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Utilization Potential of Sawmill Residues for Particleboard Manufacturing in Myanmar

Ni Ni Thin, Assistant Manager
Myanmar Timber Enterprise
Professor Win Kyi, Technical Advisor
University of Forestry
Khin May Lwin, Research Officer
Forest Research Institute

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မြန်မာနိုင်ငံတွင်သစ်စက်စွန့်ပစ်ပစ္စည်းများဖြင့်သစ်မှုန်ပြားထုတ်လုပ်နိုင်မှု အလားအလာကိုစူးစမ်းလေ့လာခြင်း

ဒေါ်နီနီသင်း – လက်ထောက်မန်နေဂျာ၊ မြန်မာ့သစ်လုပ်ငန်း
ပါမောက္ခဦးဝင်းကြည် – ကျွမ်းကျင်သူ၊ သစ်တောတက္ကသိုလ်
ဒေါ်ခင်မေလွင် – သုတေသနအရာရှိ၊ သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်း

ဤစာတမ်းသည် မြန်မာနိုင်ငံရှိ သစ်အခြေခံ စက်မှုလုပ်ငန်း မြှင့်တင်ရေးအတွက် ကြိုးပမ်းမှု တစ်ရပ်အနေဖြင့် သစ်စက်စွန့်ပစ်ပစ္စည်းများမှ သစ်အချောထည်များ ထုတ်လုပ်နိုင်ရန် သုတေသနပြု ထားခြင်းဖြစ်ပါသည်။ မြန်မာ့သစ်လုပ်ငန်းရှိ သစ်စက်များမှရရှိသည့် လွှစာမှုန့်များကို အသုံးပြုခြင်းဖြင့် ထွက်ရှိနိုင်မည့် သစ်မှုန်ပြားပမာဏကို ခန့်မှန်းထားပါသည်။ ကျွန်းလွှစာမှုန့်၊ အင်လွှစာမှုန့်နှင့် ပန်းစုံ လွှစာမှုန့်(၃)မျိုးဖြင့် (၃၀စင်တီမီတာ x ၃၀စင်တီမီတာ x ၁.၂စင်တီမီတာ) အရွယ်ရှိသော သစ်မှုန်ပြား များကို ယူရီးရားဖော်မယ်ဒီဟိုက်ကော် အသုံးပြုလျက် အပူချိန်၁၂၀ံC တွင် ဖိအား ၁၁၀psi ဖြင့် (၈)မိနစ်အချိန်ကြာထားရှိ၍ စမ်းသပ်ပြုလုပ်ထားပါသည်။ စမ်းသပ်ထုတ်လုပ်ထားသော သစ်မှုန်ပြားများ ၏ အရည်အသွေးကို သိရှိနိုင်ရန်အတွက် ဓါတုဂုဏ်သတ္တိ၊ ရူပဂုဏ်သတ္တိနှင့် အင်အားဆိုင်ရာ ဂုဏ်သတ္တိ အချို့ကို နိုင်ငံတကာ စံနှုန်း သတ်မှတ်ချက်များနှင့်အညီ စမ်းသပ်ခဲ့ပါသည်။

