

**ASSESSMENT FOR THE SUITABILITY OF
Butea monosperma Lam. FOR PREPARATION
OF PARTICLE BOARD**

THESIS

**Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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**MASTER OF SCIENCE
IN
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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of thesis entitled “**ASSESSMENT FOR THE SUITABILITY OF *Butea monosperma* Lam. FOR PREPARATION OF PARTICLE BOARD**” or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis or publication of any University or Scientific Organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola

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Date: / /2018

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CERTIFICATE

This is to certify that the thesis entitled, “**ASSESSMENT FOR THE SUITABILITY OF *Butea monosperma* Lam. FOR PREPARATION OF PARTICLE BOARD**” submitted in partial fulfillment of the requirements for the degree of “**Master of Science in Forestry (Wood Science and Technology)**” of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Sirsalwar Amol Rajeshwar** under my guidance and supervision.

The subject of the thesis has been approved by the student’s Advisory Committee.

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Table of Contents

Sr. No.	Particulars	Page
A	Declaration of student	i
B	Certificate	ii
C	Acknowledgement	iii-iv
D	List of Tables	vi
E	List of Figures	vii
F	List of Plates	viii
G	List of Abbreviations	ix
H	Thesis Abstract	x-xii
I	INTRODUCTION	1-7
II	REVIEW OF LITERATURE	8-18
III	MATERIAL AND METHODS	19-41
IV	RESULTS AND DISCUSSION	42-54
V	SUMMARY AND CONCLUSIONS	55-57
VI	LITERATURE CITED	58-62
	Vita	63
	Appendix	64

(A) List of Tables

Table	Title	Page
1	Result of analysis of PF resin	25
2	Amount of PF resin required for preparation of particle boards	26
3	Amount of wax emulsion required for preparation of particle board	27
4	Minimum requirement of IS: 3087-1985 specifications on medium density particle boards for various physical and mechanical properties	36
5	Physical property with respect to thickness and moisture content of particle boards	43
6	Physical property with respect to density of particle boards	45
7	Physical property with respect to water absorption (2 hrs) of particle boards	46
8	Physical property with respect to water absorption (24 hrs) of particle boards	48
9	Physical property with respect to length (2 hrs) swelling of particle boards	49
10	Physical property with respect to thickness (2 hrs) swelling of particle boards	51
11	Physical property with respect to swelling due to surface absorption (2 hrs) of particle boards	52

(B) List of Figures

Figure	Title	Page
1	Moisture content (%) of particle boards at different PF resin content	44
2	Density (g/cm ³) of particle boards at different PF resin content	44
3	Water absorption (%) in 2 hrs. of particle boards at different PF resin content	47
4	Water absorption (%) in 24 hrs. particle boards at different PF resin content	47
5	Length swelling (%) in 2 hrs. of particle boards at different PF resin content	50
6	Thickness swelling (%) in 2 hrs. of particle boards at different PF resin content	50
7	Swelling due to surface absorption (%) in 2 hrs. of particle boards at different PF resin content	53

(C)

List of Plates

Plate	Title	Page
1	Trees of <i>Butea monosperma</i> and its branches	21
2	Chemical raw material used for preparation wax emulsion	21
3	Preparation of wax emulsion	21
4	Chemical raw material used for preparation of Phenol formaldehyde resin	21
5	Preparation of Phenol formaldehyde resin	24
6	Collection of woody raw materials of <i>Butea monosperma</i>	28
7	Sun drying of woody raw material of <i>Butea monosperma</i>	30
8	Mini combiplanner	30
9	Primary reduction of material of <i>Butea monosperma</i>	30
10	Wood grinder	31
11	Sun drying of <i>Butea monosperma</i> particles	31
12	Resin blending of particles	34
13	Drying of Resin blended particles	34
14	Mat formation by wooden mould	34
15	Hydraulic hot press machine	35
16	Preparation of particle board by using hot press	35
17	Trimming of boards	37
18	Particle boards	37
19	Specimens of particle boards (5 X 5 cm)	37

(D) List of Abbreviations

%	-	Per cent
/	-	Per
°C	-	Degree Celsius
cm	-	Centimeter
cc	-	cubic meter
et al.	-	et alia (and others)
etc.	-	Etcetera
Fig.	-	Figure
g	-	Gram
i.e.	-	That is
IS	-	Indian Standard
kg	-	Kilogram
m	-	Meter
mm	-	millimeter
viz.,	-	Videlicet (Namely)
wt.	-	Weight
lbs	-	Pounds
sq.	-	Square
hrs.	-	Hours
ft.	-	Feet
PF	-	Phenol Formaldehyde

(F) THESIS ABSTRACT

- a. Title of the thesis : **“ASSESSMENT FOR THE SUITABILITY OF *Butea monosperma* Lam. FOR PREPARATION OF PARTICLE BOARD”**
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ABSTRACT

The present investigation entitled, “Assessment for the suitability of *Butea monosperma* Lam. for preparation of particle board” was carried out during the year 2016-2018 at Department of Forestry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The study was carried with the objective to study the suitable percentage of PF resin content for the

preparation of particle board and to evaluate the physical properties of particle boards.

Butea monosperma was collected from the premise of Dr. Panjabrao Deshmukh Krishi Vidyapeeth Akola as a lignocellulosic wood raw material and phenol formaldehyde resin as a binder and wax emulsion as sizing agent was used for preparation of particle board. The particle boards were prepared from 8 to 12 per cent PF resin content with 0.5 and 1 per cent wax emulsion. Physical properties were examined as per the procedure laid down in IS: 2380 and IS: 3087. Thickness of the board varied from 8.7 to 9.9 mm while, moisture content varied from 7.5 to 9.6 per cent. Maximum thickness and moisture content was recorded in the board prepared with 8 per cent PF resin content whereas, minimum thickness and moisture content was observed in the boards prepared from 12 per cent of PF resin content with 1 per cent wax emulsion. Density of the particle board varied from 0.72 to 0.86 g/cm³. Maximum density was recorded in boards prepared from 12 per cent of PF resin content with 1 per cent wax emulsion whereas, minimum density was recorded in boards prepared from 8 per cent of PF resin content. Water absorption test of the boards for 2 hours and 24 hours soaking in water varied from 20.72 to 58.74 per cent and 42.34 to 82.95 per cent, respectively. Boards prepared from 10 per cent PF resin content with 0.5 per cent wax emulsion, 11 and 12 per cent PF resin content with 0.5 per cent and 1.0 per cent wax emulsion met the requirement of IS specifications. Increase in the amount of PF resin with addition of wax emulsion showed decrease in water absorption property.

Highest value (0.46 %) of length swelling was recorded in the boards prepared with 8 per cent PF resin content and lowest (0.18 %) in the boards prepared from 12 per cent PF resin content with 1 per cent wax emulsion. The values obtained for length swelling of all the boards prepared from different PF resin content met the requirement of the IS specification. Maximum thickness swelling of 24.64 per cent was recorded in the boards made from 8 per cent PF resin content and minimum value of 5.74 per cent in the board made from 12 per cent PF resin content with 1 per cent wax emulsion. The values reported for thickness swelling of the

board prepared from 10 per cent PF resin content with 0.5 per cent wax emulsion, 11 and 12 per cent PF resin content with 0.5 per cent and 1.0 per cent wax emulsion met the requirement of IS specification.

Swelling due to surface absorption after 2 hours ranges between 06.09 to 24.46 per cent. The maximum swelling due to surface absorption was observed in the board prepared from 8 per cent PF resin content and minimum swelling due to surface absorption was observed in the board prepared from 12 per cent PF resin content with 1 per cent wax emulsion. The values obtained for swelling due to surface absorption decreases as amount of PF resin increases with addition of wax emulsion. Satisfactory boards were prepared from 10 per cent PF resin content with 0.5 per cent wax emulsion, 11 and 12 per cent phenol formaldehyde resin with 0.5 per cent and 1.0 per cent wax emulsion met the requirement in respect of physical properties as specified in IS: 3087 (1985).

CHAPTER I

INTRODUCTION

1.1 Background informations

Butea monosperma is a species of Butea native to tropical and sub-tropical parts of the Indian Sub-continent and South-east Asia, ranging across India, Bangladesh, Nepal, Sri Lanka, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia, and western Indonesia. It is commonly known as flame-of-the-forest or bastard teak and it's belong to leguminaceae Family (sub-family Fabaceae) (A.K.Jaiswal and J.P.Singh,2014). The family fabaceae compromises of 630 genera and 18000 species. It is adaptable tree for subtropical regions which requires alkaline, swampy badly drained soils and a sunny location. It grows easily from seed. It finds use both medicinally and commercially with each part of the plant having utility. Extract of the plant possess significant astringent , aphrodisiac, anti-helmintic, anti-inflammatory, anti- bacterial , anti-fungal , anti-diabetic and anti -asthmatic properties.(D. fageria and D.V. Rao 2015).

It grows throughout the Indian subcontinent, especially in Indo-Gangetic plains. This tree gets up to 50 ft high, with stunning flower clusters. It loses its leaves as the flowers develop, January - March. The trunk becomes twisted and gnarled by the wind, making it a conversation piece. Use it as a specimen, or as a background component of the canopy. The plant is widely distributed in the country and called by various local names viz., Bastard Teak, Parrot Tree (Eng.), Chichra tesu, desuka jhad, dhak, palas, chalcha, kankrei (Hindi), Palashpapra (Urdu), Muthuga (Can.), Palas, Polashi (Beng.), Porasum, Parasu (Tam.), Muriku, Shamata (Mal.), Modugu (Tel.), Khakda (Guj.), Kela (Sinh.). It is a useful plant in many ways. It leaves are essential for various religious rituals in Hindu homes. These are also used as cheap leaf plates and cups for rural feasts. In some parts of the country these are used for wrapping tobacco to make beedies. These are further used as packing material for parcels. The cattle also eat the palas foliage quite eagerly. The bark yields a kind of coarse and brown

colored fiber, which is used for rough cordage. Butea gum is a dried astringent juice obtained from incisions in the stem of the tree. The juice exuded by the bark hardens in to brittle ruby colored gum beads. This gum is sanctioned to be used as a substitute for the kino gum. It finds use for caulking boats as well. The flowers yield an orange dye. A preparation of the same is used as an insecticide. The seeds are used in Ayurvedic and Unani medicine for treating a number of human maladies. The tree acts as a host for lac insect and is, therefore, useful in producing natural lac.

It is a sacred tree, referred to as a treasurer of the gods, and used in sacrifice related rituals. From its wood, sacred utensils are made. The flowers are offered as in place of blood in sacrifice rituals to goddess Kali. The dry stem pieces are used to make sacred fire. It is an anthropogenic tree of several castes. 'Chakradatta' mentions the use of its gum in external astringent application. The leaves are believed to have astringent, depurate, diuretic and aphrodisiac properties. It promotes diuresis and menstrual flow. The seed is anthelmintic. When seeds are pounded with lemon juice and applied to the skin the act as a rubefacient. The flowers are widely used in treatment of hepatic disorder, viral hepatitis, diarrhea, depurative and tonic. The flowers are also good source of flavonoids. The contents of flowers are Butein, Butrin, Isobutrin, Plastron, coreipsin and isocoreipsin. Isolation of mediacarpin with antifungal activity from this part of plant has also been reported. The Euphane triterpenoid 3 α -hydroxyeuph-25-ene and the alcohol 2,14-dihydroxy-11,12-dimethyl-8-oxo-octadec-11-enylcyclohexane has also been isolated from the stem (Mishra *et al.*, 2000).

Butea monosperma is an erect tree rising up to the height of 12-15 m with uneven branching. The bark is rough, ash coloured. The seeds are flat, reniform, and curved. Flowers in rigid racemes of 15 cm long, densely brown velvety on bare branches. The Leaves of plant are trifoliolate, petiolate with stipules linear lanceolate, all obtuse, glabrous above when old, finely silky and conspicuously reticulate veined beneath (Boutelje, 1980). From January to March the plant is bald. Flowers in rigid racemes of 15 cm long, densely brown velvety on bare branches. Calyx is

dark, olive green to brown in colour and densely velvety outside. The corolla is long with silky silvery hairs outside and bright orange red. Stamens are diadelphes, anthers uniform. Ovary 2 ovule, style filiform, curved and stigma capitate. Pods argenteoanese, narrowed, thickened at the sutures, splitting round the single apical seed, lowest part indehiscent. The seeds are flat, reniform, curved.

