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PREDICTING THE SUITABILITY OF A WOOD SPECIES OF KNOWN DENSITY FOR PRODUCING DESIRED DENSITY PARTICLEBOARD

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CONTENTS

	Contents	i
	Foreword	iv
	Summary	1
1	Introduction	2
2	Wood density and influencing factors	3
	2.1 Wood density, specific gravity and moisture	4
	2.2 Wood density, porosity and extractives	5
3	Wood density and board properties	5
4	Compression ratio, compactness of particles and board properties	7
5	Development of procedures to determine mass/weight and volumetric compositions of a particleboard panel	7
	5.1 Procedures to determine Mass/Weight composition of a board (Development of equations)	8
	5.1.1 Mass of Air dry (AD) board [MB_{AD}]	8
	5.1.2 Mass of moisture (m_{AD}) in a board	8
	5.1.3 Mass of oven dry (OD) board [MB_{OD}]	9
	5.1.4 Mass of OD binder [Mb_{OD}] in a board	9
	5.1.5 Mass of OD additives [MA_{OD}] in a board	9
	5.1.6 Mass of OD particles [MP_{OD}] in a board	10
	5.1.7 Mass of particles at desired mc, say 12%, i.e., MP 12%	10
	5.2 Determining the mass composition of a board of given parameters. (Application of developed equations)	11
	(i) Board parameters (An Example)	11
	(ii) Board components determination (Solution)	11

5.3 Procedures to determine volumetric composition of AD board (Development of equations) 12

5.3.1 Volume of AD board (general) 12

5.3.2 Volume occupied by AD particles in a board 13

5.3.3 Volume occupied by air in AD board (Va_{AD}) 13

5.4 Determining volumetric composition of a board of given parameters (Application of developed equations) 14

(i) Board parameters (An example) 14

(ii) Volumetric Board Components Determination (Solution) 14

6 Compression ratio 16

7 Theoretical thickness of board 16

8 Suitability grading of different density woods for producing different density particleboard's 16

8.1 Methodology to determine the suitability of 720 kg/m^3 density wood for producing 13 mm thick, 600 kg/m^3 density board 17

8.2 Which density particleboard (13 mm thick) of acceptable properties can be produced from 720 kg/m^3 density wood (An Example) 17

8.3 Acceptable quality particleboards 18

9 References 19

10 Appendices

10.1 Mass of (AD) particles in boards of density 400-1000 Kg/m^3 21

10.2 Suitability grading of different density woods for producing particleboard of density 400 Kg/m^3 22

10.3 Suitability grading of different density woods for producing particleboards of density 440 Kg/m^3 23

10.4 Suitability grading of different density woods for producing particleboards of density 480 Kg/m^3 24

10.5 Suitability grading of different density woods for producing particleboards of density 520 Kg/m^3 25

10.6 Suitability grading of different density woods for producing particleboards of density 560 Kg/m^3 26

10.7 Suitability grading of different density woods for producing particleboards of density 600 Kg/m^3 27

10.8 Suitability grading of different density woods for producing particleboards of density 640 Kg/m^3 28

10.9 Suitability grading of different density woods for producing particleboards of density 680 Kg/m^3 29

10.10 Suitability grading of different density woods for producing particleboards of density 720 Kg/m^3 30

10.11 Suitability grading of different density woods for producing particleboards of density 760 Kg/m^3 31

10.12 Suitability grading of different density woods for producing particleboards of density 800 Kg/m^3 32

10.13 Suitability grading of different density woods for producing particleboards of density 840 Kg/m^3 33

10.14 Suitability grading of different density woods for producing particleboards of density 880 Kg/m^3 34

10.15 Suitability grading of different density woods for producing particleboards of density 920 Kg/m^3 35

10.16 Suitability grading of different density woods for producing particleboards of density 960 Kg/m^3 36

10.17 Suitability grading of different density woods for producing particleboards of density 1000 Kg/m^3 37

10.18 Suitability of different wood density species for producing desired density particleboard 38

11 Wood producing trees in Pakistan and their wood densities 39

FOREWORD

In order to assist the Particleboard industry in Pakistan, the Forest Products Research Division at the Pakistan Forest Institute, Peshawar, has planned to produce a series of Technical Bulletins containing information on different aspects of board properties and manufacturing. The First Technical Bulletin "Designing a Particleboard Panel of Desired Parameters" (PB: TB-1), by S. M. Yasin and T. A. Qureshi, was published in 1992, which contained information on different aspects of particleboard designing and techniques to determine wood density, moisture etc.

This Technical Bulletin "Predicting the Suitability of a Wood Species of Known Density for Producing Desired Density Particle-board" (PB: TB-2), is designed to provide necessary information and data base to predict the suitability of a specific density wood for producing specific density particleboard. Although low density particleboards are neither commonly produced nor used, however information on such boards is provided for use when desired.

I would like to thank the staff and officers of the Forest Products Division, who contributed to the completion of this work, and to the Winrock International/Forestry Planning and Development Project, for assistance in the editing and publication of this bulletin.

Comments and suggestions to improve the information given in this technical bulletin from the industry, would be highly appreciated.

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PREDICTING THE SUITABILITY OF A WOOD SPECIES OF KNOWN DENSITY FOR PRODUCING DESIRED DENSITY PARTICLEBOARDS

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SUMMARY

A large number of hardwoods available in Pakistan have no commercial importance other than fuel. Their acceptance by the particleboard manufacturers is hindered by their high density which lowers the properties of medium density particleboards when produced from these woods for general use.

Realizing the importance of compression ratio and the effects of wood density on board properties, a trial was made to develop a data base to predict the suitability of a wood species for producing particleboard panels of desired densities. For producing such a data base some mathematical procedures were developed to process basic information on different parameters of particleboard panels of density ranging from 400 to 1000 Kg/m^3.

For grading the suitability of different wood species of density between 280 and 1000 Kg/m^3 for producing particleboard panels of density 400 to 1000 kg/m^3, data was developed on parameters such as compression ratio, compactness of particles, volume occupied by particles, inter-particle voids, and expected/ theoretical thickness of board. All the computations and tabulations were done by using Lotus 1-2-3, version 3.1, and the text by using Wordperfect version 5.1, software.

PREDICTING THE SUITABILITY OF A WOOD SPECIES OF KNOWN DENSITY FOR PRODUCING DESIRED DENSITY PARTICLEBOARDS

INTRODUCTION

Particleboards are mainly categorized on the basis of their density, as low density ($\leq$ 600 Kg/m^3), medium density (from 600 to 800 Kg/m^3), and high density ($\geq$ 800 Kg/m^3) particleboards. The high density and low density particleboards are neither commonly used nor commercially manufactured by the local industry. Their use because of their low strength is limited to applications involving heat and sound insulations.

The medium density particleboards have wide applications because of their suitability for varying end uses like furniture manufacture, false partitioning, false ceiling, wall panelling, kitchen cabinets and wardrobes, etc. These are used even for insulation purposes where the density is decreased by artificial means, e.g., by drilling holes in the boards. The insulating potential of the boards is further increased by allowing air spaces between the board and the wall against which they are fixed during panelling.

The primary choice of particleboard manufacturers for producing medium density boards is, softwoods followed by low density hardwoods. The main reason for such preference is that low density woods are versatile raw material for producing desired density boards. The high density woods produce high density boards having high strength and other properties. Unfortunately, such boards have limited uses because of high manufacturing cost, heavy weight, cutting tool hazards, high cost of transportation and handling difficulties during working.

Because of insufficient supply of softwoods in Pakistan, even for building industry, the particleboard manufacturers have the only choice to use bagasse and hardwoods such as low quality shisham (Dalbergia sissoo); mulberry (Morus alba); mango (Mangifera indica); eucalyptus spp., i.e., E. Camaldulensis, E. tereticornis, E. globulus, E. Glandulosa etc.; phulai (Acacia modesta), babul (Acacia nilotica); bakain (Melia azedarasch); siris (Albizzia lebbek); pilu (Salvadora oleoides); ghaz (Tamarix aphylla); lai (Tamarix dioica); ber (Zizyphus mauritiana), mesquite Prosopis spp., like Prosopis juliflora, Prosopis cineraria, Prpsppis specigera; Poplars Populus ciliata, P. euphretica, P. euramericana, P. alba, P. nigra; Ipil Ipil (Leucenea leucephela), etc.

Among these species, mango wood is extensively being used by some manufacturers because of its adequate supply and comparatively lower density. Majority of the hardwood species are reluctantly accepted by the local particleboard manufacturers because of their

inadequate supplies and the unpredictable properties of the board derived from them.

This technical bulletin has been prepared to develop a data base for achieving the following objectives:

- to predict the suitability of a wood species of known density for producing particleboards of desired density.
- to predict the appropriate panel density obtainable from a wood species.
- to predict strength of a board derived from a wood species by predicting the compactness of particles.