စမ်းသပ်ချက်များအရ ကျွန်းလွှစာမှုန့်တွင် ဓါတုဒြပ်ပေါင်းများ၊ အထူးသဖြင့် လစ်ဂ်နင် ပါဝင်မှုနှုန်း များသည်နှင့်အမျှအရည်အသွေး ပိုမိုကောင်းမွန်သည်ကို တွေ့ရှိရပါသည်။ သစ်မှုန်ပြားများ ၏ သိပ်သည်းခြင်းများအရ ကျွန်းသစ်မှုန်ပြားသည် အတော်အသင့် သိပ်သည်းသော သစ်မှုန်ပြား ဖြစ်ပြီး အင်နှင့်ပန်းစုံ သစ်မှုန်ပြားများသည် အလွန်သိပ်သည်းသော သစ်မှုန်ပြားများအဖြစ် သတ်မှတ် နိုင်ပါသည်။ ရေစုပ်ယူမှုတွင် စမ်းသပ်ထားသော သစ်မှုန်ပြားသုံးမျိုးသည် စံကန့်သတ်စည်း အတွင်း၌ ရှိသည်သာမက ဒုအတိုင်း ကြွမှုသည်လည်း စံကန့်သတ်စည်းထက် နည်းကြောင်းတွေ့ရှိ ရပါသည်။ သစ်မှုန်ပြားများ၏ MOR သည် စံသတ်မှတ်ချက်ထက် နည်းသော်လည်း သစ်မှုန်ပြားသုံးမျိုး၏ MOE သည် စံသတ်မှတ်ချက်ထက်များ ကြောင်းတွေ့ရှိရပါသည်။ ထို့ကြောင့် စမ်းသပ်ထုတ်လုပ်ထားသည့် သစ်မှုန်ပြား သုံးမျိုးသည် စံသတ်မှတ်ချက်များကိုမီကြောင်း ကောက်ချက်ချနိုင်ပါသည်။ မြန်မာ့ သစ်လုပ်ငန်းရှိ သစ်စက်များမှရရှိသည့် လွှစာမှုန့်များကို အသုံးပြု၍ (၈' x ၄' x ၁၂ မမ) အရွယ်ရှိ သစ်မှုန်ပြား အချပ်ပေါင်း ၄၉၉,၀၀၀ ခန့်ကို နှစ်စဉ်ထုတ်လုပ်နိုင်မည်ဟုခန့်မှန်းပါသည်။ လွှစာမှုန့်အမျိုးအစား၊ ကော်အမျိုးအစားနှင့်ထုတ်လုပ်သည့် စက် အမျိုးအစားစသည်များပေါ်တွင် မူတည်၍ သစ်မှုန်ပြား၏ အရည်အသွေး ကွာခြားမှု ရှိနိုင်သော်လည်း သစ်စက်စွန့်ပစ်ပစ္စည်းများမှ သစ်မှုန်ပြားများ ထုတ်လုပ်ရန် အလားအလာ အလွန်ကောင်းပါသည်။

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Daw Ni Ni Thin – Assistant Manager, Myanmar Timber Enterprise

Professor Win Kyi – Technical Advisor, University of Forestry

Daw Khin May Lwin – Researcher Officer, Forest Research Institute

ABSTRACT

This study is an attempt to promote the downstream wood-processing industries by transforming wood waste into usable products, and to estimate the total volume of particleboards which can be produced by using sawdust obtained from MTE saw mills. This research paper is mainly concerned with the production of particleboards using three types of raw material, Teak (*Tectona grandis*), In (*Dipterocarpus tuberculatus*) and assorted sawdust on an experimental scale. The important tests are carried out for chemical, physical and mechanical properties. The sawdust was mixed with urea-formaldehyde adhesive. After mixing with adhesive, the raw materials were laid in an iron mould to form (30 × 30 × 1.2) cm^3 sheets. The consolidated mat was finally pressed between two stainless steel cauls plates which was electrically heated at the temperature 120 ºC for 8 minutes at 110 psi. Chemical properties were tested in accordance with the designations in TAPPI (Technical Association of Pulp and Paper Industry) and physical and mechanical properties were tested in accordance with the designation in ASTM (American Society for Testing and Material) Standard D 1037-64.According to the investigated data, it was found that Teak sawdust has high chemical content especially in lignin content and it enhances better quality. In accordance with the classification of their densities, Teak particleboard can be determined as medium-density particleboard and In and assorted particleboards can be determined as high-density particleboard.

Water absorption percent of three types of board lies in the range of standard limit. Thickness swelling is less than the standard value. Modulus of rupture of Teak and assorted boards are close to that of the standard board. However, MOR of In particleboard is less than the standard value. Moduli of elasticity of three tested boards are higher than the standard value. This study shows that particleboards produced from sawdust of Teak, In and assorted species have the standard level. By using sawdust obtained from MTE saw mills, about 499,000 sheets of particleboards (8′×4′×12 mm) could be produced annually. Therefore, utilization of sawmill residues in terms of sawdust has a significant potential for particleboard manufacturing in the future although variations in the boards' quality may occur depending on the species, type of raw material, type of resin and type of machine.

Key Words: particleboard, sawmill residue, sawdust, adhesive, chemical, physical , mechanical.