The odor is faint, and the taste slightly acid and bitter. It is porous and soft in texture and has annual rings though not very distinct. It generally perishes fast when used at sites open to vagaries of weather, but lasts much longer when used under water. It is therefore used for making well curbs and piles (Jhade *et al.*2009).

The wood is dirty white and soft and, being durable under water, is used for well-curbs and water scoops. Good charcoal can be obtained from it. The wood specific gravity is 0.42–0.54 and Density of 480 kg/cubic m. Its wood is greenish white in colour, soft and weighs about 14 to 15 kg per cubic foot. It is a cheap board wood. The soft and not durable wood is light, about 570 kg/m³ air dry, white or yellowish-brown when fresh, but often turning greyish because of susceptibility to sap stain. It is not of great value but is sometimes used for utensils. Wood pulp is suitable for newsprint manufacturing. The dry wood or stem used to make sacred fire. India is rich in its forest wealth having a huge land area under forests but unfortunately the forest resources in India is depleting due to increase of population and other causes. The gap between supply and demand is increasing day by day. Shortage of the raw material is being experienced in the country. In view of this some substitute in raw materials for solid has been developed. Composite wood like plywood, particle board, MDF, block board, etc. playing major role in providing one of the most important substitute for timber in various applications in furniture industries, building constructions, railways, automobiles, etc (Shukla and Singh,1994).

A particle board is a board or sheet constituted from fragments of wood and other lignocellulosic materials, bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc (Mehta,1981). Particle board is reconstituted constructional

panel particularly developed as a substitute for natural constructional wood and is made from low grade waste woods or from certain agricultural ligneous wastes. In that respect particle board assumes one of the greatest importance in the wood panel products industry from the point of view of conservation of scarce forest resources in a country. Particle board offers a mean to utilize as much as the forest and industrial wood waste as possible because it is so tolerant of wood quality and a wide variety of species, both softwood and hardwood can be used. There is no doubt that the particle board is going to stay for a long time due to plenty of raw materials, manufacturing properties and product properties.

Particle board was first manufactured in Bremen, Germany in 1941. The raw material was dried spruce dust blended with 8-10% Phenolic resins. The boards were produced in large sizes 3 m x 2 m with thickness varying from 4-25 mm. A high pressure of 80-100 kg/cm² and temperature of 160°C were used. Due to fine particles, the density of the board was too high ranging from 0.9 to 1.1 g/cc. In the year 1942, Ross and co-workers in Germany established a particle board unit in which beech veneer were chopped by using wing beater and urea formaldehyde (8-10%) as binder. The board was found useful in paneling and interior walls.

Till the 1946, basic problems encountered in the manufacture of particle board were not deal with in a systematic and scientific manner. It was established that a relationship exists between length, width and thickness of the particles, which not only determines the internal surface available for gluing but the strength properties and the economics of the manufacture. Later on Hummelheber (1949), Interwood (1947) and Triangel (1947) studied the effect of chip size and shape on the manufacture and properties and also the influence of various wood species on the equality of particle board.

In India the first particle board plant was set up in late 1950s at Sitapur in Uttar Pradesh by M/s Plywood products with the capacity of 1500 tonnes. There are presently about 12 wood based and agriculture lignocellulosic waste based particle board units in India with total installed

capacity of 64,100 tonnes. Particle boards are now finding increased applications as building material besides furniture.

The manufacture of wood-based panels has been brought about by the ever increasing cost of logs and lumber, which in turn has caused managers of the world's forest resources to investigate ways and means of using trees more efficiently. Wood composites can utilize low grade logs such as thinning, bowed and twisted logs. They can also use wood waste material. All sawmills produce a lot of residue in the form of chips, sawdust and slabs. These residues can be utilized to manufacture many composites such as particle board (Nemli, 2003).

1.2 Importance and need of study

The *Butea monosperma* trees growing in most part of the country and its can be available in large quantities is one such lignocellulosic wood material can be utilized for the preparation of the particle board.

Particle board is mainly used for structural purpose as well as substitute for solid wood. The major uses of particle board are as core material in furniture, store fixtures and laminates, sink tops and sliding doors. It is widely used in the manufacture of cabinets for TV sets, loudspeakers and tape recorder etc. Greater quantities of particle board are also used in the automobile construction, sports goods, packing cases and for various specialized uses for example bodies of buses, railway coaches, ship building etc. Due to low thermal conductivity and good acoustical properties, low density particle board is extensively used in lecture halls etc (Shukla and Singh, 1994).

Keeping in view the importance of particle board on utilization of *Butea monosperma* for making the particles board and non-commercial wood is also use for particle board. The present study was carried out with the following objectives.

1.3 Objectives

1. To study the suitable percentage of PF resin content for the preparation of particle board from *Butea monosperma*.

2. To evaluate the physical properties of particle boards prepared from *Butea monosperma*.

1.4 Hypothesis

1. *Butea monosperma* is suitable for preparation of particle boards at different PF resin content.
2. The physical properties of particle boards prepared from *Butea monosperma* follows the prescribed standards laid down by Indian standard specification (IS: 3087-1985).

1.5 Scope and limitations

Within the 'family' of wood-based panels, particle board is a mature and established product. However, demand for the product is still strong and continues to grow. According to Drake (1995, 1997), particle board consumption worldwide represented 57 per cent of the total volume of panel products consumed. Worldwide demand for particle board has been steadily growing since then at a rate between 2 and 5 per cent per annum (Gamage *et al.*, 2006).

Wood and biomass based particle boards find wide applications in construction and furniture industries. The demand for wood based particle boards has increased greatly due to population growth while the timber resources are alarmingly depleted. Therefore, a huge imbalance in the supply and demand for wood based particle board has initiated search for wood substitutes as raw materials for the board industry. Research on alternative plant fibres and agro wastes, recycling and efficient conversion technologies has assumed priority to meet the rapidly increasing demand for boards in future. A number of studies have been conducted for production of particle boards from agro residues like cotton, sunflower, guar and sorghum stalks, jute stick, tea leaves, date palm, sugar beet leaf fiber, cotton carpel, etc. The physical and mechanical properties of the boards made from the agricultural crop residues meet the requirement of standard medium density particle board.

The wide gap between demand and supply of various raw materials is likely to further widen due to rise in population and standard of

living. In view of this some, substitute raw material for solid wood have been developed. It is expected that composite wood product like plywood, blockboard, particle board and fiber board etc. can play a major role in providing one of the most important substitute for timber in various applications.

The appreciation of the need for rational utilization of wood as a raw material has resulted in the increased consumption of these products everywhere. In developed countries, wood based panels have largely replaced solid wood and have become indispensable for housing. Particle board offers a man to utilize as much as forest and industrial wood waste as possible because of its capability to use a wide variety of species including both softwood and hardwood.

CHAPTER II

REVIEW OF LITERATURE

Research is a continuous process and the review of literature is one of the important aspects in research. It helps the researcher to get acquainted with the subject matter and channelizes research efforts in a desirable direction. Efforts were made to review the relevant literature that has direct or indirect bearing with the study. The reviewed literature has been presented according to different variables studied. Suitable assumptions have been made on the basis of review of literature. A brief resume of the work done on different aspects pertaining to the present investigation has been reviewed and presented as under:

Fickler (1972) described a process which developed in Scandinavia for producing particle boards from sawdust, shavings, or bark, faced on both sides with wood veneer, paper, or thin fiberboard. The boards were particularly suitable for use in the building industry.

Rodgers (1973) worked on the strength properties of UF-bonded particle boards (density 650 kg/m^3) made from beech, oak and *Khayaivorensis*. Strength was generally comparable to that of standard scots pine boards of the same density. Boards of density 800 kg/m^3 made of oak were stronger than those of pine of the same density. Oak chips were unsuitable for manufacture of boards with alkaline-setting phenol-formaldehyde adhesive.

Volz (1973) investigated the production and properties of board from spruce, pine and beech bark and reported that the density of the board and amount of binder use had a major influence on board properties.

Beech (1975) reported an investigation on the effects of grain orientation within the wood particles, species of timber, type and content of adhesive and treatment of pressed boards with saturated steam, on the thickness stability of particle board. Boards were made mainly from scots pine particles with PF resin. A distinction is made between reversible and

irreversible swelling. Boards were tested for thickness swelling after immersion in water for 2 and 24 hours. Irreversible swelling was reduced by increasing the resin content, and reversible swelling was affected by wood species and grain orientation. Treatment with steam at 160°C reduced reversible and irreversible thickness changes.

Saito and Kunisue (1975) made boards from Scots pine sawdust produced by a band saw required >10 per cent resin binder. Increases in resin content improved the mechanical properties to a greater extent in higher-density than in lower-density boards. The sawdust boards had low bending strength, but higher internal bond and stability in thickness and could be used for core materials.

Takahashi *et al.* (1975) made tests on the mechanical and water-absorption properties of particle boards manufactured from mixtures consisting of wood particles and bark or wood particles and sawdust, in various proportions. The results showed that under certain manufacturing conditions boards conforming to Japanese standard JIS A 5908 could be produced.

Gupta and Singh (1978) studied the effect of resin content and properties of board prepared from *Mechelia champaca*. The board met the standard at 9 per cent and more. Urea formaldehyde resin content gave the satisfactory strength properties.

Singh and Gupta (1982) investigated varying amounts of urea formaldehyde (UF) and phenol formaldehyde (PF) resins were used for making particle boards from four hardwood species namely *Dalbergia sissoo* (Shisham), *Artocarpus chaplasha* (Chaplash), *Chloroxylon sweitenia* (Satin Wood) and *Eucalyptus hybrid* (Eucalyptus) to study the relative performance of wood species vis-a-vis the two resins. Results showed that phenolic resin gave slightly better performance than urea resins. As the amount of resin was increased, strength properties of the boards were increased while the water absorption and thickness swelling properties were reduced. It was further observed that in most boards the properties were related to the basic properties of the wood used.

Shukla and Prasad (1985) worked on the suitability of baggage for manufacturing medium density particle board. Good quality of boards meeting the requirements of IS were prepared by using 8 percent PF resin on dry basis of graded fibers.

Singh and Rawat (1990) evaluated suitability of pine sawdust for medium density particle boards. It is observed that after removing the undesired portion from sawdust satisfactory boards meeting the requirements of specification could be prepared from pine sawdust using 12 per cent phenol formaldehyde resin. The properties of the boards could be further improved by mixing 20 per cent wood particles in the sawdust.

Singh *et al.* (1995) worked on the suitability of *Populus deltoids* with or without bark for making particle board. The result shows that satisfactory boards meeting the requirements of specifications were made by using 10 percent phenol formaldehyde resin and 1 per cent wax emulsion as sizing agent in both the cases.

Akaranta (1999) worked on production of particle boards from rubber seed pod, cashewnut shell and their blends using an adhesive resin based on cashewnut-shell liquid. Performance evaluation showed that the boards satisfied the ASTM specifications for construction-grade building boards.

Nimkar and Singh (2000) evaluated suitability of Bamboo (*Bambusa polymorpha*) as a raw material for particle board manufacture. The results showed that *Bambusa polymorpha* was suitable for making particle board. Satisfactory boards were made using 10 per cent phenol formaldehyde resin and 0.5 per cent wax emulsion as sizing agent.

Vishwanathan *et al.* (2000) worked on water absorption and swelling characteristics of coir pith particle board. The water absorption and swelling were least for the board made from largest-size particles and phenol-formaldehyde resin.

Grigoriou and Ntalos (2001) worked on the potential use of *Ricinus communis* L. (Castor) stalks as a lignocellulosic resource for particle boards. Properties of the boards produced in this study were

relevant to European and American Standards, it was found that, with the exception of screw holding strength for three-layer boards, the experimental one layer and three-layer boards containing up to 25 per cent and 75 per cent castor particles respectively meet or exceed the standards requirements for interior boards.

Singh and Negi (2001) examined the suitability of lops and tops of *Populus deltoids* with or without bark as a raw material for manufacturing of particle boards and observed that *Populus deltoids* wood alone and with bark (about 19%) was suitable for making particle boards. However, the strength properties of particle board without bark were slightly better than the board with bark.

Nimkar *et al.* (2001) worked on particle board prepared from Bamboo dust. Phenol formaldehyde bonded particle boards were made from bamboo (*Bambusa polymorpha*) dust with resin content of 6, 8, 10 and 12 per cent. Subsequently, boards were tested for different physical and mechanical properties according to Indian Standard IS: 3087. Result showed that bamboo (*Bambusa polymorpha*) dust was suitable for manufacturing of particle board. Satisfactory boards were made using 12 per cent phenol formaldehyde resin and 0.5 per cent wax emulsion as sizing agent.