To achieving these objectives data on the following parameters was developed:

- Mass of particles of different density woods required for producing boards of density 400-1000 Kg/m^3 (with intervals of 40).
- Compression ratios between board densities 400 - 1000 Kg/m^3 and wood densities 280 - 1000 kg/m^3.
- Volume occupied by particles in a board derived from different density woods.
- Volume occupied by voids/interparticle air spaces in boards derived from different density woods
- Theoretical/expected board thickness and its deviation from nominal/desired thickness.

2. WOOD DENSITY AND INFLUENCING FACTORS

Wood is a cellular structure containing wood substance, air spaces (voids), moisture and chemical substances or extractives, depending upon the species and nature of wood, (i.e., sapwood or heartwood). The density of wood indicates its lightness or heaviness and is expressed as mass per unit volume at specific moisture content i.e., D = M/V. It is measured as weight of wood at a specific moisture content contained in a unit volume, e.g., pounds per cubic foot, kilograms per cubic meter or grams per cubic centimeter (i.e., lbs/cft., kg/m^3 or gm/cm^3).

It is a common phenomenon for wood density to differ significantly within a tree as well as within species. Many factors, like location in a tree, geographic location, genetic sources and site related factors, such as moisture, availability of sun light,

nutrients, wind and temperature etc., lead to variation in density and specific gravity of wood. The influences of these factors occur in combination, and it is difficult to separate them as independent effects. Inconsistencies of relationship between specific gravity and its sources of variation indicate the complex interactions among these factors. The elevation, slope, latitude, soil type, stand composition and spacing etc., also affect the wood density within a species (Zobel 1956, Paul 1963, Koch et.al. 1968).

Within a tree, the butt logs tend to have higher density than the logs cut higher in the main stem. In some species, the wood near the base of a tree may be lighter than the wood towards the top. Generally in softwoods, the density decreases with height and increases with distance from the pith (Mitchell 1964). The density of juvenile wood is usually lesser than that of mature wood. The specific gravity of compression as well as tension wood is greater than that of normal wood (upto 40%). However, in some cases, the density of compression and normal wood may not differ significantly. The specific gravity of summer wood is greater than that of spring wood (Steiner and Sybertz, 1975).

2.1 Wood Density, Specific Gravity and Moisture

The density of wood is expressed as, density, basic density, or specific gravity.

Density in general is the quantity of air dry wood contained in a unit volume, i.e., air dry mass/air dry volume. The density of wood can be measured at any moisture content level. An increase in moisture content increases the weight of wood considerably, resulting into increase in its density. While recording wood density, mention of moisture content is, therefore unavoidable.

Basic density of wood is a ratio between its oven dry weight and green volume. It indicates the oven dry content in unit volume of water saturated wood. The basic density characterization, being based on oven dry weight has many advantages in comparison to density.

Specific gravity of a material is a ratio between its weight and the weight of an equivalent volume of water at the same temperature. Specific gravity is also defined as the ratio between the density of wood (at specified moisture content), and the density of water at 4^0 C. The density of water at 4^0 C is taken as 1 gm/cm^3 or 62 lbs/cft.

In any case, while determining wood density, weight and volume of wood should be taken as, (a) green weight & green volume or, (b) oven dry weight & green volume or, (c) weight & volume at specific moisture content. This is because loss of moisture from wood changes its weight, volume & ultimately the density as shown below:

	Weight		Volume		Density	
	lb	kg	cft	m^3	lb/cft	kg/m^3
- green	22	9.77	.50	.014	-	-
- at 12% MC	18	8.00	.45	.013	-	-
- oven dry	15	6.66	-	-	-	-
- oven dry weight/ green volume					30	480
- oven dry weight/ volume at 12% MC					33	528
- weight at 12% MC/ volume at 12% MC					40	640
- green weight/ green volume					44	704
- green weight/ volume at 12% MC					48	782

Density of some local timbers at 12% moisture content was collected from the literature and is given in Appendix 11, [Pearson et.al. 1932; Siddiqui et.al. 1978, 82, 83, 85, 86, 88, Ayaz 1981]

2.2 Wood Density, Porosity and Extractives

Wood density is considerably influenced by the presence of voids and the infiltration materials or extractives such as terpene, resins; polyphenols: tannins, sugars and oils; inorganic compounds, such as silicates, carbonates and phosphates. These are mainly present in cell walls, where they are deposited during the maturation of the secondary wall and heartwood formation. The heartwood has a higher concentration of extractives than sapwood resulting into increasing its density.

The extractives in wood varying from about 3% to over 30% of its oven dry weight, cause variation in wood specific gravity in the range of 1.45 to 1.54. The specific gravity of wood from which extractives have been removed tends to be more uniform. If the volume of voids, extractives and moisture in wood are avoided, the specific gravity of wood substance is nearly the same for all species, and has a value of about 1.5 (Wilfong 1966; Tarash and Saucier 1967). The density values for the same wood species are also influenced by precision of equipment used in measuring weight and volume of wood.

3. WOOD DENSITY AND BOARD PROPERTIES

The density of the raw material is the most critical parameter while determining the potential of a given species for particle-board manufacturing. The compaction of mat in the hot press, and the raw material density control the final density of a particle-

board panel. A change in any of these factors requires an adjustment of the other if the board density is required to be kept constant. Likewise, either of these factors can be changed to increase or decrease the average board density.

However, a higher density panel produced by increasing the compaction level will not have properties equal to the same density panel produced from higher density wood particles. Isolation of the effect of individual processing parameters on particleboard properties is extremely difficult and can, at best, only be approximated, (Kelley 1977; Maloney 1977).

The density of the wood species in particleboard manufacturing is related to adhesive consumption, the bulk of the particles, the strength and surface smoothness of the board. As a very general conclusion, woods of higher density produce smaller area of particles, requiring smaller amount of adhesive. While manufacturing a particleboard panel from low and high density woods separately, if the quantity of binder used is the same, the amount of binder received per particle would be comparatively lesser in low density wood particles. This is because of greater number of particles contained in the same weight of low density wood. Basing upon the quantity of binder per particle, the higher density wood should produce stronger board. Contrarily, the board derived from high density wood is weaker than that of lower density wood. This is because of lower density of the board made from high density wood particles. The strength of such a board can be increased by increasing its density, (Milton 1968).

For achieving a specific level of strength in a particleboard panel, it is required to produce high density board from higher density wood. However in a lower density wood, a board of comparatively lower density can offer the same level of strength (Klauditz and Stegmann 1958).

The behavior of different wood species of varying specific gravities, in producing particleboards of different specific gravities, containing different quantities of resin indicate that board density is of primary influence and resin content of secondary, in controlling board strength. The interruptions to the relation between the specific gravity of wood and strength properties of particleboard may be due to variation in the specific gravity of the wood within a species (Turner 1954).

In general it is concluded that among the large number of factors influencing particleboard properties, wood density is of prime importance as it controls the weight and volume compositions responsible for the compactness of particles, board density and strength. The preferential demand of low density woods by the particleboard manufacturers is based on their higher rate of compressibility in comparison to high density woods. Because of this reason, the low density woods are a versatile raw material for

producing boards of desired densities. In case of converting high density woods into particleboards, the particles are not enough to fill the considerable volume of a mat, resulting in poor particle compaction and bonding, and low strength in a board.

4 COMPRESSION RATIO, COMPACTNESS OF PARTICLES AND BOARD PROPERTIES

The compression ratio i.e., board density/wood density is an indicator of compaction of particles and the volume of air spaces in a board. A board having lower specific gravity than the species from which it is made, contains more air spaces (voids) than the species did in its normal state. As a result, voids occurring between the particles (interparticle spaces), cause stress concentrations which lower the strength of the board. It has been investigated that if the board density and resin content are held constant, the strength of boards derived from low density wood species would be higher than those made from high density woods (Prieser and Thielman 1954).

The strength properties of board improve with an increase in its density. This can be accomplished by increasing mat compression resulting into reducing the number and extent of voids in the board (Gatchel et. al. 1966). When the wood density is equal to the board density, the compression ratio is one. At this stage the board is compact enough to develop some strength. An increase in compression ratio has generally favorable effect on mechanical properties like internal bond strength, MOR and MOE. This indicates that compression ratio is an indicator of interparticle pressure during bonding. The lower compression ratio relates to insufficient and poor interparticle pressure or compactness and vice versa (Rice and Carey 1978).

Compression ratio in the range of 1.2 to 1.3 is generally recommended to produce acceptable strength in a board. At this stage the interparticle air spaces are removed completely, however the intraparticle air spaces are expected to be present. The boards of compression ratio greater than 1.3 offer further higher strength provided the quantity of binder is enough and properly cured. It has been investigated that the boards pressed at a compression ratio value of 1.6 offer higher Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) than those made at 1.2 at the same board density (Vital et. al. 1974).

