
<tr>
<td>1</td>
<td>Minimum water absorption after 2h (%)</td>
<td>11.25</td>
<td>450</td>
<td>27.74</td>
<td>425</td>
</tr>
<tr>
<td>2</td>
<td>Minimum water absorption after 24h (%)</td>
<td>25.82</td>
<td>450</td>
<td>35.48</td>
<td>425</td>
</tr>
<tr>
<td>3</td>
<td>Minimum thickness expansion (%) after 24 h</td>
<td>10.08</td>
<td>450</td>
<td>16.15</td>
<td>425</td>
</tr>
<tr>
<td>4</td>
<td>Minimum length expansion (%) after 24 h</td>
<td>0.48</td>
<td>400</td>
<td>0.48</td>
<td>425</td>
</tr>
<tr>
<td>5</td>
<td>Maximum T.S. Perpendicular to the surface (N/mm²)</td>
<td>0.059</td>
<td>400&amp; 450</td>
<td>0.046</td>
<td>425</td>
</tr>
<tr>
<td>6</td>
<td>Maximum T.S. Parallel to the surface(N/mm²)</td>
<td>0.095</td>
<td>450</td>
<td>0.076</td>
<td>425</td>
</tr>
<tr>
<td>7</td>
<td>Maximum MOR (N/mm²)</td>
<td>5.1</td>
<td>450</td>
<td>3.60</td>
<td>425</td>
</tr>
<tr>
<td>8</td>
<td>Maximum MOE N/mm²</td>
<td>693.8</td>
<td>450</td>
<td>410</td>
<td>425</td>
</tr>
<tr>
<td>9</td>
<td>Maximum Stress at the limit of proportionality</td>
<td>3.73</td>
<td>450</td>
<td>2.44</td>
<td>425</td>
</tr>
</tbody>
</table>

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TABLE 9: MECHANICAL AND WATER ABSORPTION PROPERTIES OF PARTICLE BOARDS PREPARED FROM PF RESIN USING GRAFTED PINE CELLULOSIC FIBER

<table>
<thead>
<tr>
<th>S.No</th>
<th>Sample</th>
<th>Modulus of rupture (N/mm²)</th>
<th>Modulus of elasticity (N/mm²)</th>
<th>Tensile strength perpendicular to the surface (N/mm²)</th>
<th>Tensile strength parallel to the surface (N/mm²)</th>
<th>Stress at limit of proportionality (N/mm²)</th>
<th>Water absorption after 2h (%)</th>
<th>Water absorption after 24h (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pine cellulosic fiber</td>
<td>5.65</td>
<td>590.54</td>
<td>0.021</td>
<td>0.037</td>
<td>4.80</td>
<td>22.35</td>
<td>32.07</td>
</tr>
<tr>
<td>2</td>
<td>Methylacrylate grafted pine cellulosic fiber</td>
<td>4.80</td>
<td>547.40</td>
<td>0.017</td>
<td>0.039</td>
<td>4.80</td>
<td>18.12</td>
<td>28.26</td>
</tr>
<tr>
<td>3</td>
<td>Ethylacrylate grafted pine cellulosic fiber</td>
<td>4.87</td>
<td>449.41</td>
<td>0.018</td>
<td>0.039</td>
<td>4.80</td>
<td>17.36</td>
<td>28.61</td>
</tr>
</tbody>
</table>

Amount of PF resin used = 225gm (F/P mole ratio = 2.44)

Amount of pine cellulosic fiber used = 500gm

Thickness of the board = 5mm