Singh *et al.* (2002) studied the suitability of lop and tops of *Ailanthus excels* with bark for making particle board. Suitable particle boards meeting the requirements of specification were made by using 10 percent phenol formaldehyde resin and 1 percent wax emulsion as sizing agent.

Bektas *et al.* (2005) worked on three-layer particleboards are produced from a mixture of sunflower stalks (*Helianthus annuus*L.) and poplar wood (*Populus alba* L.) at certain ratios utilizing urea-formaldehyde (UF) adhesives. Results show that all the panels provide properties required by the Turkish standards for general purpose-use particleboards.

Islam *et al.* (2006) conducted a study to evaluate the feasibility of using Dhaincha (*Sesbaniaaculeata*) for particleboard

manufacturing. The standard of dhaincha particleboard was assessed by examining the physical and mechanical properties. Particle board from dhaincha was one of international standard.

Bhaduri and Mojumder (2008) studied on medium density particle board from khimp plant. Plant stem was investigated for production of medium density particle boards with phenol-formaldehyde (PF) and urea-formaldehyde (UF) resins as binders in varying quantities. The properties of particle boards prepared with PF and UF resin binders conformed to the BIS specifications for medium density particle boards for general purpose requirements.

Kamal *et al.* (2009) studied on physical and mechanical properties of flame retardant-treated kenaf particle boards using physical tests such as water absorption, thickness swelling and mechanical tests such as modulus of rupture, modulus of elasticity and internal bond. The kenaf core particles were treated with 10% concentrations of three types of flame retardants namely diammonium phosphate, monoammnium phosphate and BP® [mixture of 27-33 % boric acid, 67-73 % guanylurea phosphate and 0.0-4.2 % phosphoric acid]. BP®-treated particleboards were found to have performance values superior than the British-European standard requirement values for MOR [BS EN 310:1993] and MOE [BS EN 310:1996]. Overall, the flame retardants affected the physical and mechanical properties of the kenaf core particleboard.

Setunge *et al.* (2009) established a methodology for making particle board in the laboratory using 100 per cent hardwood sawmill residues, developing a particle board product made in the laboratory which had acceptable mechanical properties and density profiles in accordance with the Australian Standards.

Kshirsagar *et al.* (2012) studied on the particle board, prepared from *Dendrocalamus strictus*. Phenol formaldehyde bonded particle boards were made from *Dendrocalamu sstrictus* with resin content of 6, 7, 8, 9, 10, 11, 12, 13 and 14 per cent. Boards were tested for different physical and mechanical properties according to Indian Standard

specification. Satisfactory boards were made using 11 per cent phenol formaldehyde resin met the requirement of IS specification.

Parab *et al.* (2013) worked on evaluation suitability of sawdust of five hardwood species namely, Teak (*Tectona grandis*), Neem (*Azadiracta indica*), Behda (*Terminalia belerica*), Mango (*Mangifera indica*) and Babul (*Acacia nilotica*) for preparation of particle board. Satisfactory boards were prepared from Mango (*Mangifera indica*) and Teak (*Tectona grandis*) sawdust using 12 per cent phenol formaldehyde resin met the requirement in respect of physical properties as specified in IS specification.

Elbadawi *et al.* (2013) study was to investigate the effect of adding a blend of tannins to commercial urea formaldehyde (UF) on the properties of particle board made from wood particles of *Acacia seyal* var. *seyal*. The tannins were extracted from the bark of *Acacia seyal* var. *seyal* (Ass) and *Acacia nilotica* subsp. *tomentosa* (Ant) with hot water (initial temperature was 90 °C), using a ratio of powdered bark to water of 1:6 (w/v). The tested *Acacia* species (Ass and Ant) exhibited high tannin contents (82.18% and 73.09%, respectively). A blend from the two tannin types (BT) was made (1:1 w/w) and added to UF in the form of a concentrated solution (35%) at three different percentages (5%, 10% and 15%, weight/weight). The different UF–BT formulations were used to produce particleboards (340 mm × 340 mm × 10 mm in size). The obtained panels were tested according to the BSEN relevant standards and showed high mechanical properties, compared to the ones produced by solely UF. It was also observed that the addition of BT to UF did not improve the physical properties of the panels (thickness swelling (TS) and water absorption (WA)), but the results obtained were slightly higher than the ones for the UF panels.

Mamza *et al.* (2014) studied on comparing the properties of particleboards produced from sawdust with phenol formaldehyde and urea formaldehyde resins. The particleboards were produced using varied quantities of particle size 2mm. 30ml each of the resins which was prepared under same conditions, compression temperature of 180°C,

pressure of 10tons, and pressing time of 15 minutes. The properties of the particleboards were tested and compared. The results showed that the particleboards produced with phenol formaldehyde had better properties compared to that of urea formaldehyde.

De Melo *et al.* (2014) worked on the physical-mechanical properties of particleboards manufactured with wood (*Eucalyptus grandis*), bamboo (*Bambusa vulgaris*) and/or rice husk (*Oryza sativa*) particles, combined or not, were assessed. They were produced in the following proportions: 100% wood; 100% bamboo; 100% rice; 50% wood and 50% bamboo; 50% wood and 50% rice husk. The results indicated that the use of rice husk caused reduction in particleboard quality. Particleboards manufactured with bamboo showed better quality than those using rice husks as raw material. For most parameters, the particleboards manufactured exclusively with wood particles showed similar performance to bamboo and wood-bamboo particleboards.

Moya *et al.* (2014) studied on physical, mechanics and hydration properties of particle boards manufactured with woody biomass (*Cupressus lusitanica*, *Gmelina arborea*, *Tectona grandis*), and either agricultural wastes and Tetra Pak residues. Resulted that the particle board prepared with tetra pack packages and woody biomass can reduce the swelling and water absorption in up to 40 per cent and 50 per cent compared with particle boards without tetra pack packages. On the contrary, particleboards prepared with pineapple leaves in combination with woody biomass showed the lowest mechanical properties, particularly for tensile strength, hardness, glue line shear and nail and screw evaluation.

Yeniocak *et al.* (2014) investigate the suitability of vine pruning (*Vitis vinifera* L. cv. *Sultani*) in Turkey as an alternative raw material for particleboard production. In this study, vine pruning and wood particles in various proportions were used as the raw material for three-layer flat pressed particleboards. A commercial urea-formaldehyde resin was used as binder. Some physical and mechanical properties of panels were determined. Results indicated that the bending strengths of A, B, C and D

panels met the minimum bending strengths value (11.5 N.mm^{-2}) required in TS-EN 312-2 (1999) standard for general purpose particleboards.

Washington *et al.* (2014) observed that this paper discusses the potential use of Tauari (*Couratari oblongifolia*) wood waste as a raw material for the production of particleboards, using castor oil-based bi-component polyurethane adhesive. Experimental boards were prepared with dry wood particles and a castor-oil polyurethane adhesive content of 16%. The boards, whose nominal density was 1000 kg/m^{-3} , were subjected to uniaxial compression (5 MPa) at 90, 110 and 130°C for ten minutes. The particleboards were characterized by performing the following tests: Apparent density (DAP), Moisture (M), Water Absorption (WA), Thickness Swelling (TS), Static bending strength: MOR (Modulus of rupture) and MOE (Modulus of elasticity), Perpendicular Tensile Strength (IB – internal bonding) and Screw Pullout (SP). The results indicate that, regardless of the processing temperature, the average density of Tauari particleboard is 930 to 941 kg/m^{-3} , with higher IB and TS than those specified by the NBR 14810-2 and ANSI A208.1 standards, enabling this product to be classified as high-density particleboard suitable for industrial and commercial use.

Gawaliet *et al.* (2015) examined the particle board prepared from *Lantana camara*. Phenol formaldehyde bonded particle boards were made from *Lantana camara* with resin content of 8, 9, 10, 11, 12, 13 and 14 per cent. Boards were tested for different physical properties according to Indian Standard specification. Satisfactory boards were made using 13 and 14 per cent phenol formaldehyde resin met the requirement of IS specification.

Bhadewad (2015) studies on preparation of particle board from *Prosopis juliflora* (sw.) dc. at different resin content. Phenol formaldehyde bonded particle boards were made from *Prosopis juliflora* with resin content of 8, 9, 10, 11 and 12 per cent. Boards were tested for different physical properties according to Indian Standard specification. Satisfactory boards were made using 11 and 12 per cent phenol formaldehyde resin content with 0.5 and 1.0 per cent wax emulsion met the

requirement in respect of physical properties as specified in IS specification.

Alao (2015) reported that the potentiality of rice husk in the production of particleboards using starch wood glue (Top bond) as an alternative source of adhesives. The weighing scale was used to weigh the rice husk, starch, wood glue (Top bond) the mixture ratio adopted being 0.75 kg: 0.15 kg: 0.10 kg of the rice husk, starch, wood glue respectively, thoroughly mixed manually by using the mixer. The mixture was then poured into a mould with a dimension 300 mm × 300 mm × 15 mm. The particleboard was tested for water absorption in both cold hot media that rice husk waste can be utilized in the manufacture of a water-resistant particleboard tropical area. The use of starch, a biodegradable adhesive reduced the use of the more expensive synthetic adhesive based on petroleum resources. The test results showed that the rice husk, starch wood glue combination provides results which have high potential to be used in the production of particleboard.

Akinyemi *et al.* (2016) examined the possibility of developing a composite corncob (CC) and sawdust (SD) particle board using urea formaldehyde as binder. The panels were produced using 0%, 25%, 50%, 75% and 100% variations for both agricultural wastes with a constant volume of adhesive to evaluate their effect on the physical and mechanical properties. The results showed that 25% and 50% replacement of SD with CC had favourable physical properties recommendable for indoor uses in buildings. the experimental investigation and possible limitations the panels with 50% CC replacement were the most preferred since they had preferable performances for both physical and mechanical properties.

Muruganandam *et al.* (2016) observed that growing tendency of recycling of waste materials and using them production of particle boards. Particle Boards are produced from Municipal solid waste, agro-waste materials such as rice husk, jute sticks, waste wood, sugarcane waste, kitchen waste etc. all the physical and mechanical properties depend on the kind of raw material used and these properties may be improved for the quality betterment of the products The present study

reviews about the different raw materials used for particle board production and their varied properties for improving their quality and wide applications.

Kord *et al.* (2016) observed that possible feasibility of canola (*Brassica napus*) straws in the production of particleboard. Three-layer experimental particleboards with density 0,7 g/cm³ were manufactured using different canola straws particle ratios (0%, 25%, 50%, 75% and 100%) and urea formaldehyde (UF) adhesive. Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB), water absorption (WA) and thickness swelling (TS) properties of the boards were evaluated. The results have shown that production of general purpose and furniture grade particleboard used in dry conditions using canola straws is technically viable. The results of the study demonstrate that canola straws can be an alternative raw material source for particleboard industry.

Abolaji (2017) examined on suitability of using mango shell particles as alternatives to wood-based particleboard composite manufacturing has been investigated in this study. The mango shell composite boards were produced by compressive moulding using recycled high density polyethylene (RHDPE) as binder. The RHDPE was varied from 30 to 70 wt. % at intervals of 10 wt. % using 420µm particle size. The microstructure, water absorption (WA), thickness swelling index (TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength (IB), impact strength, and hardness values of the boards were evaluated. From the results, boards produced using 60 % RHDPE gave the best physical and mechanical properties as follows: modulus of rupture 11.49MPa, MOE of 2450MPa, IB of 0.58MPa, and hardness value of 5.17HBR. The uniform distribution of the agro-waste particles and the RHDPE in the microstructure of the composites is the major factor responsible for the improvement in the mechanical properties. Equally, the MOE, MOR and IB meet the minimum requirements of the European standards (BS EN 312:2003) for general purpose boards for paneling, ceiling and partitioning. Hence mango shell particles can be used as a substitute to wood-based particleboards for general purpose applications with a minimum cost of production.

Harshavardhan (2017) studied was to use municipal dry waste, plant waste and saw dust collected from various sources to make particle boards with each individual item as well as a combination of these in various ratios. the present work focuses on finding the properties of the board without the use of fibers. The physical and mechanical properties of these boards are then determined by using a series of tests. The results are then compared and most of the samples are found to comply with the IS standards.