5. PROCEDURES TO DETERMINE MASS AND VOLUMETRIC COMPOSITIONS OF A PARTICLEBOARD PANEL

Data for suitability grading of woods of different densities for producing particleboards was developed in the form of para-

meters such as voids volume, interparticle pressure/compactness of particles in terms of compression ratio and theoretical thickness of board. These parameters of a particleboard panel are based on its volumetric composition which in turn depends upon its mass composition.

5.1 Procedures to determine mass composition of a board (Development of equations)

The quantitative composition of a board consists of particles, binder, additives and moisture. The quantities of these board components depend upon design parameters such as board size, rate of binder and additive addition, moisture in board and board density. The board available in the market always contains some moisture. The weight and volume of such a board and its components are called air dry (AD) mass and volumes. The quantities of different board components after eliminating their moisture are termed as oven dry (OD) quantities.

5.1.1 Mass of Air dry (AD) board(MB_{AD})

The particleboard panels available in the market contain some moisture i.e., 10 - 12% of their air dry weight. The weight/mass of a board at this moisture level is called air dry weight and is calculated as under:

$$MB_{AD} = [D \times V]_{AD} \ldots (Equation\ 1)$$

Where MB_{AD} = mass of air dry board
D_{AD} = density of air dry board
= mass per unit volume (M/V)
V_{AD} = volume of air dry board
= length x width x thickness

5.1.2 Mass of moisture (m_{AD}) in AD board

The moisture content of AD board available in the market is calculated as under:

$$m_{AD} = [MB \times \frac{mcB}{100}]_{AD} \ldots (Equation\ 2)$$
$$= [DV \times \frac{mcB}{100}]_{AD}$$

Where MB_{AD} = mass of air dry board.
$(mcB)_{AD}$ = moisture expressed as % of AD board
DV_{AD} = density x volume of board
m_{AD} = moisture in AD board

5.1.3 Mass of oven dry (OD) board (MB_{OD})

$$MB_{OD}=MB_{AD}-m_{AD}\ldots(Equation\ 3)$$
$$=[DV-(DV\times\frac{mcB}{100}]_{AD}$$

Where MB_{OD} = mass of oven dry board

5.1.4 Mass of OD binder (Mb_{OD}) in a board

METHOD I

$$Mb_{OD}=MB_{OD}\times[\frac{b}{(100+b+A)}]_{OD}\ldots(Equation\ 4)$$
$$=[MB-m]_{ADx}[\frac{b}{(100+b+A)}]_{OD}$$
$$=[(DV-(\frac{DV\times mcB}{100})]_{AD}\times[\frac{b}{(100+b+A)}]_{OD}$$

METHOD II

$$Mb_{OD}=[MP\ x\ \frac{b}{100}]_{OD}\ldots(Equation\ 5)$$

Determination of MP_{OD} is given in para 5.1.6

5.1.5 Mass of OD additive (MA_{OD}) in a board

METHOD I

$$MA_{OD}=[MB\ x\ \frac{A}{(100+A+B)}]_{OD}\ldots(Equation\ 6)$$
$$=[MB-m]_{AD}\times[\frac{A}{(100+A+b)}]_{OD}$$
$$=[DV-(DV\times\frac{mcB}{100})]_{AD}\times[\frac{a}{(100+A+b)}]_{OD}$$

METHOD II

$$MA_{OD}=MP_{OD}x(\frac{A}{100})_{OD}\ldots(Equation\ 7)$$

MP_{OD} is determined as in 5.1.6

5.1.6 Mass/Weight of OD particles (MP_{OD}) in a board

METHOD I

$$MP_{OD} = [MB \times \frac{100}{(100+b+A)}]_{OD} \ldots\ldots (Equation\ 8)$$
$$= [MB-m]_{AD} \times [\frac{100}{100+b+A}]_{OD}$$
$$= [(DV-(DV \times \frac{mcB}{100})]_{AD} \times [\frac{100}{(100+b+A)}]_{OD}$$

METHOD II

$$MP_{OD} = MB_{OD} - Mb_{OD} - MA_{OD} \ldots (Equation\ 9)$$
$$= [MB-m]_{AD} - [(MB \times (\frac{b}{100+b+A})]_{OD} - [(MB \times (\frac{A}{100+b+A})]OD$$
$$= [(DV-(DV \times (\frac{mcB}{100})]_{AD} - [(DV-(DV \times \frac{mcB}{100})_{AD} \times (\frac{b}{100+b+A})]_{OD} - [(DV-(DV \times (\frac{mcB}{100})$$

METHOD III

$$MP_{OD} = [DV-(DV \times \frac{mcB}{100})]_{AD} \times (\frac{1}{(1+.01b+.01A)_{OD}}) \ldots (Equation\ 10)$$

5.1.7 Mass of particles at required/desired mc (say 12% i.e. MP12%

$$MP_{12}\% = MP_{OD} \times [\frac{mcP+100}{100}]_{OD} \ldots (Equation\ 11)$$

In all these:

MP_{OD}	=	mass of oven dry particles
b	=	rate of binder addition
A	=	rate of additive addition
DV_{AD}	=	density x volume of AD board
mcB_{AD}	=	moisture content of board
AD	=	air dry
mcP	=	Any desired moisture content of particles

5.2 Determining mass composition of a board of given parameters (Application of developed procedures)

(i) Board Parameters (An EXAMPLE)

- Moisture in board = 12% of AD board mass
- Length of board (L) = 2.438 m
- Width of board (w) = 1.219 m
- Thickness of board (T) = 0.013 m = 13 mm
- Volume of AD board (V) = L x W x T = 0.0386 m^3
- Density of the AD board = 500 Kg/m^3
- Rate of additive addition = A% = 1% of OD particles
- Rate of binder addition = b% = 8% of OD particles
- Density of wood used = DW = 400 Kg/m^3

(ii) Mass/Weight of Board Components

[SOLUTION to above EXAMPLE]

a) Mass of AD board(MB_{AD})

$MB_{AD} = DV_{AD}$ ..... (Equation 1)

= 500 x 0.0386

= 19.30 Kg

b) Mass of moisture (m_{AD}) in AD board

$m_{AD} = [DV \times mcB/100]_{AD}$ ..... (Equation 2)

= 500 x 0.0386 x 12/100

= 2.316 Kg

c) Mass of OD board(MB_{OD})

$MB_{OD} = DV_{AD} - m_{AD}$ ..... (Equation 3)

$= [DV - (DV \times mcB /100)]_{AD}$

= (500 x 0.0386) - (500 x 0.0386 x 12 /100)

= 19.30 - 2.316

= 16.984 Kg

d) Mass of OD binder (Mb_{OD}) in a board

METHOD I

$Mb_{OD} = [(MB \times (b/(100 + b + A)]_{OD}$ ..... (Equation 4)

$= [MB - (MB \times mcB/100)]_{AD} \times [b/(100 + b + A)]_{OD}$

= [(500 x .0386)-(500 x .0386 x 12/100)] x [8/(100+8+1)]

= [(19.30) - (2.316)] x 8/109

= 1.246

METHOD II

$Mb_{OD} = [MP \times b/100]_{OD}$ ..... (Equation 5)

$= 15.582 \times 8/100$

$= 1.246$ Kg

e) Mass of OD additive (MA_{OD}) in a board

$MA_{OD} = [MB \times [(A /(100 + b + A)]_{OD}$ ..... (Equation 6)

$= [(DV_{AD} - (DV \times mcB /100)]_{AD} \times [A /(100 + b + A)]_{OD}$

$= (500 \times 0.0386) - (500 \times .0386 \times 12/100) \times 1/(100 +8+1)$

$= (19.30 - 2.316) \times 1/109$

$= 0.156$ Kg

f) Mass of OD particles in a board

METHOD I

$MP_{OD} = MB_{OD} \times [100/100 + b + A]_{OD}$ ..... (Equation 7)

$= [(DV - (DV \times mcB /100)]_{AD} \times [100/(100 + b +A)]_{OD}$

$= (500 \times .0386) - 500 \times .0386 \times 12/100) \times [100/(100+8 +1)$

$= (19.30 - 2.316) \times 1/1.09$

$= 15.582$ Kg

g) Mass of particles at 12% mc in a board

$MP_{(12\%)} = (MP) \times (mcP + 100)/100]_{OD}$ ..... (Equation 11)

$= 15.582 \times 1.12$

$= 17.452$ Kg

5.3 Development of procedures to determine volumetric composition of AD board (Development of equations)

5.3.1 Volume of AD board

The whole space in an air dry board is occupied by particles, binder, additives, moisture and air expressed as under:

$VB_{AD} = [VP + Va + Vm + Vb + VA]_{AD}$ .... [Eq.12]

Where
- VB_{AD} = Volume of AD board
- VP_{AD} = volume of AD particles
- Vm_{AD} = Volume of moisture in AD board
- Vb_{AD} = Volume of binder in AD board
- VA_{AD} = Volume of additive in AD board

The binder, additives and moisture find access mainly to the cavities in the wood elements leaving very little to stick to the surface of particles. It is presumed because the mechanism of adhesion in porous materials is explained to be more mechanical

than surface adhesion. Presuming that the volume occupied in a board by binder (Vb), additives (VA) and moisture (Vm) is small enough to be negligible, the board volume is expressed as under:

$VP_{AD} = [VP + Va]_{AD}$. . . . (*Equation* 12)

5.3.2 Volume occupied by AD particles in a board

$$VP_{AD} = \frac{MP_{AD}}{DP_{AD}} \text{ . . . (Equation 13)}$$

(DP_{AD} = DW_{AD} ...presumption)

hence VP_{AD} = MP_{AD} / DW_{AD}

Now MP_{AD} = $[MP \times (mcp + 100)/100]_{OD}$ .... (Equation 10)

Now MP_{OD} = $[MB \times [100/(100 + b + A)]_{OD}$ .... (Equation 8)

Now MB_{OD} = $[DV - (DV \times mcB/100)]_{AD}$ .... (Equation 3)

hence VP_{AD} = $DV - (DV \times mcB/100)]_{AD} \times [100/(100+b+A)]_{OD}$

$\times [(mcp + 100)/100] / DW_{AD}$

Where MP_{AD} = mass of particles at 12% mc

DW_{AD} = density of wood at 12% mc

5.3.3 Volume occupied by air in AD board(Va_{AD})

$Va_{AD} = [VB_{AD} - VP_{AD})$ . . . . (*Equation* 14)

$= (LB_{AD} \times WB_{AD} \times TB_{AD}) - (\frac{MP_{AD}}{DW_{AD}})$

now $VP = [DV_{AD} - (DV \times \frac{mcB}{100})]_{AD} \times [\frac{100}{100+b+a}]_{OD} \times [\frac{mcp+100}{100}]/D$

hence $VP_{AD} = \frac{MP_{AD}}{DW_{AD}}$

Where Va = volume of air spaces or voids in AD board

VB_{AD} = volume of AD board
LB_{AD} = length of AD board
WB_{AD} = width of AD board
TB_{AD} = thickness of AD board
MP_{AD} = Mass of AD particles
DW_{AD} = Density of AD wood

5.4 Determining volumetric composition of a board of given parameters (Application of developed procedures)

(i) Board Parameters [An EXAMPLE]

- Length of AD board LB_{AD} = 2.438 m
- Width of AD board WB_{AD} = 1.219 m
- Thickness of AD board TB_{AD} = 0.013 m
- Density of AD board D_{AD} = 500 Kg/m^3
- Rate of binder addition = 8% by weight of OD Particles
- Rate of additive addition = 1% by weight of OD particles
- Density of AD wood DW_{AD} = 400 Kg/m^3

(ii) Volumetric Board Components

[SOLUTION to ABOVE EXAMPLE]

(a) Volume of AD board

$VB_{AD} = [LB \times WB \times TB]_{AD}$

$= 2.438 \times 1.219 \times 0.013$

$= 0.0386\ m^3$

(b) Volume of particles in an AD board

$VP_{AD} = MP_{AD} / DP_{AD}$ .... (Equation 14)

Now $MP_{AD} = [MP_{OD} \times (mcp + 100)/100]_{OD}$ .... (Equation 10)

Now $MP_{OD} = [MB \times (100/100 + b + A)]_{OD}$ .... (Equation 8)

Now $MB_{OD} = [DV - (DV \times mcB/100)]_{AD}$ .... (Equation 3)

hence $[VP_{AD} = DV - (DV \times mcB/100)]_{AD} \times [100/100 + b + A]_{OD} \times$

$\times [(mcp + 100/100)]_{OD} / DW_{AD}$

$= 500 \times .0386 - (500 \times .0386 \times 12/100) \times (100/100+8+1) \times (12+100)/100 \times 1/40$

$= (19.30 - 2.316) \times (100/109) \times (112/100) \times 1/400$

$= 16.984 \times 0.917 \times 1.12 \times 0.0025 = 0.0436\ m^3$

Where MP_{AD} = Mass of particles at 12% mc

DW_{AD} = Density of wood at 12% mc

b = Rate of binder addition (OD based particles)

mcP = MC of AD particles (i.e. 12% of their OD mass)

mcB = MC of AD board (i.e. 12% of its AD mass)

A = Rate of additive addition (OD based particles)

MP_{OD} = Mass of oven dry particles

MB_{AD} = Mass of AD board (i.e. at 12% MC)

MB_{OD} = Mass of oven dry board

DV_{AD} = Density x Volume of AD board

MC = Moisture content

(c) Volume of air in AD board

$$Va_{AD} = [VB - VP]_{AD} \ldots (Equation\ 15)$$

= 0.0386 - 0.0436

= (-) 0.005 m^3

[Note: The negative value of air volume indicates that there is no air in the board]

(d) Volume of air as % of AD board volume

$$Va_{AD}\% = [\frac{VB - VP}{VB}]_{AD} \times 100 \ldots (Equation\ 16)$$

= 100 - (0.0386 - 0.0436) / 0.0386 ... (V in m^3)
= (-) 13%

[Note: Negative value of air volume indicates that there is no air in the board i.e. the board is compact enough to develop strength]

(e) Volume of particles as % of AD board volume

$$VP_{AD}\% = 100 \times [\frac{VP}{VB}]_{AD} \ldots (Equation\ 17)$$

= 100 x .0436/0.0386 (V in m3)
= 112.5 %

6. COMPRESSION RATIO

$$CR = [\frac{BD}{WD}]_{AD} \ldots (Equation\ 18)$$

= 500 / 400 (density in kg/m3) = 1.25

Where CR = compression ratio

BD_{AD} = density of AD board(i.e. at 12% MC)

WD_{AD} = density of AD wood (i.e. at 12 % MC)

7. THEORETICAL THICKNESS OF BOARD

$$Tt_{AD} = \frac{VP_{AD}}{AB_{AD}} \ldots\ldots (Equation\ 19)$$

= 0.0436 m3 / 1.219 m x 2.438 m

= .0144 m = 14.4 mm

Where Tt_{AD} = Theoretical thickness of AD board

VP_{AD} = Volume of particles in a board

AB_{AD} = Area of AD board

8. SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING DIFFERENT DENSITY PARTICLEBOARDS

The suitability level of a wood species for particleboard manufacturing is generally indicated by the compression ratio i.e. board density/wood density. Compression ratio controls the volume of interparticle spaces and in turn the compactness of board. An increase in compression ratio beyond 1 predicts an increase in compactness of particles/interparticle pressure, decreasing interparticle spaces or voids, increasing theoretical thickness of board and in turn the strength of board.

The absence of interparticle voids or air spaces in the board at compression ratio 1.2 to 1.3, evidences adequate compactness of particles and in turn acceptable properties. It is further supported by the theoretical thickness of board which is always greater than nominal board thickness at this stage. Beyond compression ratio 1.3, the board properties further increase provided the quantity of binder and the other board manufacturing parameters are properly looked after.

For predicting the suitability of woods of density 280 - 1000 kg/m^3, for producing 13 mm thick particleboard panels of density 400 - 1000 kg/m^3, data on volumetric composition of important board components, compression ratio, volume of voids and theoretical board thickness are given in Appendices 1 - 17. Methodology to analyze and use this data is given as under.

8.1 Methodology to determine the suitability of 720 kg/m^3 density wood for producing (13 mm thick) 600 kg/m^3 density board [AN EXAMPLE]

Check Appendix 10.7 which describes the suitability grading of different density woods for producing 600 kg/m^3 density board. Check the values of different parameters against wood density 720 kg/m^3 and record the observations e.g.

- compression ratio = 0.83
- theoretical board thickness = 9.782 mm
- voids volume as % of board volume = 24.68%

CONCLUSION : The value of compression ratio lower than 1.2 and presence of voids indicate inadequate compaction of particles and insufficient interparticle pressure. It is further evidenced by the lower value of theoretical thickness against nominal/desired board thickness i.e. 13 mm. HENCE a wood species of density 720 kg/m^3 cannot produce 600 kg/m^3 density board of acceptable properties.

8.2 Which density particleboard (13 mm thick) of acceptable properties can be produced from 720 kg/m^3 density wood [AN EXAMPLE]

For predicting appropriate board density obtainable from 720 kg/m^3 wood, check the values of board parameters at and around CR 1.2 in different appendices against this wood density e.g.

Observations against 720 kg/m^3 wood density in Appendix 10.14

- compression ratio = 1.22
- voids volume = - 10.46%
- theoretical board thickness = 14.347 mm

CONCLUSION : This data indicates that a board of density 880 kg/m^3 made from 720 kg/m^3 density wood is expected to offer acceptable properties because at this stage the particles are compacted enough to develop sufficient interparticle pressure and board strength. It is supported by (i) the negative value and amount of voids volume (ii) greater value of board thickness as compared to nominal. HENCE it is concluded that 880 kg/m^3 density board of acceptable properties can be made from 720 kg/m^3 density wood. The boards of density lower than this would have comparatively poor properties. On the other hand, the boards of density greater than 880 kg/m^3 would have better properties.