Gul *et al.* (2017) reported that hot pressing temperature is determined according to the performance of boards, type of glue, and production efficiency of hot Press. This research investigates the performance of MDF with respect to hot pressing temperature. The strength and water resistance of the product are improved with the increase of hot pressing temperature from 140°C to 160°C, the Modulus of Rupture (MOR) is increased by 9.8%, the Internal Bonding (IB) is increased by 33.6%, the water absorption (Wt) is decreased by 38.2%, and the thickness expansion rate (T_s) is decreased by 15.2%.

Asha (2017) observed that the growing shortage of wood has also led to the development of suitable alternative materials for construction. Rice husk particleboard is one such material, which is being considered as a potential substitute for wood and wood-based board products. The particles, whose mass fraction was the variable were cut down into smaller sizes and mixed with resins and other binders. The resulting slurry were compacted until the composite became hard Water absorbity, electrical conductivity tests were carried out on the samples. These tests confirmed the possible use of sponge particles as reinforcement in the production of particleboard.

CHAPTER III

MATERIAL AND METHODS

The present investigation entitled “Assessment for the suitability of *Butea monosperma* Lam. for preparation of particle board” was carried out at Forest Product Workshop, Department of Forestry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Details of the material used and the procedure for preparation of particle board employed during the course of investigation are as given below.

3.1 Experimental Details

Butea monosperma wood raw material was used for the preparation of particleboards. The particleboards were prepared from different PF resin content *i.e.* 8, 9, 10, 11 and 12 per cent. Similarly, the boards were also prepared with 0.5 and 1.0 per cent wax emulsion as a sizing agent. At each resin content, three particle boards were made *i.e.* without wax emulsion and with 0.5 and 1.0 per cent wax emulsion.

The particle boards were examined as per the procedure laid down in IS: 2380 (Anonymous, 1977) and IS: 3087 (Anonymous, 1985).

Observation recorded:

1. Thickness (mm)
2. Density (g/cm³)
3. Moisture content (%)
4. Water absorption (%) - 2 hrs and 24 hrs.
5. Length and Thickness swelling (%) - 2hrs
6. Swelling due to surface absorption (%) - 2 hrs

[IS: 2380 (Anonymous, 1977) and IS: 3087 (Anonymous, 1985)]

3.2 Experimental material

The following raw materials were used for the preparation of particle boards.

3.2.1 Lignocellulosic material

Butea monosperma wood raw materials was collected from the campus of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The height of the selected *Butea monosperma* trees was in the range 8 to 11 m and diameter of branches was in range 2 to 5 cm. A photograph of *Butea monosperma* and its branches shown in Plate 1.

3.2.2 Additive

3.2.2.1 Sizing material

Paraffin wax dissolved in mineral sprit or alternatively emulsified with water or melted shall be used a sizing material. Wax emulsion was prepared as follows:

3.2.2.2 Preparation of wax emulsion

Wax emulsion was prepared to use it as a sizing agent in preparation of particle board. For preparation of wax emulsion, first a mixture of 120 g of paraffin wax and 12 g of stearic acid was prepared. The another solution of 6 cc liquid ammonia and 182 cc of water was prepared. Then heated the first mixture and while stirring vigoursly add the second solution to first and then heat the mixture at constant temperature of 55°C and stirring until uniform emulsion is seen. A photograph of chemical raw material and the procedure used for preparation of wax emulsion is presented in Plate 2 and Plate 3.

3.2.3 Chemical raw material

Chemical raw material namely phenol, formalin and sodium hydroxide (NaOH) were used for the preparation of phenol formaldehyde resin as an adhesive used for preparation of particle board. A photograph of chemical raw material used for preparation of phenol formaldehyde resin is presented in Plate 4.

3.2.3.1 Procedure for preparation phenol formaldehyde resin

1000 g of phenol was taken in a round bottom flask. Then 1200 g of formalin was added in the flask. The pH of whole solution was maintained at 9-9.5 by adding 50 g of NaOH dissolved in 100 ml of water.



Plate 1: Tree of *Butea monosperma* and its branches



PLATE 2: Chemical raw material used for wax emulsion



Plate 3 : preparation of wax emulsion



plate 4:chemical material for PF resin

The round flask with solution was mounted on a heating mantle and observed till actual reaction started inside the flask. Actual reaction started when first time the bubbling was seen in the solution. The solution was refluxed for 30 min. The PF resin was kept for cooling. Cooled PF resin was analyzed for suitability in making particle board. A photograph taken during preparation of phenol formaldehyde resin is depicted in Plate 5.

3.3 Analysis of PF resin

3.3.1 Solid content of the PF resin

This is the amount of the solid PF resin present in 10 ml of PF resin solution. 10 ml of phenol formaldehyde resin sample was taken in petri-dish and kept in oven at $105 \pm 3^{\circ}\text{C}$ for drying till constant weight. The solid content was determined by applying the following formula.

$$\text{Solid content (\%)} = \frac{\text{Weight of the dry PF resin}}{\text{Weight of liquid PF resin}} \times 100$$

$$\text{Solid content (\%)} = \frac{(Z - A)}{(B - A)} \times 100$$

Where,

A = Weight of the petri dish

B = Weight of the petri dish + PF resin

(B - A) = Weight of the PF resin

Z = Oven dried weight of the PF resin + petri dish

(Z - A) = Weight of the dry PF resin

3.3.2 Ash content of the PF resin

This is the amount of the inorganic material present in 100 g of the solid PF resin. 100 g of phenol formaldehyde resin sample was taken in silica crucible covered with lid and placed in muffle furnace. The PF resin was ashed at 300°C for about an hour, the temperature was increased

slowly up to 700-740⁰C and heating at this temperature was continued for 2 hours.

After cooling, the silica crucible were taken out from muffle furnace and placed in desiccator. The weights of silica crucible with and without ash were taken and percentage of ash was calculated.

$$\text{Ash content (\%)} = \frac{\text{Weight of the ash}}{\text{Weight of solid PF resin}} \times 100$$

$$\text{Ash content (\%)} = \frac{(C - A)}{(B - A)} \times 100$$

Where,

A = Weight of the empty silica crucible

B = Weight of the empty silica crucible + dry PF resin

(B -A) = Weight of the dry PF resin

C = Weight of crucible+ PF resin after furnace

(C -A) = Weight of ash

3.3.3 Specific gravity of PF resin

Specific gravity of PF resin is the ratio of weight of PF resin to the weight of water. Specific gravity of phenol formaldehyde resin was determined using specific gravity bottle of 10 ml capacity. The specific gravity bottle was weighed as empty, with PF resin and water. Specific gravity of the phenol formaldehyde resin was calculated with the following formula.

$$\text{Specific gravity of PF resin} = \frac{\text{Weight of PF resin}}{\text{Weight of water}}$$

$$\text{Specific gravity of PF resin} = \frac{(Z - X)}{(Y - X)}$$



Plate 5: preparation of PF resin

Where,

X = Weight of the empty specific gravity bottle

Y = Weight of the specific gravity bottle with water

(Y – X) = Weight of the water

Z = Weight of the specific gravity bottle with PF resin

(Z – X) = Weight of the PF resin

3.3.4 Results of PF resin analysis

The result of PF resin analysis is appended in Table 1.

Table 1. Result of analysis of PF resin

Solid content	39.94%
Specific gravity	1.064
Ash content	4.1%

3.4 Estimation of amount of PF resin required for particle boards.

Example for calculation

Weight of dried particle - 500 g

Solid content of PF resin- 39.94%

Suppose,

$$\text{Calculation for 8 \% PF resin content} = \frac{500 \times 8}{100}$$

$$= 40 \text{ g}$$

Since, PF resin is having 39.94 per cent solid content

Therefore,

$$\begin{aligned} \text{Weight of PF resin} &= \frac{100 \times 40}{39.94} \\ &= 100.15 \text{ g} \end{aligned}$$

Weight of PF resin / board = 100.15 g (i.e. 8 % resin content)

Accordingly, the amount of PF resin required for preparation of particle board was worked out for 9, 10, 11 and 12 per cent of PF resin content and as given in the Table 2.

Table 2. Amount of PF resin required for preparation of particle boards

Sr. No.	PF resin content (%)	Weight of PF resin required per board (g)
1	8	100.15
2	9	112.69
3	10	125.18
4	11	137.70
5	12	150.22

3.5 Estimation of amount of wax emulsion (0.5 % and 1%) required for particle boards

$$\text{Calculation for amount of wax emulsion} = \frac{\text{Wax emulsion (\%)} \times \text{weight of dried particles}}{100}$$

Weight of dried particle - 500 g

Example,

$$\begin{aligned} \text{Calculation for 0.5 \% wax emulsion} &= \frac{0.5 \times 500}{100} \\ &= 2.5 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{Calculation for 1\% wax emulsion} &= \frac{1 \times 500}{100} \\ &= 5 \text{ g} \end{aligned}$$

Accordingly, the amount of wax emulsion required for preparation of particle board with 8, 9, 10, 11 and 12 per cent of PF resin content is given in Table 3.

Table 3. Amount of wax emulsion required for preparation of particle board

Sr. No.	PF resin content (%)	Amount of wax emulsion required per board (g)
1	8 ^{**}	2.5
2	8 ^{***}	5.0
3	9 ^{**}	2.5
4	9 ^{***}	5.0
5	10 ^{**}	2.5
6	10 ^{***}	5.0
7	11 ^{**}	2.5
8	11 ^{***}	5.0
9	12 ^{**}	2.5
10	12 ^{***}	5.0

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

3.6 Procedure for preparation of particle board.

3.6.1 Collection of raw materials

Butea monosperma a wood raw material collected from the campus of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Collection of raw material of *Butea monosperma* presented in Plate 6.



Plate 6: collection of raw material of *Butea monosperma*

3.6.2 Drying of raw material

The procured materials was sun dried for 8 to 15 days, so as to bring down the moisture level up to 11 to 12 per cent. A photograph of sun drying of *Butea monosperma* is shown in Plate 7.

3.6.3 Primary reduction

This involves the reduction in the size of raw materials. Raw materials was further reduced into small pieces with the help of cross cutting machine (Mini Combi planner). A photograph of Mini Combi planner and primary reduction of material are presented in Plate 8 and Plate 9.

3.6.4 Drying of cross cut small pieces

After primary reduction, the small cross cut pieces were obtained from cutting over Mini Combi planner. This material was again sun dried for 2 to 3 days, to bring down the moisture level.

3.6.5 Secondary reduction

Secondary reduction is the next stage in which the dried small cross cut pieces was further reduced with the help of wood grinder to convert into small particles. A photograph of wood grinder is shown in Plate 10.

3.6.6 Drying of particles

The drying of particles is an essential and important operation. It was carried out by sun drying for 3 days. After drying, the moisture content of the particle was about 9.5 per cent. A photograph of *Butea monosperma* particles during sun drying is shown in Plate 11.

3.6.7 Sieving

The dried particles were screened through 10 mesh sieves. The particles retained over 10 mesh sieve were used for preparation of particle boards.

3.6.8 Resin blending

About 500 g of dried particles was taken for making each particle boards. The dried particles was uniformly blended with different PF



plate 7:Sun drying of woody raw material



Plate 8:Mini combiplanner



Plate 9: Primary reduction of butea monosperma



Plate 10: Wood grinder



Plate 11: Sun drying of Butea monosperma particles

resin content i.e. 8, 9, 10, 11 and 12 per cent on the basis of dried particles of *Butea monosperma* and solid content of phenol formaldehyde resin. A photograph taken during PF resin blending of particles of *Butea monosperma* is shown in Plate 12.

3.6.9 Drying of resin blended particles

The resin blended particles were air dried to bring down the moisture content of about 6-8 per cent. A photograph of air dried PF resin blended particles is shown in Plate 13.

3.6.10 Mat formation

Over the aluminum cauls plates the cakes were made from the PF resin blended particles. Before making the cakes, wax was applied on the caul plates. The wooden mould of size 30 × 30 cm was kept over the caul plates. The PF resin blended particles was uniformly laid to form a mat in the wooden mould. This was manually pre-pressed and after pre-pressing for 5 minute wooden mould was taken out. The size of the cake was 30 × 30 cm was obtained after removing the wooden mould. A photograph of mat formation by using wooden mould is shown in Plate 14. Other caul plates on which wax was applied were then placed over the mat. The mat in between two cauls plates was then kept in the hot press.