8.3 Acceptable quality particleboards

Each wood species cannot produce particleboard of any desired quality level. The suitability of a large number of woods having different densities was predicted on the basis of compression ratio (i.e., board density/wood density) and shown in Appendix 10.18.

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MASS OF (AD) PARTICLES IN BOARDS OF
DENSITY 400 - 1000 Kg/m

BOARD DENSITY Kg/m D	BOARD VOLUME m V	AD BOARD MASS Kg MB(AD) C1xC2	MOISTURE IN BOARD Kg mcB C3x0.12	OD BOARD MASS Kg MB(OD) C3-C4	OD PARTICLES Kg MP(OD) C5x0.917	AD PARTICLES Kg MP(AD) C6x1.12
400	0.0386	15.44	1.853	13.587	12.459	13.955
440	0.0386	16.984	2.038	14.946	13.705	15.350
480	0.0386	18.528	2.223	16.305	14.951	16.746
520	0.0386	20.072	2.409	17.663	16.197	18.141
560	0.0386	21.616	2.594	19.022	17.443	19.536
600	0.0386	23.16	2.779	20.381	18.689	20.932
640	0.0386	24.704	2.964	21.740	19.935	22.327
680	0.0386	26.248	3.150	23.098	21.181	23.723
720	0.0386	27.792	3.335	24.457	22.427	25.118
760	0.0386	29.336	3.520	25.816	23.673	26.514
800	0.0386	30.88	3.706	27.174	24.919	27.909
840	0.0386	32.424	3.891	28.533	26.165	29.305
880	0.0386	33.968	4.076	29.892	27.411	30.700
920	0.0386	35.512	4.261	31.251	28.657	32.096
960	0.0386	37.056	4.447	32.609	29.903	33.491
1000	0.0386	38.6	4.632	33.968	31.149	34.886

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 400 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	CR	THEORETICAL BOARD THICKNESS mm	THEORETICAL INCREASE / DECREASE IN THICKNESS m
		C1/C2	C3x100 /.0386	100-C4	400/C2	(C3/2.972) 1000	C7-0.013
13.955	280	0.0498	129.12	-29.12	1.43	16.770	16.757
13.955	320	0.0436	112.98	-12.98	1.25	14.673	14.660
13.955	360	0.0388	100.42	-0.42	1.11	13.043	13.030
13.955	400	0.0349	90.38	9.62	1.00	11.739	11.726
13.955	440	0.0317	82.17	17.83	0.91	10.672	10.659
13.955	480	0.0291	75.32	24.68	0.83	9.782	9.769
13.955	520	0.0268	69.52	30.48	0.77	9.030	9.017
13.955	560	0.0249	64.56	35.44	0.71	8.385	8.372
13.955	600	0.0233	60.25	39.75	0.67	7.826	7.813
13.955	640	0.0218	56.49	43.51	0.63	7.337	7.324
13.955	680	0.0205	53.17	46.83	0.59	6.905	6.892
13.955	720	0.0194	50.21	49.79	0.56	6.522	6.509
13.955	760	0.0184	47.57	52.43	0.53	6.178	6.165
13.955	800	0.0174	45.19	54.81	0.50	5.869	5.856
13.955	840	0.0166	43.04	56.96	0.48	5.590	5.577
13.955	880	0.0159	41.08	58.92	0.45	5.336	5.323
13.955	920	0.0152	39.30	60.70	0.43	5.104	5.091
13.955	960	0.0145	37.66	62.34	0.42	4.891	4.878
13.955	1000	0.0140	36.15	63.85	0.40	4.695	4.682

Nominal/desired board thickness is 13 mm

APPENDIX 10.3

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 440 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	440/C2	(C3/2.972) 1000
15.35	280	0.0548	142.02	-42.02	1.57	18.446
15.35	320	0.0480	124.27	-24.27	1.38	16.140
15.35	360	0.0426	110.46	-10.46	1.22	14.347
15.35	400	0.0384	99.42	0.58	1.10	12.912
15.35	440	0.0349	90.38	9.62	1.00	11.738
15.35	480	0.0320	82.85	17.15	0.92	10.760
15.35	520	0.0295	76.47	23.53	0.85	9.932
15.35	560	0.0274	71.01	28.99	0.79	9.223
15.35	600	0.0256	66.28	33.72	0.73	8.608
15.35	640	0.0240	62.14	37.86	0.69	8.070
15.35	680	0.0226	58.48	41.52	0.65	7.595
15.35	720	0.0213	55.23	44.77	0.61	7.173
15.35	760	0.0202	52.32	47.68	0.58	6.796
15.35	800	0.0192	49.71	50.29	0.55	6.456
15.35	840	0.0183	47.34	52.66	0.52	6.149
15.35	880	0.0174	45.19	54.81	0.50	5.869
15.35	920	0.0167	43.22	56.78	0.48	5.614
15.35	960	0.0160	41.42	58.58	0.46	5.380
15.35	1000	0.0154	39.77	60.23	0.44	5.165

Nominal/desired board thickness is 13 mm

APPENDIX 10.4

SUITABILITY GRADING OF DIFFERENT DENSITY WOOD FOR PRODUCING PARTICLEBOARD OF DENSITY 480 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS m
		C1/C2	C3x100 /.0386	100-C4	480/C2	(C3/2.972) 1000
16.746	280	0.0598	154.94	-54.94	1.71	20.12
16.746	320	0.0523	135.57	-35.57	1.50	17.61
16.746	360	0.0465	120.51	-20.51	1.33	15.65
16.746	400	0.0419	108.46	-8.46	1.20	14.09
16.746	440	0.0381	98.60	1.40	1.09	12.81
16.746	480	0.0349	90.38	9.62	1.00	11.74
16.746	520	0.0322	83.43	16.57	0.92	10.84
16.746	560	0.0299	77.47	22.53	0.86	10.06
16.746	600	0.0279	72.31	27.69	0.80	9.39
16.746	640	0.0262	67.79	32.21	0.75	8.80
16.746	680	0.0246	63.80	36.20	0.71	8.29
16.746	720	0.0233	60.25	39.75	0.67	7.83
16.746	760	0.0220	57.08	42.92	0.63	7.41
16.746	800	0.0209	54.23	45.77	0.60	7.04
16.746	840	0.0199	51.65	48.35	0.57	6.71
16.746	880	0.0190	49.30	50.70	0.55	6.40
16.746	920	0.0182	47.16	52.84	0.52	6.12
16.746	960	0.0174	45.19	54.81	0.50	5.87
16.746	1000	0.0167	43.38	56.62	0.48	5.63

Nominal/desired board thickness is 13 mm

APPENDIX 10.5

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 520 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	520/C2	(C3/2.972) 1000
18.141	280	0.0648	167.85	-67.85	1.86	21.800
18.141	320	0.0567	146.87	-46.87	1.63	19.075
18.141	360	0.0504	130.55	-30.55	1.44	16.955
18.141	400	0.0454	117.49	-17.49	1.30	15.260
18.141	440	0.0412	106.81	-6.81	1.18	13.873
18.141	480	0.0378	97.91	2.09	1.08	12.717
18.141	520	0.0349	90.38	9.62	1.00	11.738
18.141	560	0.0324	83.92	16.08	0.93	10.900
18.141	600	0.0302	78.33	21.67	0.87	10.173
18.141	640	0.0283	73.43	26.57	0.81	9.537
18.141	680	0.0267	69.11	30.89	0.76	8.976
18.141	720	0.0252	65.27	34.73	0.72	8.478
18.141	760	0.0239	61.84	38.16	0.68	8.032
18.141	800	0.0227	58.75	41.25	0.65	7.630
18.141	840	0.0216	55.95	44.05	0.62	7.267
18.141	880	0.0206	53.41	46.59	0.59	6.936
18.141	920	0.0197	51.08	48.92	0.57	6.635
18.141	960	0.0189	48.96	51.04	0.54	6.358
18.141	1000	0.0181	47.00	53.00	0.52	6.104

Nominal/desired board thickness is 13 mm

APPENDIX 10.6

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARDS OF DENSITY 560 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	CR	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	560/C2	(C3/2.972) 1000
19.536	400	0.0488	126.53	-26.53	1.40	16.433
19.536	440	0.0444	115.03	-15.03	1.27	14.939
19.536	480	0.0407	105.44	-5.44	1.17	13.694
19.536	520	0.0376	97.33	2.67	1.08	12.641
19.536	560	0.0349	90.38	9.62	1.00	11.738
19.536	600	0.0326	84.35	15.65	0.93	10.956
19.536	640	0.0305	79.08	20.92	0.88	10.271
19.536	680	0.0287	74.43	25.57	0.82	9.667
19.536	720	0.0271	70.29	29.71	0.78	9.130
19.536	760	0.0257	66.59	33.41	0.74	8.649
19.536	800	0.0244	63.26	36.74	0.70	8.217
19.536	840	0.0233	60.25	39.75	0.67	7.825
19.536	880	0.0222	57.51	42.49	0.64	7.470
19.536	920	0.0212	55.01	44.99	0.61	7.145
19.536	960	0.0204	52.72	47.28	0.58	6.847
19.536	1000	0.0195	50.61	49.39	0.56	6.573

Nominal/desired thickness of board is 13 mm

APPENDIX 10.7

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 600 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m C1/C2	VOL. OF PARTICLES AS % OF BOARD VOL C3x100 /.0386	VOL. OF VOIDS AS % OF BOARD VOL 100-C4	COMPRESSION RATIO 600/C2	THEORETICAL BOARD THICKNESS mm (C3/2.972) 1000
20.932	400	0.0523	135.57	-35.57	1.50	17.608
20.932	440	0.0476	123.25	-23.25	1.36	16.007
20.932	480	0.0436	112.97	-12.97	1.25	14.673
20.932	520	0.0403	104.28	-4.28	1.15	13.544
20.932	560	0.0374	96.84	3.16	1.07	12.577
20.932	600	0.0349	90.38	9.62	1.00	11.738
20.932	640	0.0327	84.73	15.27	0.94	11.005
20.932	680	0.0308	79.75	20.25	0.88	10.357
20.932	720	0.0291	75.32	24.68	0.83	9.782
20.932	760	0.0275	71.35	28.65	0.79	9.267
20.932	800	0.0262	67.78	32.22	0.75	8.804
20.932	840	0.0249	64.56	35.44	0.71	8.385
20.932	880	0.0238	61.62	38.38	0.68	8.003
20.932	920	0.0228	58.94	41.06	0.65	7.656
20.932	960	0.0218	56.49	43.51	0.63	7.337
20.932	1000	0.0209	54.23	45.77	0.60	7.043

Nominal/desired board thickness is 13 mm

APPENDIX 10.8

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 640 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m C1/C2	VOL. OF PARTICLES AS % OF BOARD VOL C3x100 /.0386	VOL. OF VOIDS AS % OF BOARD VOL 100-C4	COMPRESSION RATIO 640/C2	THEORETICAL BOARD THICKNESS mm (C3/2.972) 1000
22.327	400	0.0558	144.60	-44.60	1.60	18.781
22.327	440	0.0507	131.46	-31.46	1.45	17.074
22.327	480	0.0465	120.50	-20.50	1.33	15.651
22.327	520	0.0429	111.23	-11.23	1.23	14.447
22.327	560	0.0399	103.29	-3.29	1.14	13.415
22.327	600	0.0372	96.40	3.60	1.07	12.521
22.327	640	0.0349	90.38	9.62	1.00	11.738
22.327	680	0.0328	85.06	14.94	0.94	11.048
22.327	720	0.0310	80.34	19.66	0.89	10.434
22.327	760	0.0294	76.11	23.89	0.84	9.885
22.327	800	0.0279	72.30	27.70	0.80	9.391
22.327	840	0.0266	68.86	31.14	0.76	8.943
22.327	880	0.0254	65.73	34.27	0.73	8.537
22.327	920	0.0243	62.87	37.13	0.70	8.166
22.327	960	0.0233	60.25	39.75	0.67	7.825
22.327	1000	0.0223	57.84	42.16	0.64	7.512

Nominal/desired board thickness is 13 mm

APPENDIX 10.9

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 680 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	680/C2	(C3/2.972) 1000
23.723	400	0.0593	153.65	-53.65	1.70	19.955
23.723	440	0.0539	139.68	-39.68	1.55	18.141
23.723	480	0.0494	128.04	-28.04	1.42	16.630
23.723	520	0.0456	118.19	-18.19	1.31	15.350
23.723	560	0.0424	109.75	-9.75	1.21	14.254
23.723	600	0.0395	102.43	-2.43	1.13	13.304
23.723	640	0.0371	96.03	3.97	1.06	12.472
23.723	680	0.0349	90.38	9.62	1.00	11.738
23.723	720	0.0329	85.36	14.64	0.94	11.086
23.723	760	0.0312	80.87	19.13	0.89	10.503
23.723	800	0.0297	76.82	23.18	0.85	9.978
23.723	840	0.0282	73.16	26.84	0.81	9.503
23.723	880	0.0270	69.84	30.16	0.77	9.071
23.723	920	0.0258	66.80	33.20	0.74	8.676
23.723	960	0.0247	64.02	35.98	0.71	8.315
23.723	1000	0.0237	61.46	38.54	0.68	7.982

Nominal/desired thickness of board is 13 mm

APPENDIX 10.10

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 720 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m3\	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	680/C2	(C3/2.972) 1000
23.723	400	0.0593	153.65	-53.65	1.70	19.955
23.723	440	0.0539	139.68	-39.68	1.55	18.141
23.723	480	0.0494	128.04	-28.04	1.42	16.630
23.723	520	0.0456	118.19	-18.19	1.31	15.350
23.723	560	0.0424	109.75	-9.75	1.21	14.254
23.723	600	0.0395	102.43	-2.43	1.13	13.304
23.723	640	0.0371	96.03	3.97	1.06	12.472
23.723	680	0.0349	90.38	9.62	1.00	11.738
23.723	720	0.0329	85.36	14.64	0.94	11.086
23.723	760	0.0312	80.87	19.13	0.89	10.503
23.723	800	0.0297	76.82	23.18	0.85	9.978
23.723	840	0.0282	73.16	26.84	0.81	9.503
23.723	880	0.0270	69.84	30.16	0.77	9.071
23.723	920	0.0258	66.80	33.20	0.74	8.676
23.723	960	0.0247	64.02	35.98	0.71	8.315
23.723	1000	0.0237	61.46	38.54	0.68	7.982

Nominal/desired thickness of board is 13 mm

APPENDIX 10.11

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 760 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m C1/C2	VOL. OF PARTICLES AS % OF BOARD VOL C3x100 /.0386	VOL. OF VOIDS AS % OF BOARD VOL 100-C4	COMPRESSION RATIO 760/C2	THEORETICAL BOARD THICKNESS mm (C3/2.972) 1000
26.514	400	0.0663	171.72	-71.72	1.90	22.303
26.514	440	0.0603	156.11	-56.11	1.73	20.276
26.514	480	0.0552	143.10	-43.10	1.58	18.586
26.514	520	0.0510	132.09	-32.09	1.46	17.156
26.514	560	0.0473	122.66	-22.66	1.36	15.931
26.514	600	0.0442	114.48	-14.48	1.27	14.869
26.514	640	0.0414	107.33	-7.33	1.19	13.939
26.514	680	0.0390	101.01	-1.01	1.12	13.120
26.514	720	0.0368	95.40	4.60	1.06	12.391
26.514	760	0.0349	90.38	9.62	1.00	11.739
26.514	800	0.0331	85.86	14.14	0.95	11.152
26.514	840	0.0316	81.77	18.23	0.90	10.621
26.514	880	0.0301	78.06	21.94	0.86	10.138
26.514	920	0.0288	74.66	25.34	0.83	9.697
26.514	960	0.0276	71.55	28.45	0.79	9.293
26.514	1000	0.0265	68.69	31.31	0.76	8.921

Nominal/desired board thickness is 13 mm

APPENDIX 10.12

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 800 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	800/C2	(C3/2.972) 1000
27.909	400	0.0698	180.76	-80.76	2.00	23.477
27.909	440	0.0634	164.33	-64.33	1.82	21.342
27.909	480	0.0581	150.63	-50.63	1.67	19.564
27.909	520	0.0537	139.04	-39.04	1.54	18.059
27.909	560	0.0498	129.11	-29.11	1.43	16.769
27.909	600	0.0465	120.51	-20.51	1.33	15.651
27.909	640	0.0436	112.97	-12.97	1.25	14.673
27.909	680	0.0410	106.33	-6.33	1.18	13.810
27.909	720	0.0388	100.42	-0.42	1.11	13.043
27.909	760	0.0367	95.14	4.86	1.05	12.356
27.909	800	0.0349	90.38	9.62	1.00	11.738
27.909	840	0.0332	86.08	13.92	0.95	11.179
27.909	880	0.0317	82.16	17.84	0.91	10.671
27.909	920	0.0303	78.59	21.41	0.87	10.207
27.909	960	0.0291	75.32	24.68	0.83	9.782
27.909	1000	0.0279	72.30	27.70	0.80	9.391