3.6.11 Hot pressing

The hot pressing was the most important step for making of the particle boards and required a lot of technical knowledge. The hot pressing operation for making particle board was carried out in hydraulic hot press. The photograph of hydraulic hot press machine and preparation of particle board by using hydraulic hot press are shown in Plate 15 and plate 16. The mats were pressed in the hydraulic hot press at specific pressure of 300 lbs/inch² and gauge pressure of 91.86 lbs/inch² at temperature of 150 to 155⁰C for about 12 minutes for making each particle boards. The single layers flat pressed particle boards were made. The gauge pressure required during hot pressing was worked out by using following formula.

$$\begin{aligned}
\text{Area of piston} &= 470.24 \text{ sq. inches} \\
\text{Specific pressure} &= 300 \text{ lbs. /inch}^2 \\
\text{Area of particle board} &= 12" \times 12" \\
\text{Gauge pressure} &= \frac{\text{Specific pressure} \times \text{area of board}}{\text{Area of piston} \times \text{No. of piston}} \\
&= \frac{300 \times 12 \times 12}{470.24 \times 1} \\
&= 91.86 \text{ lbs./inch}^2
\end{aligned}$$

3.6.12 Trimming of the Boards

After emergence from the hot press the boards were trimmed length wise and width wise by the circular saw. A photograph taken during trimming of particle boards is shown in Plate 17.

3.6.13 conditioning of the boards

Conditioning of the boards exit from the hot press refers to equalization of their temperature and moisture content. As boards emerged from the hot press, its temperatures were very high. At this stage, the hot boards were solid stacked so that temperature reduction takes place at a very slow rate. Conditioning of boards was done for one week to attain the normal moisture content. Conditioning is of importance in equalizing the moisture content throughout the boards to avoid warping. A photograph of particle boards is shown in Plate 18.

3.6.14 Making of test specimens

Five samples of size 5 × 5 cm were taken from each board for each test. These samples were then used for testing various physical properties of board. A photograph of specimens of particle board is presented on Plate 19.



Plate 12: Resin blending of particles



Plate 13 : Drying of resin blended particles



Plate 14 : Mat formation by wooden mould



Plate 15: Hydraulic hot press



Plate 16: Preparation of particle board by using hydraulic hot press

3.7 Testing of Particle boards

Particle boards were tested for various physical properties as per the procedure laid down in IS: 2380 (Anonymous, 1977) and IS: 3087 (Anonymous, 1985). Minimum requirement of IS: 3087-1985 specifications on medium density particle boards for various physical properties Table 4. Five specimens of particle boards were taken from each board for each test and the average was worked out.

Table 4. Minimum requirement of IS:3087-1985 specifications on medium density particle boards for various physical properties

Properties	Minimum requirement of flat pressed single layered particle board
1. Moisture content	5 to 15%
2. Density Variation, percent	500 to 900 kg/m ³
3. Water Absorption <ul style="list-style-type: none">• 2 hrs soaking• 24 hrs soaking	$\leq 25\%$ $\leq 50\%$
4. Length and Thickness swelling 2 hrs soaking <ul style="list-style-type: none">• Length• Thickness	$\leq 0.5\%$ $\leq 10\%$
5. Swelling due to surface absorption	$\leq 9\%$

3.7.1 Thickness

The thickness of boards was measured along the edges of the boards with the help of vernier calliper to an accuracy of ± 0.1 mm. Measurements were taken 25 mm from the edge. It was measured at four sides and mean value of these four observations was recorded as thickness of particle board.



Plate 17 : Trimming of board

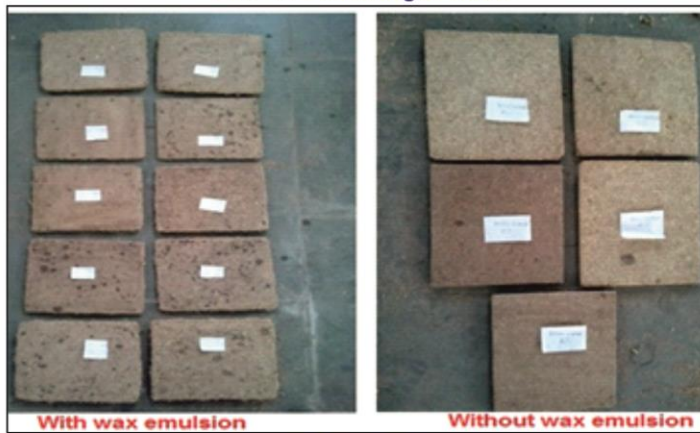


Plate 18 : Particle boards

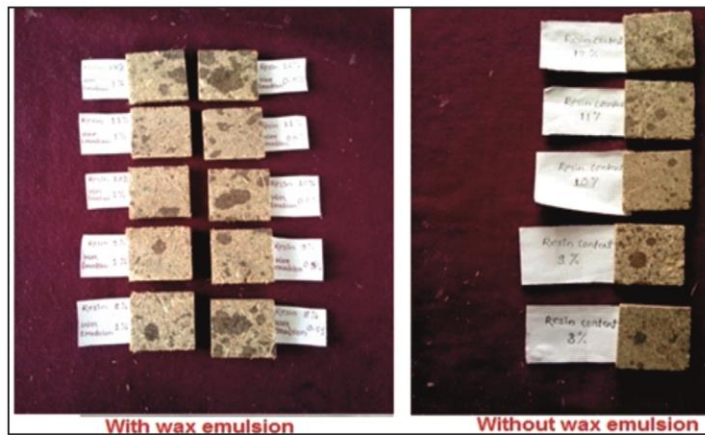


Plate 19 : Specimens of particles board (5 X 5)

3.7.2 Density

Sample size of 5 cm x 5 cm from each board was taken for the estimation of density. The average dimensions at the three faces i.e. length, width, thickness and weight of each test specimen were recorded. The dimensions of each test specimens were measured to an accuracy of ± 0.3 per cent and each specimen were weighed to an accuracy of ± 0.2 per cent.

$$\text{Density (g / cm}^3\text{)} = \frac{\text{Mass of the test specimen in g}}{\text{Length (cm) x Width (cm) x Thickness (cm)}}$$

3.7.3 Moisture content of the board

Sample size of 5 cm x 5 cm from each board was taken for the estimation of moisture content of the board. Each specimen was weighed to accuracy not less than ± 0.2 per cent. The specimens were dried in an oven at a temperature $103 \pm 2^{\circ}\text{C}$, until the mass is constant to ± 0.2 per cent between two successive weighing made at an interval of not less than one hours. The moisture content expressed as percentage of the oven dry mass was calculated by following formula.

$$\text{Moisture content \%} = \frac{M_1 - M_0}{M_0} \times 100$$

Where,

M_1 = initial mass

M_0 = oven dry mass

3.7.4 Water absorption

Sample size of 5 cm x 5 cm from each board was taken for water absorption test. Each test specimen was weighed to an accuracy of not less than ± 0.2 per cent and the width, thickness and length were measured to accuracy not less than ± 0.3 per cent. Then the specimens were submerged horizontally in 25 mm fresh clean water maintained at a temperature of $27 \pm 2^{\circ}\text{C}$. Each test specimens were separated by at least

15 mm from each other and from the bottom and the sides of the container. After a 2 hours submersion, the specimens were suspended to drain for 10 minutes, at the end of which time the excess surface water was removed and then specimens were immediately weighed. The specimens were then submerged for an additional period of 22 hours and the above weighing procedure was repeated. The amount of water absorbed by each test specimen after 2 hours and 24 hours was calculated from the increase in weight of the specimen during the submersion and it is expressed as follows:

$$\text{Water absorption \%} = \frac{M_2 - M_1}{M_1} \times 100$$

Where,

M_1 = Initial mass

M_2 = Final mass

3.7.5 Length and thickness of swelling

Sample size of 5 cm x 5 cm from each board was taken for length and thickness swelling of the particle board. The thickness at the edge of each test specimen was measured to an accuracy of 0.01 mm at three places along one edge. The points at which the thickness was measured were clearly and indelibly marked. Each test specimen was immersed in fresh clean water having a temperature of $27 \pm 2^{\circ}\text{C}$ water was renewed for each test. The short edge of the specimen was vertical with the measured edges lower most and the test specimen was separated by at least 15 mm from each other and from bottom and sides of the container. They were covered by 25 mm of water.

At the end of 2 hours each test specimen was taken out from the water, wiped with a damp cloth and allowed to stand under room conditions for 1 hour with its bottom edge on a glass sheet. Each test specimen was remeasured after 2 hours and 24 hours respectively at the same points and to same degree of accuracy. The increases in dimensions

were recorded. The average of four values obtained for the changes in thickness expressed as a percentage of the original average thickness was reported as the swelling value.

$$\text{Swelling in length \%} = \frac{L_2 - L_1}{L_1} \times 100$$

Where,

L_1 = Initial length

L_2 = Final length.

$$\text{Swelling in thickness \%} = \frac{T_2 - T_1}{T_1} \times 100$$

Where,

T_1 = Initial thickness

T_2 = Final thickness

3.7.6 Swelling due to surface absorption

Sample size of 50 mm x 50 mm from each board was taken for the estimation of swelling due to surface absorption test. The thickness of each test specimen was measured to an accuracy of ± 0.03 mm at four places one in the centre of each side and approximately 20 mm from the edge. The point at which thickness was measured was clearly and indelibly marked. The average of four readings was recorded. The edges of each test specimen was then sealed by quickly dipping them in turn to a depth of 5 mm in to a shallow bath of molten paraffin wax having a melting point about 55°C , the temperature of bath being about 90°C . The procedure was repeated until the pickup of wax for each test specimen was of the order of 5 gm for each 10 mm thickness of the board. Each test specimen was then immersed in fresh clean water having a temperature of $27 \pm 2^{\circ}\text{C}$, the water renewed for each test. The face being tested was immersed to a depth of approximately 3 mm. care was taken not to wet the top surface of the test specimen. At the end of the 2 hrs each test specimen was withdrawn from water and the wet surface was wiped with a damp cloth, the test specimen

was then laid, wet surface down, for one hour on a non absorbent surface such as glass sheet. The thickness of each test specimen was remeasured at the same points as before and to the same degree of accuracy and the increase in thickness was recorded.

$$\text{Swelling due to Surface absorption (\%)} = \frac{S_2 - S_1}{S_1} \times 100$$

Where,

S_1 = Initial swelling

S_2 = Final swelling

(Anonymous, 1985).

CHAPTER IV

RESULTS AND DISCUSSION

The results emerging from the present investigation entitled, “Assessment for the suitability of *Butea monosperma* Lam. for preparation of particle board” are presented in this chapter. The data obtained from the studies were examined as per procedure laid down in Indian standard specification (IS: 3087-1985). The experimental results obtained during the course of present investigation in respect of physical properties of particle boards have been discussed as under.

4.1 Thickness and moisture content

The data pertaining to the thickness and moisture content of particle boards prepared from *Butea monosperma* is presented in Table 5. The thickness of the board varies from 8.7 to 9.9 mm. Maximum thickness of 9.9 mm was recorded in the particle boards prepared from 8 per cent of PF resin content whereas, minimum thickness of 8.7 mm was observed in the boards prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion.

In case of moisture content of boards, the boards prepared with 8 per cent PF resin content had highest value of 9.6 per cent moisture content and lowest value of 7.5 per cent was reported in the boards prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion (Fig.1). All the boards in respect of moisture content are in confirmation of requirements of specification. Similar type of result has been reported by Singh and Rawat (1990) in the boards prepared from pine saw dust, Nimkar and Singh (2000), Nimkar *et al.* (2003) in the board prepared from *Bambusa polymorpha*. Kshirsagar *et al.* (2012) in boards prepared from *D. strictus*, Parab *et al.* (2013) in boards prepared from sawdust of five hardwood species, Gawali *et al.* (2015) in boards made from *Lantana camara* and Bhadewad (2015) in boards prepared from *Prosopis juliflora* have revealed the moisture content of the board within the limit of IS specification.

Table 5. Physical properties with respect to thickness and moisture content of particle boards prepared from *Butea monosperma*.