Nominal/desired board thickness is 13 mm

APPENDIX 10.13

SUITABILITY GRADING OF DIFFERENT DESNITY WOOD FOR PRODUCING PARTICLEBOARD OF DESNITY 840 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	840/C2	(C3/2.972) 1000
29.305	400	0.0733	189.80	-89.80	2.10	24.651
29.305	440	0.0666	172.54	-72.54	1.91	22.410
29.305	480	0.0611	158.17	-58.17	1.75	20.542
29.305	520	0.0564	146.00	-46.00	1.62	18.962
29.305	560	0.0523	135.57	-35.57	1.50	17.608
29.305	600	0.0488	126.53	-26.53	1.40	16.434
29.305	640	0.0458	118.62	-18.62	1.31	15.407
29.305	680	0.0431	111.65	-11.65	1.24	14.501
29.305	720	0.0407	105.44	-5.44	1.17	13.695
29.305	760	0.0386	99.89	0.11	1.11	12.974
29.305	800	0.0366	94.90	5.10	1.05	12.325
29.305	840	0.0349	90.38	9.62	1.00	11.739
29.305	880	0.0333	86.27	13.73	0.95	11.205
29.305	920	0.0319	82.52	17.48	0.91	10.718
29.305	960	0.0305	79.08	20.92	0.88	10.271
29.305	1000	0.0293	75.92	24.08	0.84	9.860

Nominal/desired board thickness is 13 mm

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 880 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	880/C2	(C3/2.972) 1000
30.7	400	0.0768	198.83	-98.83	2.20	25.824
30.7	440	0.0698	180.76	-80.76	2.00	23.477
30.7	480	0.0640	165.70	-65.70	1.83	21.520
30.7	520	0.0590	152.95	-52.95	1.69	19.865
30.7	560	0.0548	142.02	-42.02	1.57	18.446
30.7	600	0.0512	132.56	-32.56	1.47	17.216
30.7	640	0.0480	124.27	-24.27	1.38	16.140
30.7	680	0.0451	116.96	-16.96	1.29	15.191
30.7	720	0.0426	110.46	-10.46	1.22	14.347
30.7	760	0.0404	104.65	-4.65	1.16	13.592
30.7	800	0.0384	99.42	0.58	1.10	12.912
30.7	840	0.0365	94.68	5.32	1.05	12.297
30.7	880	0.0349	90.38	9.62	1.00	11.738
30.7	920	0.0334	86.45	13.55	0.96	11.228
30.7	960	0.0320	82.85	17.15	0.92	10.760
30.7	1000	0.0307	79.53	20.47	0.88	10.330

Nominal/desired board thickness is 13 mm

APPENDIX 10.15

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 920 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	920/C2	(C3/2.972) 1000
32.096	400	0.0802	207.88	-107.88	2.30	26.999
32.096	440	0.0729	188.98	-88.98	2.09	24.544
32.096	480	0.0669	173.23	-73.23	1.92	22.499
32.096	520	0.0617	159.90	-59.90	1.77	20.768
32.096	560	0.0573	148.48	-48.48	1.64	19.285
32.096	600	0.0535	138.58	-38.58	1.53	17.999
32.096	640	0.0501	129.92	-29.92	1.44	16.874
32.096	680	0.0472	122.28	-22.28	1.35	15.882
32.096	720	0.0446	115.49	-15.49	1.28	14.999
32.096	760	0.0422	109.41	-9.41	1.21	14.210
32.096	800	0.0401	103.94	-3.94	1.15	13.499
32.096	840	0.0382	98.99	1.01	1.10	12.857
32.096	880	0.0365	94.49	5.51	1.05	12.272
32.096	920	0.0349	90.38	9.62	1.00	11.739
32.096	960	0.0334	86.61	13.39	0.96	11.249
32.096	1000	0.0321	83.15	16.85	0.92	10.799

Nominal/desired board thickness is 13 mm

APPENDIX 10.16

SUITABILITY GRADING OF DIFFERENT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 960 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	960/C2	(C3/2.972) 1000
33.491	400	0.0837	216.91	-116.91	2.40	28.172
33.491	440	0.0761	197.19	-97.19	2.18	25.611
33.491	480	0.0698	180.76	-80.76	2.00	23.477
33.491	520	0.0644	166.85	-66.85	1.85	21.671
33.491	560	0.0598	154.94	-54.94	1.71	20.123
33.491	600	0.0558	144.61	-44.61	1.60	18.781
33.491	640	0.0523	135.57	-35.57	1.50	17.608
33.491	680	0.0493	127.59	-27.59	1.41	16.572
33.491	720	0.0465	120.51	-20.51	1.33	15.651
33.491	760	0.0441	114.16	-14.16	1.26	14.827
33.491	800	0.0419	108.46	-8.46	1.20	14.086
33.491	840	0.0399	103.29	-3.29	1.14	13.415
33.491	880	0.0381	98.60	1.40	1.09	12.806
33.491	920	0.0364	94.31	5.69	1.04	12.249
33.491	960	0.0349	90.38	9.62	1.00	11.738
33.491	1000	0.0335	86.76	13.24	0.96	11.269

Nominal/desired board thickness is 13 mm

APPENDIX 10.17

SUITABILITY GRADING OF DIFFERNT DENSITY WOODS FOR PRODUCING PARTICLEBOARD OF DENSITY 1000 Kg/m

AD PARTICLES Kg	WOOD DENSITY Kg/m	VOL. OF PARTICLES m	VOL. OF PARTICLES AS % OF BOARD VOL	VOL. OF VOIDS AS % OF BOARD VOL	COMPRESSION RATIO	THEORETICAL BOARD THICKNESS mm
		C1/C2	C3x100 /.0386	100-C4	1000/C2	(C3/2.972) 1000
34.886	400	0.0872	225.95	-125.95	2.50	29.346
34.886	440	0.0793	205.41	-105.41	2.27	26.678
34.886	480	0.0727	188.29	-88.29	2.08	24.455
34.886	520	0.0671	173.80	-73.80	1.92	22.574
34.886	560	0.0623	161.39	-61.39	1.79	20.961
34.886	600	0.0581	150.63	-50.63	1.67	19.564
34.886	640	0.0545	141.22	-41.22	1.56	18.341
34.886	680	0.0513	132.91	-32.91	1.47	17.262
34.886	720	0.0485	125.53	-25.53	1.39	16.303
34.386	760	0.0459	118.92	-18.92	1.32	15.445
34.886	800	0.0436	112.97	-12.97	1.25	14.673
34.886	840	0.0415	107.59	-7.59	1.19	13.974
34.886	880	0.0396	102.70	-2.70	1.14	13.339
34.886	920	0.0379	98.24	1.76	1.09	12.759
34.886	960	0.0363	94.14	5.86	1.04	12.227
34.886	1000	0.0349	90.38	9.62	1.00	11.738

Nominal/desired board thickness is 13 mm

SUITABILITY OF DIFFERENT WOOD DENSITY SPECIES FOR PRODUCING DESIRED DENSITY PARTICLEBOARD

Wood density (Kg/m^3)	Acceptable quality particleboard (Kg/m^3)															
	400	440	480	520	560	600	640	680	720	760	800	840	880	920	960	1000
1000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pq
960	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Pq	Pq
920	-	-	-	-	-	-	-	-	-	-	-	-	-	Pq	Pq	Pq
880	-	-	-	-	-	-	-	-	-	-	-	-	Pq	Pq	Pq	Pq
840	-	-	-	-	-	-	-	-	-	-	-	Pq	Pq	Pq	Pq	Aq
800	-	-	-	-	-	-	-	-	-	-	Pq	Pq	Pq	Pq	Aq	H
760	-	-	-	-	-	-	-	-	-	Pq	Pq	Pq	Pq	Aq	H	H
720	-	-	-	-	-	-	-	-	Pq	Pq	Pq	Pq	Aq	H	H	H
680	-	-	-	-	-	-	-	Pq	Pq	Pq	Aq	Aq	H	H	H	H
640	-	-	-	-	-	-	Pq	Pq	Pq	Aq	Pq	H	H	H	H	H
600	-	-	-	-	_	Pq	Pq	Pq	Aq	Aq	H	H	H	H	H	H
560	-	-	-	-	Pq	Pq	Pq	Aq	Aq	H	H	H	H	H	H	H
520	-	-	Pq	Pq	Pq	Aq	Aq	H	H	H	H	H	H	H	H	H
480	-	-	Pq	Pq	Aq	H	H	H	H	H	H	H	H	H	H	H
440	-	Pq	Pq	Aq	H	H	H	H	H	H	H	H	H	H	H	H
400	Pq	Pq	Aq	H	H	H	H	H	H	H	H	H	H	H	H	H