Sr. No.	Amount of PF resin used (%)	Thickness of the board (mm)	Moisture content of the board (%)
1	8*	9.9	9.6
2	8**	9.6	9.5
3	8***	9.5	9.1
4	9*	9.7	9.4
5	9**	9.4	9.0
6	9***	9.2	8.8
7	10*	9.4	9.0
8	10**	9.3	8.7
9	10***	9.2	8.5
10	11*	9.5	8.7
11	11**	9.1	8.3
12	11***	8.9	8.0
13	12*	9.1	8.2
14	12**	8.8	7.9
15	12***	8.7	7.5
	Requirement of IS:3087 (1985)	—	5 to 15

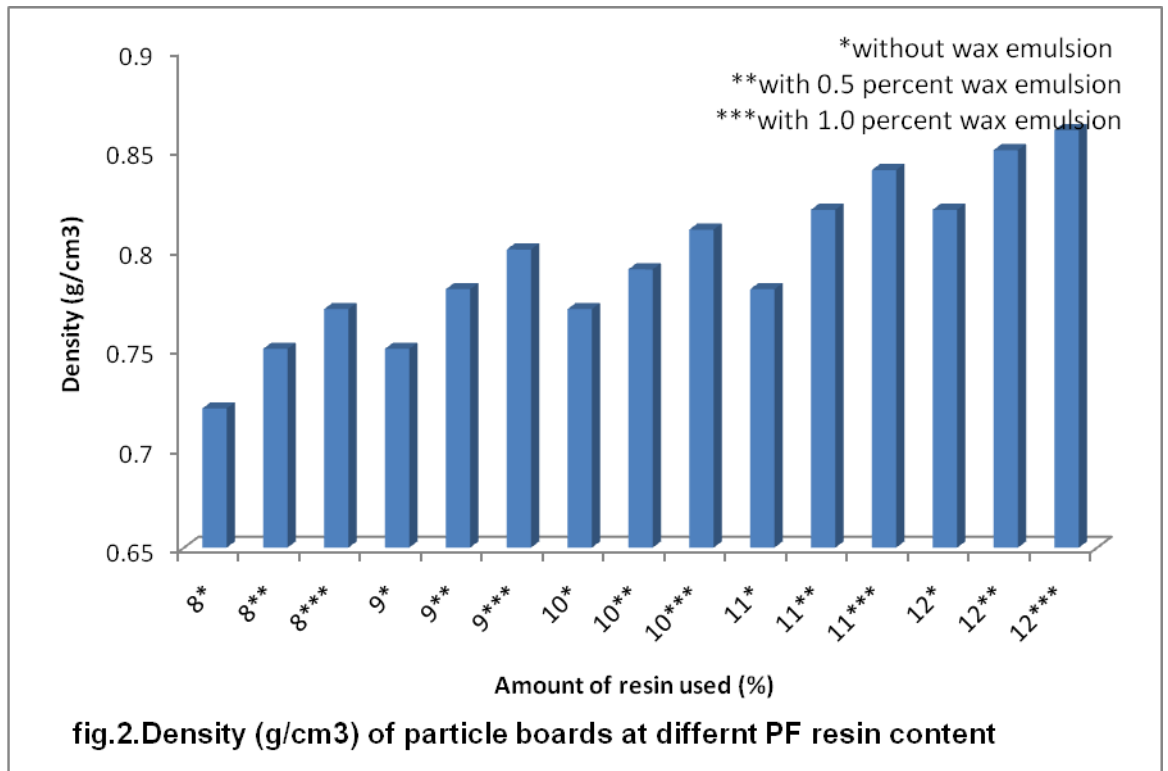
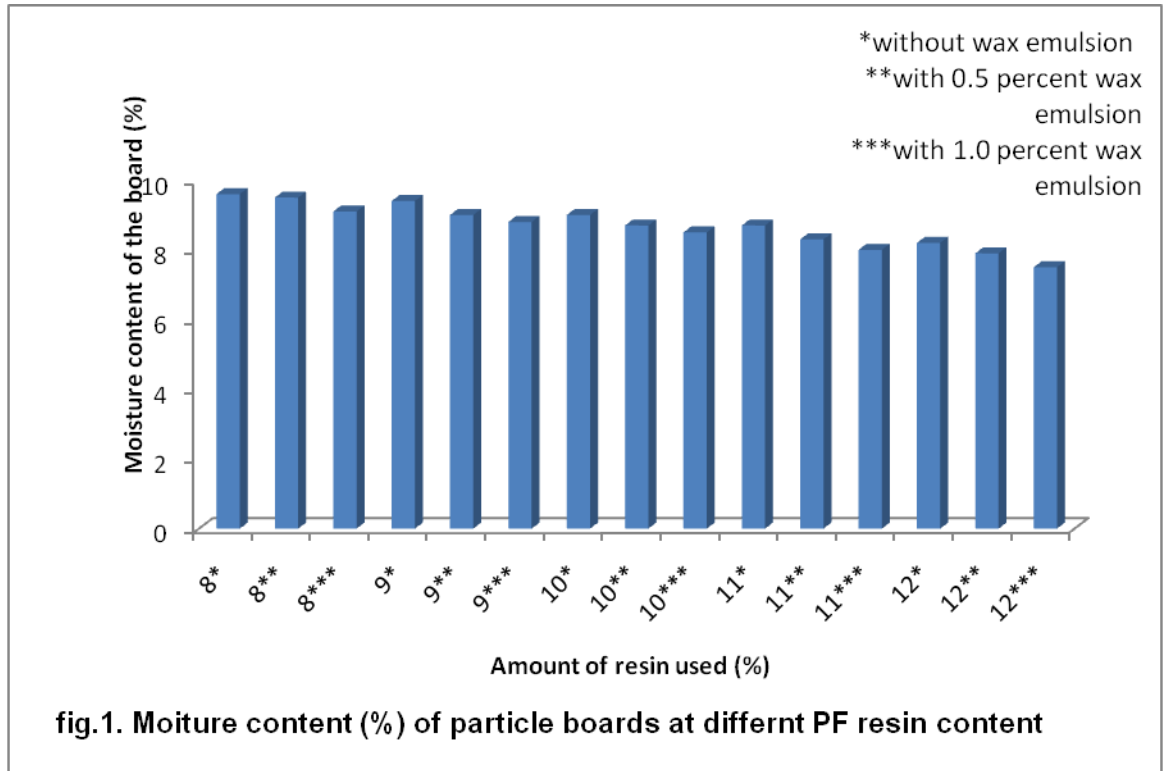
*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

4.2 Density of particle boards

The data on density of particle boards prepared from *Butea monosperma* is presented in Table 6. Density of particle boards varies from 0.72 to 0.86 g/cm³ (Fig. 2). Maximum density of 0.86 g/cm³ was recorded in the particle boards prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion whereas, minimum density of 0.72 g/cm³ was recorded in the particle boards prepared from 8 per cent of PF resin content. Density of all the boards prepared from different PF resin content met the requirement of the IS specification. Similar findings have been



reported by Singh and Rawat (1990), Singh *et al.* (1995), Nimkar *et al.* (2001), Kshirsagar *et al.* (2012), Parab *et al.* (2013), Gawali *et al.*(2015) and Bhadewad (2015). Generally increase in amount of PF resin increases the density of the particle board. Density is an important parameter correlating strength and acoustical properties of particle board.

Table 6. Physical properties with respect to density of particle boards prepared from *Butea monosperma*.

Sr. No.	Amount of PF resin used (%)	Density (g/cm ³)
1	8*	0.72
2	8**	0.75
3	8***	0.77
4	9*	0.75
5	9**	0.78
6	9***	0.80
7	10*	0.77
8	10**	0.79
9	10***	0.81
10	11*	0.78
11	11**	0.82
12	11***	0.84
13	12*	0.82
14	12**	0.85
15	12***	0.86
	Requirement of IS:3087 (1985)	0.5-0.9

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

4.3 Water absorption of particle boards

The values of water absorption (2 hours and 24 hours) of particle boards prepared from *Butea monosperma* are appended in Table 7 and Table 8. Water absorption test of the boards for 2 and 24 hours soaking in water varied from 20.72 to 58.74 and 42.34 to 82.95 per cent, respectively (Fig. 3 and Fig. 4). Boards prepared with 10, 11 and 12 per

cent of PF resin content with 0.5 and 1.0 per cent wax emulsion met the requirement of the IS specification of water absorption for 2 hours and 24 hours. While, the boards prepared with 8 to 10 per cent PF resin content did not meet the requirement of specification. Addition of sizing agent is therefore necessary to achieve this property. With the increase in PF resin content from 8 to 12 per cent and addition of sizing agent, the water absorption values decreased significantly when soaked in water for a certain interval of time. Generally the amount of resin shows significant effect on water absorption of the boards as reported by various workers, Singh and Rawat (1990), Singh *et al.* (1995), Nimkar and Singh (2000), Bhaduri and Majumdar (2008), Kshirsagar *et al.* (2012), Parab *et al.* (2013), Gawali *et al.* (2015) and Bhadewad (2015).

Table 7. Physical properties with respect to water absorption (2hrs) of particle boards prepared from *Butea monosperma*.

Sr. No.	Amount of PF resin used (%)	Sample weight (gm)		Water absorption 2 hrs (%)
		Initial	Final	
1	8*	18.01	28.20	56.57
2	8**	18.20	27.01	48.40
3	8***	18.35	26.45	44.14
4	9*	18.39	26.50	45.73
5	9**	18.44	25.52	38.39
6	9***	18.50	24.35	31.62
7	10*	18.55	24.60	32.61
8	10**	18.59	23.18	24.69
9	10***	18.66	22.86	22.50
10	11*	18.68	23.28	24.62
11	11**	18.70	22.64	21.06
12	11***	18.72	22.15	18.32
13	12*	18.75	22.60	20.53
14	12**	18.77	22.25	18.54
15	12***	18.82	21.95	16.63
	Requirement of IS:3087 (1985)	-	-	≤25

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

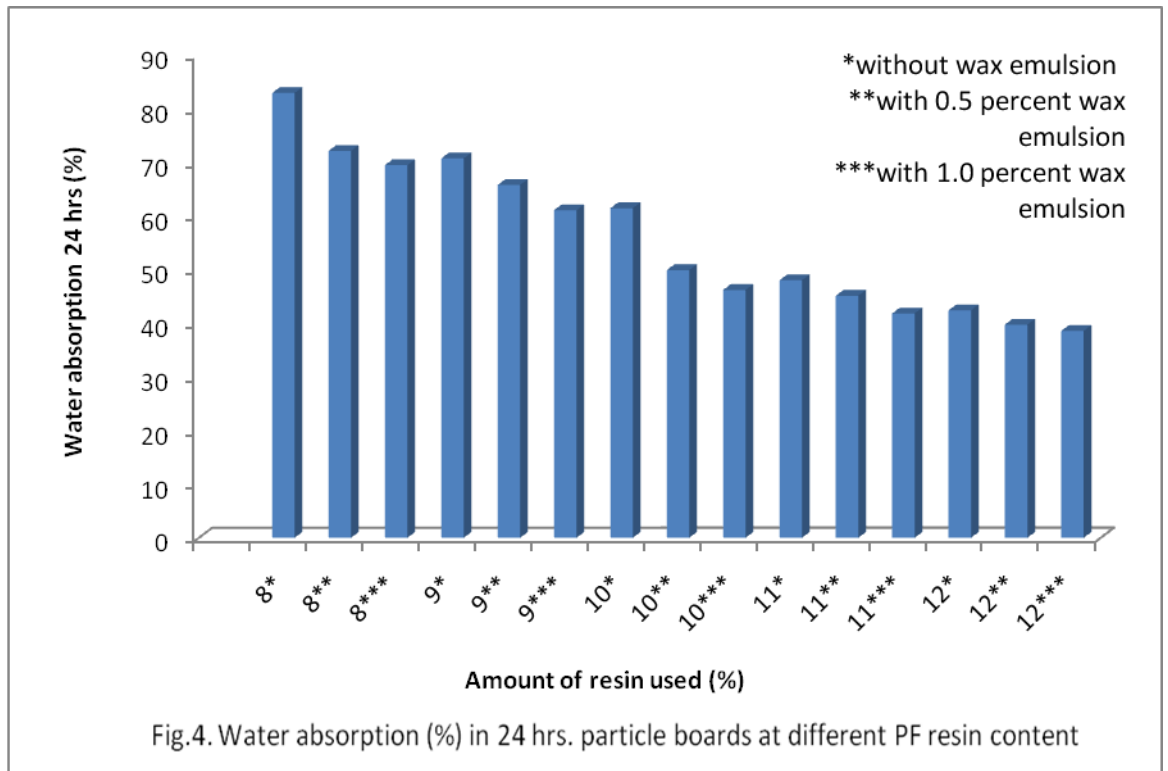
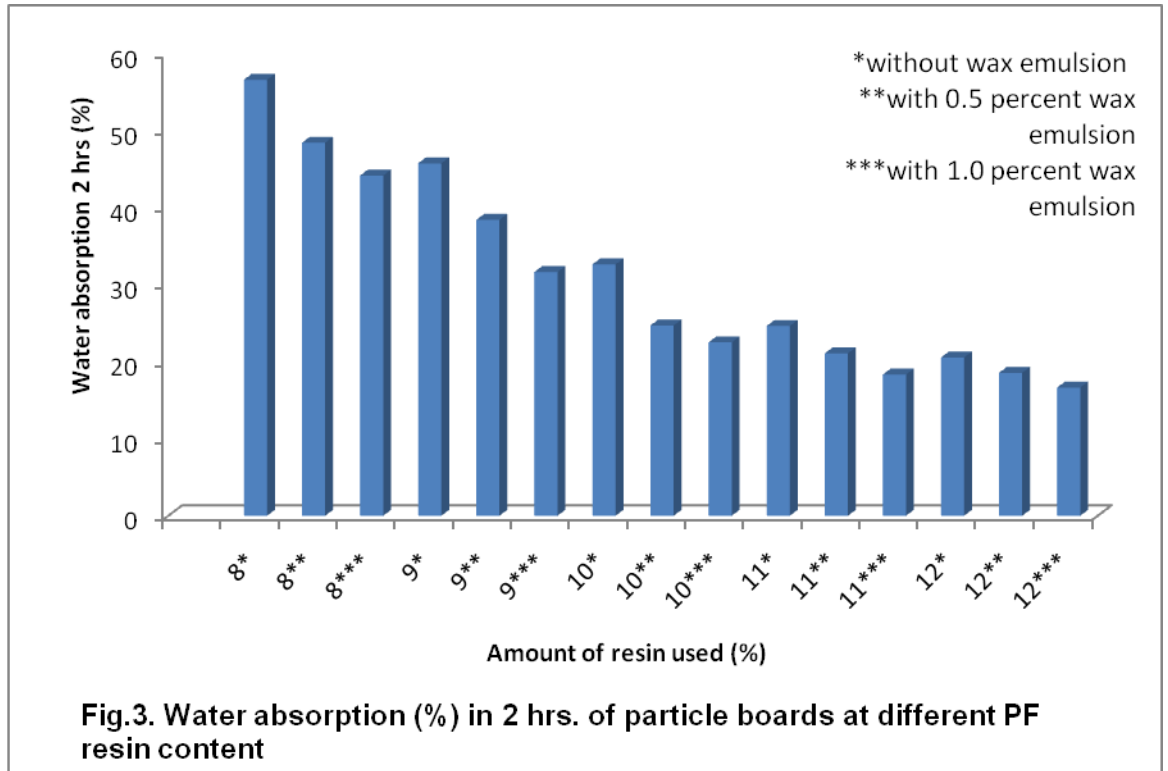