H = Heavy board
Aq = Acceptable quality board
Pq = Poor quality board

WOOD PRODUCING TREES[1] IN PAKISTAN

SCIENTIFIC NAME	LOCAL NAME	WOOD DENSITY Kg/m^3	Lbs/cft
Abies pindrow	Partal, Fir, Paludar	432-480	27-30
Acacia albida	-		
Acacia aneura	-		
Acacia catechu	Khair	1008-1040	63-65
Acacia cupresiformis	Saru kikar		
Acacia cyanophylla	-		
Acacia cyclops	-		
Acacia farnesiana	-		
Acacia modesta	Phulai	960-992	60-62
Acacia nilotica	Babul, Kikar	736-880	46-55
Acacia senegal	Khor	816	51
Acacia tortilis	Sudani kikar		
Acacia victorae	-		
Acer caesium	Maple, trekhan	592-656	37-41
Acer oblongum	Panjori, maple, mandar	720	45
Aesculus indica	Horse chestnut, Bankhor	528-560	33-35
Ailanthus altissima	Shajr-e-behisht		
Ailanthus excelsa	White bakain	432	27
Ailanthus glandulosa	-		
Albizia lebbeck	Kala sirin, siris	625	39
Albizzia procera	Safed sirin	464	29
Alnus nitida	Sharol, chamb, sirin	384-448	24-28
Alstonia scholaris	Chatiyan	416-480	26-30
Amorpha fruitocosa	Bastard indigo		
Amygdalud cummunis	Badam		
Artocarpus spp.	Kathal	592	37
Atriplex canescens	Saltbush		
Avicennea marina	Timar	896	56
Azadirachta indica	Neem	672-688	42-44
Bauhinia variegata	Kachnar		
Bauhinia purpurea	Kachnar, khairwal	576	36
Bischofia javanica	Indrakne, bishopwood	752	47
Bombax ceiba	Semal, simbal	254-400	16-25
Broussonetia papyrifera	Jangli toot		
Butea monosperma	Dhak, palah		
Butea frondosa	Dhak, palas, palah	544	34

[1] These include trees as well as bushes. Some are forest species and natives. Some are grown on farm lands, orchards and nurseries and have been introduced from abroad.

Callistemon viminalis	Bottle brush		
Cassia fistula	Choti Amaltas	800	50
Cassia glauca	Amaltas		
Casuarina equisetifolia	Casuarina	896	56
Cedrus deodara	Deodar, diar	852-608	33-38
Cedrela serrata	Drawi	448-496	28-31
Cedrela toona	Toon	560-608	35-38
Celtis australis	Tagho, Batkarar, kharak, khirik	608	38
Ceratonia siliqua	-		
Chukrassia tubularis	Chittagong wood		
Chukrassia tuburosa	-		
Conocorpus lancifolius	Damas, Ethiopian teak	846	53
Cornus macrophylla	Kandar	669	42
Cordia myxa	Lasura, Chanjual	544	34
Cordia dichotoma	Lasura		
Cordia obliqua	-		
Cornus macrophylla	Kandar	669	42
Crataeva religiosa	Barn		
Cupressus arizonica	Saru		
Cupressus semperverens	Saru		
Dalbergia sissoo	Shisham, tali, shawa	800-848	50-53
Delonix regia	Gul-e-mohr		
Diospyros lotus	Amluk	738	46
Dodonaea viscosa	Sanatha		
Ehretia leavis	Chamror, sakar	624	39
Elaegnus angustifolia	Roosi zaitoon	784	49
Emblica officinalis	Amla		
Erytherina suberosa	Gul-e-nishtar	240	15
Eriobotrya japonica	Lokath		
Eucalyptus camaldulensis	Lachi, sfaeda	680-705	38-44
Eucalyptus citriodora	-	760	48
Eucalyptus glandulosa	-	760	48
Eucalyptus globulus	-		
Eucalyptus kitsoniana	-	920	58
Eucalyptus malanophloia	-		
Eucalyptus microtheca	-		
Eucalyptus siderophola	-	950	59
Eucalyotus tereticornis	-	739	46
Eucalyptus spp.	-	896	56
Eunonymus japonicus	-		
Ficus elastica	Rubber plant		
Ficus infectoria	-		
Ficus bengalensis	Borh, barh	624	39
Ficus palmata	-		
Ficus religiosa	Pipal		
Fraxinus excelsior	Ash, sum	512-608	32-38
Fraxinus xanthoxyloides	Hanuz	736	46

Gleditschita triacanthos	Dozakhh		
Gmelina arborea	Gumhar, kumbar	480	30
Grevillea robusta	Silver oak, silk oak	576	36
Grewia asiatica	Falsa		
Grewia optiva	Falsa		
Grewia oppositifolia	Dhamman, behel, biung, biul	768	48
Haloxylon grifithii	-		
Heterophragma adenophyllum	Saanp phali		
Jacaranda mimosifolia	Neel gulmohar		
Juglans regia	Akhrot	528-608	33-38
Juniperus excelsa	Obusht, Juniper	448-464	28-29
Kigelia pinnata	Gul-e-fanoos		
Lagerstroemia indica	Gul dasta		
Lagerstroemia speciosa	Gul dasta		
Leucaena leucocephalla	Ipil Ipil		
Lagestrum indicum	-		
Livistonia chinensis	-		
Magnolia grandiflora	Magnolia, Bull bay		
Mallotus phillipinensis	Kamila, rahuni, kuku	768	48
Mangifera indica	Mango, amb	608	38
Melia azedarach	Drek, bakain	576-608	36-38
Millingtonia hortensis	Nim chameli		
Moringa oleifera	Sohanjna		
Morus alba	White toot	640-674	40-42
Morus nigra	Black toot		
Myrtus communis	-		
Nyctanthes arbortristis	Har sanghar		
Olea ferruginea	Kao	1104-1184	69-74
Oroxlyum indicum	Tat		
Parrotia jacquemontiana	Passer	875	55
Parkinsonia aculeata	Juda's thorn, ratama		
Paulownia sp.	-	290	18
Peltophorum pterocarpum	Peeli gulmohr		
Picea smithiana	Pludar, kachal	464-480	29-30
Pinus brutia	-		
Pinus helepensis	-		
Pinus gerardiana	Chilghoza	580	36

Pinus roxburghii	Chir, chil	527-608	33-38
Pinus wallichiana	Blue pine, biar	480-512	30-32
	kail, anandar	512-528	32-33
Pinus alderica	Quetta pine		
Pistacia khinjuk	Pista	1088	68
Pistacia integerrima	Kagar, kangar, kakroi	684-784	43-49
Pistacia chinensis	-		
Pithoclobium dulce	-		
Platanus orietalis	Chinar	608-640	38-40
Pongamia glabra	Sukh Chaen	592	37
Populus euramericana	Poplar	512	32
Populus euramericana	Hybrid poplar, sofeda	390	24
Populus euphretica	Bhan, ban	480	30
Populus deltoides	Sufed poplar	480	30
Populus nigra	Kala poplar	432	27
Populus alba	White poplar	464	29
Populus spp.	Safeda, poplar	512	32
Pongamia glabra	Karang		
Prosopis cineraria	Jand	930	58
Prosopis glandulosa	-		
Prosopis juliflora	Mesquite	928	58
Prunus armeniaca	Apricot		
Prunus bukhariensis	Alubokhara, plums		
Prunus padus	Kalakat		
Psidium guayava	-	544	34
Pterospermum spp.	-	544	34
Pterospermum acerifolium	Kanak champa,		
	jaunsar, mayung	624	39
Punnica granatum	-		
Putranjiva roxburghii	Putranjiva		
Pyrus pashia	Batangi	683	43
Quercus incana	Oak, shahbloot,	896-1024	56-64
	rin, ban, banj		
Quercus dilatata	Barungi, bangi,		
	moru, marghang	912-960	57-60
Quercus semcarpifolia	Shahbloot, banjar	848	53
Quercus ilex	-	944	59
Robinia pseudoacacia	Robinia		
Rhus cotinus	-		
Salvadora oleoides	Pilu	624	39
Salix alba	Willow, baid	512	32
Salix tetrasperma	Willow, baid	384-496	24-31
Salix acomophylla	Willow, baid		
Salvadora oleoides	Pilu		
Sapindus mukorossi	Retha		
Sapium sebiferum	Churbi		
Saraca indica	Ashok		
Schinus molle	Kali mirch		

Sesbania sesban	Sesban	416	26
Sesbanea aegyptiaca	Jantar		
Sterculia alata	Sterculia	384	24
Sterculia diversifolia	-		
Swientonia mehagoni	Mahogany		
Syzygium cumini	Jaman	850	55
Tabernaemontana coronaria	Crape jasmine		
Tamarix aphylla	Gaz, farash	656-720	41-45
Tamarix dioica	Lai	688	43
Tamarix trophii	Saline aru		
Tamarindus indica	Imli		
Tamarindus articulata	Imli		
Taxus baccata	Bermi	720	45
Tecoma undulata	Lahura	576	36
Tectona grandis	Teak	608-688	38-43
Terminalia arjuna	Arjan	752	47
Terminalia belerica	Bahera	602	37
Terminalia catappa	Badam, almond wood	672	42
Thespesia populnea	Bhendi tree		
Ulmus wallichiana	Kain	672	42
Woodfordia fructicosa	-		
Xylosoma longifolium	Chopra	640	40
Zizyphus mauritiana	Ber, Karkana	720-896	45-56
Zizyphys nummularia	Mukh, Mallah		