Table 8. Physical properties with respect to water absorption (24hrs) of particle boards prepared from *Butea monosperma*.

Sr. No.	Amount of PF resin used (%)	Sample weight (gm)		Water absorption 24 hrs (%)
		Initial	Final	
1	8*	18.01	32.95	82.95
2	8**	18.20	31.33	72.14
3	8***	18.35	31.10	69.48
4	9*	18.39	31.40	70.74
5	9**	18.44	30.57	65.78
6	9***	18.50	29.80	61.08
7	10*	18.55	29.95	61.45
8	10**	18.59	27.87	49.91
9	10***	18.66	27.25	46.20
10	11*	18.68	27.65	48.01
11	11**	18.70	27.14	45.13
12	11***	18.72	26.55	41.82
13	12*	18.75	26.70	42.40
14	12**	18.77	26.23	39.74
15	12***	18.82	26.08	38.57
	Requirement of IS:3087 (1985)	-	-	≤50

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

4.4 Length and Thickness swelling of particleboards

Physical properties with respect to length and thickness swelling of particle boards prepared from *Butea monosperma* are presented in Table 9 and Table 10. The values for length swelling of the particle boards for 2 hours soaking varied from 0.18 to 0.46 per cent (Fig.5). Maximum value of length swelling was recorded in the boards prepared from 8 per cent PF resin content and minimum in the boards prepared from 12 per cent PF resin content with 1.0 per cent wax emulsion. The values obtained for length swelling of all the boards prepared from different PF resin content met the requirement of the IS specification.

Table 9. Physical properties with respect to length swelling (2hrs) of particle boards prepared from *Butea monosperma*.

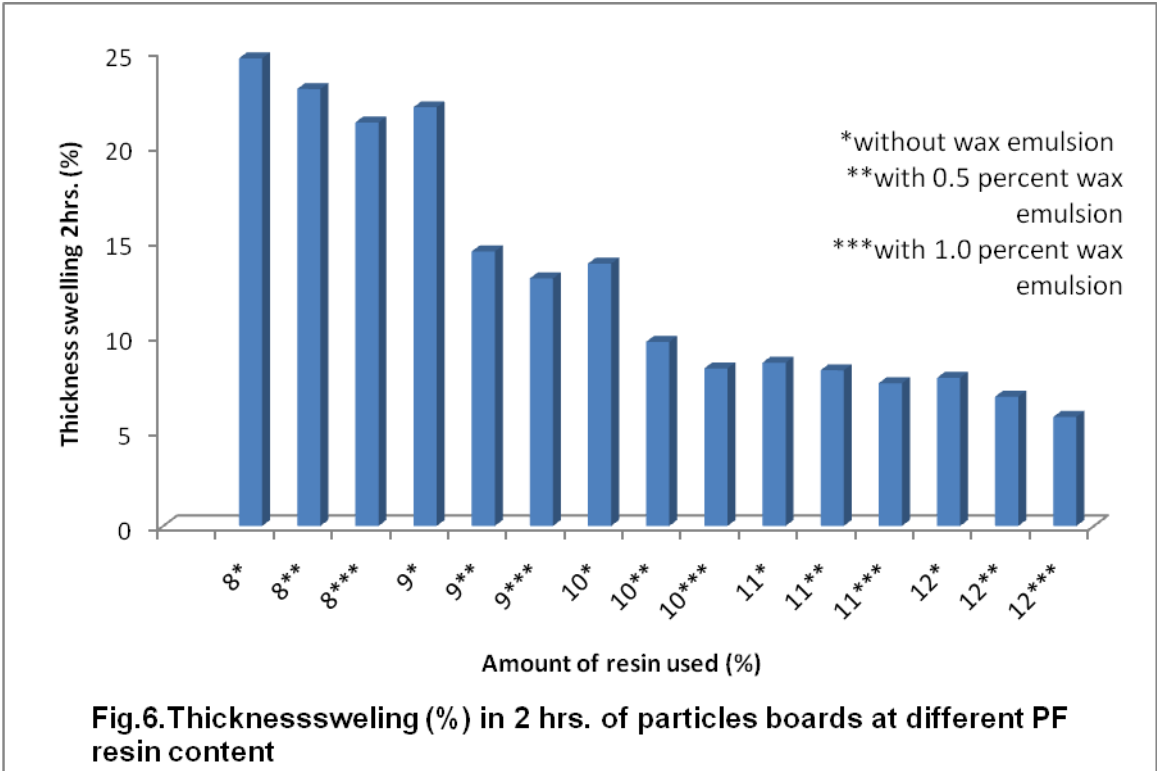
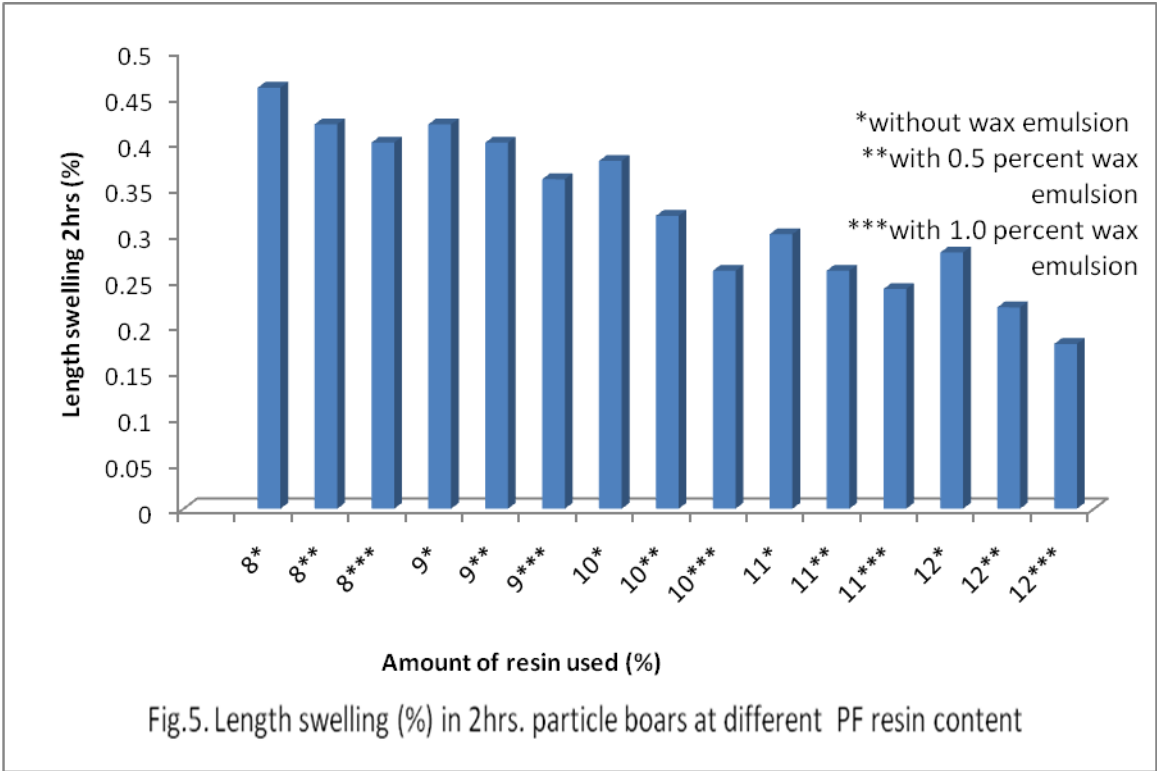
Sr. No.	Amount of PF resin used (%)	Sample size (mm)		Length swelling 2hrs (%)
		Initial	Final	
1	8*	50	50.23	0.46
2	8**	50	50.21	0.42
3	8***	50	50.20	0.40
4	9*	50	50.21	0.42
5	9**	50	50.20	0.40
6	9***	50	50.18	0.36
7	10*	50	50.19	0.38
8	10**	50	50.16	0.32
9	10***	50	50.13	0.26
10	11*	50	50.15	0.30
11	11**	50	50.13	0.26
12	11***	50	50.12	0.24
13	12*	50	50.14	0.28
14	12**	50	50.11	0.22
15	12***	50	50.09	0.18
	Requirement of IS:3087 (1985)	-	-	0.50

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

Maximum thickness swelling was recorded 24.64 per cent in the boards prepared from 8 per cent PF resin content and minimum value of 5.74 per cent in boards made with 12 per cent PF resin content with 1.0 per cent wax emulsion (Fig. 6). The values reported for thickness swelling of the board exceeded the minimum requirement up to 10 per cent PF resin content. However, requirement as per specification was met with the boards prepared from 10 to 12 per cent PF resin content with 0.5 and 1.0 per cent wax emulsion. With increase in PF resin content and addition of sizing agent, the values of length and thickness swelling of boards decreased when soaked in water for a period of 2 hours. Findings emerged



out of this study were in line with findings given by Beech (1975) who reported irreversible swelling was reduced by increasing the PF resin content and reversible swelling was affected by wood species and grain orientation. Differences in length and thickness swelling of particle boards prepared from different resin content has also been reported by Singh and Rawat (1990), Singh and Gupta(1982), Singh *et al.* (1995), Kshirsagar *et al.*(2012), Parab *et al.*(2013, Gawali *et al.*(2015) and Bhadewad (2015).

Table 10. Physical properties with respect to Thickness swelling (2 hrs) of particleboards prepared from *Butea monosperma*

Sr. No.	Amount of PF resin used (%)	Sample size (mm)		Thickness swelling 2hrs (%)
		Initial	Final	
1	8*	9.9	12.34	24.64
2	8**	9.6	11.81	23.02
3	8***	9.5	11.52	21.26
4	9*	9.7	11.84	22.06
5	9**	9.4	10.76	14.46
6	9***	9.2	10.40	13.04
7	10*	9.4	10.70	13.82
8	10**	9.3	10.21	09.70
9	10***	9.2	09.97	08.30
10	11*	9.5	10.10	08.60
11	11**	9.1	9.85	08.20
12	11***	8.9	9.57	07.52
13	12*	9.1	9.81	07.80
14	12**	8.8	9.40	06.81
15	12***	8.7	9.20	05.74
	Requirement of IS:3087 (1985)	-	-	≤10.00

**without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

4.5 Swelling due to surface absorption of particle boards

Perusal of data from the Table 11 revealed that the range of values for swelling due to surface absorption of particle boards for 2 hours was found to be 06.09 to 26.46 per cent (Fig. 7). Maximum value of 26.46 per cent swelling due to surface absorption was observed in the board prepared from 8 per cent PF resin content.

Table 11. Physical properties with respect to swelling due to surface absorption (2 hrs) of particle boards prepared from *Butea monosperma*

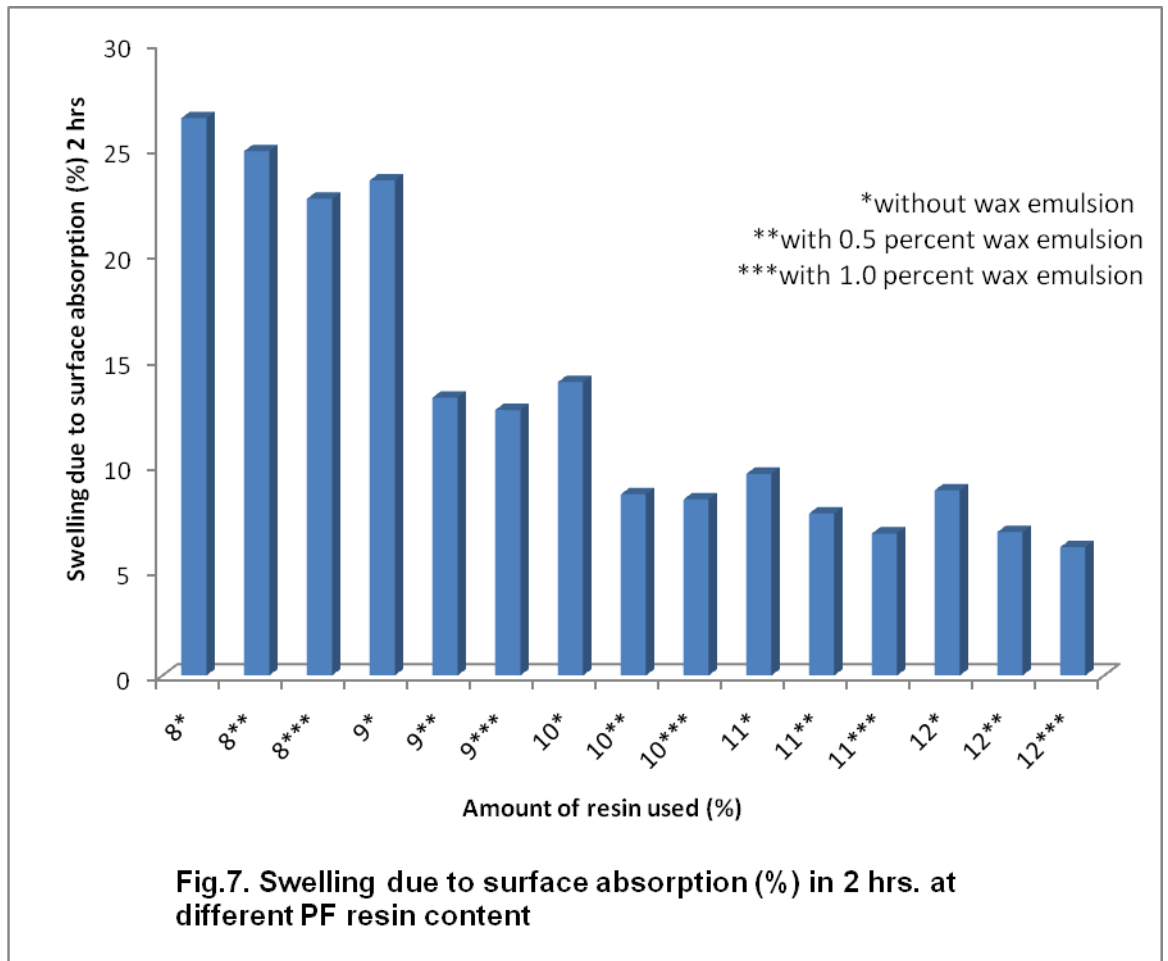
Sr. No.	Amount of PF resin used (%)	Sample size (mm)		Swelling due to surface absorption 2hrs (%)
		Initial	Final	
1	8*	9.9	12.52	26.46
2	8**	9.6	11.99	24.89
3	8***	9.5	11.65	22.63
4	9*	9.7	11.98	23.50
5	9**	9.4	10.64	13.19
6	9***	9.2	10.36	12.60
7	10*	9.4	10.71	13.93
8	10**	9.3	10.10	08.60
9	10***	9.2	9.97	08.36
10	11*	9.5	10.41	09.57
11	11**	9.1	9.70	07.69
12	11***	8.9	9.50	06.74
13	12*	9.1	9.90	08.79
14	12**	8.8	9.40	06.81
15	12***	8.7	9.23	06.09
	Requirement of IS:3087 (1985)	-	-	≤09.00

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion

Minimum swelling due to surface absorption 06.09 per cent was observed when the board prepared from 12 per cent PF resin content



with 1.0 per cent wax emulsion. The values obtained for swelling due to surface absorption decreases as the PF resin content increases with addition of sizing agent. The particle board prepared with 10, 11 and 12 per cent PF resin content with 0.5 and 1.0 per cent wax emulsion, met the said property other boards could not meet the requirement of the specification. The present findings were in close conformity with those of Singh and Rawat (1990), Singh *et al.* (1995), Nimkar and Singh (2000), Nimkar *et al.* (2003), Kshirsagar *et al.*(2012), Parab *et al.*(2013) ,Gawali *et al.* (2015) and Bhadewad (2015).

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation entitled, "Assessment for the suitability of *Butea monosperma* Lam. for preparation of particle board" was carried out during the year 2016-2018 at Department of Forestry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The study was conducted with the following objective:

1. To study the suitable percentage of PF resin content for the preparation of particle board from *Butea monosperma*.
2. To evaluate the physical properties of particle boards prepared from *Butea monosperma*.

Butea monosperma as a lignocellulosic raw materials was collected from the campus of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Chemical raw material namely phenol, formaldehyde and sodium hydroxide were used for the preparation of phenol formaldehyde resin and paraffin wax, liquid ammonia and stearic acid for the preparation of wax emulsion as sizing agent. The boards were prepared from different PF resin content i.e. 8, 9, 10, 11 and 12 per cent with 0.5 and 1.0 per cent wax emulsion. Physical properties were examined by testing the boards as per the procedure laid down in IS: 2380 (Anonymous, 1977) and IS: 3087 (Anonymous, 1985).

The results of this study are summarized as under:

1. Thickness of the particle boards varied from 8.7 to 9.9 mm. Maximum thickness of 9.9 mm was recorded in particle boards prepared from 8 per cent of PF resin content and minimum thickness of 8.7 mm was observed in the boards prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion.
2. Moisture content of the boards varied from 7.5 to 9.6 per cent. Maximum moisture content of 9.6 per cent was recorded in particle boards prepared from 8 per cent of PF resin content and minimum

moisture content of 7.5 per cent was observed in boards prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion. All the boards met the requirement of the IS specification in respect of moisture content.

3. Density of the particle boards varied from 0.72 to 0.86 g/cm³. Maximum density of 0.86 g/cm³ was recorded in particle board prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion whereas, minimum density of 0.72 g/cm³ was recorded in the boards prepared from 8 per cent of PF resin content. Density of all the boards met the requirement of the IS specification.
4. Water absorption test of the boards for 2 hours and 24 hours soaking in water varied from 20.72 to 58.74 and 42.34 to 82.95 per cent, respectively. Boards prepared from 10 per cent PF resin content with 0.5 and 1.0 per cent wax emulsion, 11 and 12 per cent PF resin content with 0.5 and 1.0 per cent wax emulsion met the requirement of IS specifications. Increase in the amount of PF resin and addition of sizing agent shows significant effect on water absorption property.
5. The range of length swelling varied from 0.18 to 0.46 per cent. Maximum length swelling of 0.46 per cent was recorded in the board prepared from 8 per cent of PF resin content whereas, minimum value of 0.18 per cent of length swelling was observed in the board prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion. The values obtained for length swelling of all the boards prepared from different PF resin content met the requirement of the IS specification.
6. Thickness swelling varied from 05.74 to 24.64 per cent. Maximum thickness swelling of 24.64 per cent was recorded in the board prepared from 8 per cent of PF resin content and minimum value of 05.74 per cent thickness swelling was observed in the board prepared from 12 per cent of PF resin content with 1.0 per cent wax emulsion. The values reported for thickness swelling of the board exceeded the minimum requirement in the boards prepared with 8 to 10 per cent.

However, requirement as per specification was attained with 10 per cent PF resin content with 0.5 per cent wax emulsion.

7. Swelling due to surface absorption after 2 hour ranges between 06.09 to 26.46 per cent. The minimum swelling due to surface absorption of 06.09 per cent was observed in boards prepared from 12 per cent PF resin content with 1.0 per cent wax emulsion and maximum swelling due to surface absorption of 26.46 per cent was observed in boards prepared form 8 per cent PF resin content. The swelling due to surface absorption decreases as the PF resin content increases with addition of wax emulsion. The board prepared with 10 per cent PF resin content with 0.5 per cent and 1.0 per cent wax emulsion, 11 and 12 per cent PF resin content with 0.5 and 1.0 per cent wax emulsion met the requirements of IS specification in respect of swelling due to surface absorption property.
8. From the above study, it is concluded that *Butea monosperma* can be utilized for producing medium density particle boards. The physical properties of the boards produced with phenol formaldehyde resin confirmed to IS specification for medium density general purpose particle board. In this investigation varying amount of phenol formaldehyde resin with wax emulsion were used for making particle boards from *Butea monosperma*. As the amount of PF resin increased, density of the boards were increased while, moisture content, water absorption, length and thickness swelling and swelling due to surface absorption properties were reduced. Satisfactory boards were prepared by using 10 per cent PF resin content with 0.5 per cent and 1.0 per cent wax emulsion , 11 and 12 per cent phenol formaldehyde resin content with 0.5 and 1.0 per cent wax emulsion met the requirement in respect of physical properties as specified in IS: 3087 (1985).

CHAPTER VI

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APPENDIX

Physical properties of particle boards prepared from *Butea monosperma* Lam.

Amount of PF resin used (%)	Thickness of the board (mm)	Moisture content of the board (%)	Density (g/cm ³)	Water absorption on 2 hrs (%)	Water absorption on 24 hrs (%)	Length swelling 2 hrs (%)	Thickness swelling 2 hrs (%)	Swelling due to surface absorption on 2 hrs (%)
8*	9.9	9.6	0.72	58.74	82.95	0.46	24.64	26.46
8**	9.6	9.5	0.75	49.45	74.56	0.42	23.02	24.89
8***	9.5	9.1	0.77	44.14	69.48	0.40	21.26	22.63
9*	9.7	9.4	0.75	45.73	70.74	0.42	22.06	23.50
9**	9.4	9.0	0.78	38.39	65.78	0.40	14.46	13.19
9***	9.2	8.8	0.80	33.02	62.21	0.36	13.04	12.60
10*	9.4	9.0	0.77	36.17	62.80	0.38	14.89	13.93
10**	9.3	8.7	0.79	28.77	53.09	0.32	10.64	08.60
10***	9.2	8.5	0.81	25.93	50.42	0.26	08.91	08.36
11*	9.5	8.7	0.78	29.12	51.98	0.30	09.68	09.57
11**	9.1	8.3	0.82	24.27	48.55	0.26	08.79	07.69
11***	8.9	8.0	0.84	22.11	45.35	0.24	07.86	06.74
12*	9.1	8.2	0.82	25.70	47.30	0.28	08.79	08.79
12**	8.8	7.9	0.85	22.16	43.31	0.22	06.81	06.81
12***	8.7	7.5	0.86	20.72	42.34	0.18	05.74	06.09
Requirement of IS:3087 (1985)		5 to 15	0.5-0.9	≤25	≤ 50	0.50	≤10.00	≤09.00

*without wax emulsion

**with 0.5 per cent wax emulsion

***with 1.0 per cent wax emulsion