Content

1. INTRODUCTION

Forests have played a very significant role to sustain human life on earth from the very beginning. Even today man depends on forest products, especially wood and bamboo, for variety of purposes. Due to increasing population, demand of wood is being increased and forest degradation is being accounted. In the past, forest industries had assumed an almost infinite supply of raw materials that the region's forests provide. Today, this erroneous perception is not as it used to be and raw material shortages are occurring. The demand for forestry and agricultural land is increasing. As a result of population expansion, a permanent decline in forest areas has been noted. Environmental pressures have managed to prohibit forest harvesting resulting in wood shortages, the closing down of wood industries, unemployment, etc. in some countries (FAO, 2001). Growing social demands for wood-based panels result in the continuous need to find new wood resources as an alternative to wood (Gokay, 2002).

The forests of Myanmar are capable of providing a wide range of economic, social and environmental benefits to the people living in the country. Forest area of Myanmar in the year 2005 was estimated to be 33,966 km^2 (i.e., 50.2% of total land area) (Tin Tun, 2006). Although there are forests all over the country, the densities of marketable species are scarcely distributed. It is a basic matter of fact that the achievement of sustainable timber production in tropical forest will be largely dependent on an efficient utilization of our resources. It is generally accepted that it is simply not enough to just grow trees better and faster. Improved utilization of the available resources will have a more immediate and dramatic impact on timber supply and sustainability of these resources.

More products will be made with less wood from the forests' situation that has major long-term implication for the sustainable management of forests and adequacy of raw materials. Also, while some have recognized wood waste as a valuable by-product for further processing or energy-generation, the growing shortages of supply of wood, especially the solid wood, all over the world direct man to find ways to substitute other form of materials for wood. In the present era of environmental consciousness, more and more material are emerging in construction, furniture and other sectors as substitute of wood. Wide range of plastics, synthetic material, metals, etc. is being used to substitute wood. However, production of wood alternatives from plastic and metal is highly energy-consuming and such products, especially plastic, are not biodegradable and hence not environment-friendly. The later is a residue that has been identified as a suitable substitute for wood in some applications, as it has been observed that agricultural residues provide renewable and environmentally friendly alternative biomass resources for easing the high demand for woody materials (Khali, 2006).

Production of wood-based panels and paper products are relatively fewer than other products of minor importance. As in the other countries there has been an ever-widening gap between the supply and demand of timber products both for export and domestic consumption. Until recently, the utilization of logging and wood-processing residues in developing countries have generally lagged behind developed countries. However, over the last five years, the number of wood-based panel producers that utilize mill residues exclusively has increased dramatically (FAO, 2001). In some countries 'shortages' of residues have actually developed as a result of increased local demand for panel production (Pennington *et al*., 2001). Therefore, it is highly desirable to produce more efficient and effective timber products with minimum supply of raw materials.

In this condition of diminishing raw material supplies, logging and mill waste are emerging as a major potential raw material source (FAO, 2001). Lingering impediments to the sustainability of forests and forest industries are inefficient utilization of wood raw material and the high volume of residues that are left in the forest and which remain after wood processing. At the same time it is hoped that more efficient use of residues can lead to a reduction in the logged areas every year (Dykstra, 2001; FAO, 2001). These residues can be utilized to manufacture many composites such as particleboards, waferboard and chipboard. In some countries shortages of residues have actually developed as a result of increased local demand for panel production. It is actually based on the sustainable management of forest and creation of clean environment by full utilization of waste materials. The aim of this study is to promote the downstream wood processing industries by transforming wood waste into usable products. Therefore, in this study, sawdust was used as a raw material for making particleboard. This development is ecologically sound as previously wasted material is now being transformed into usable products, thereby conserving our natural resources.

The general aim of this study is to produce the particleboard as a new product by using sawdust in Myanmar. Besides, the following specific objectives of the present study are expected to elaborate.

1) To promote the downstream wood-processing industries by transforming wood waste into usable products.
2) To estimate the total volume of particleboards which can be produced by using sawdust obtained from MTE saw mills.
3) To investigate some chemical content of raw material, i.e sawdust.
4) To investigate some physical and mechanical properties of the tested particleboards.

2. LITERATURE REVIEW

2.1 Definition of particleboard

Particleboard is a product in the form of panels made from chips or particles of wood or other fibrous lignio-cellulosic matter bonded together with an organic binder (glue) by means of heat and pressure, etc.

2.1 Distinction between particleboard and fibreboard

To avoid possible confusion, a distinction must be drawn at the outset between particleboard and fiberboard; the latter is manufactured from wood pulp or other processed or semi-processed materials, and the bonding results from the arrangement or felting of the fiber and their inherent adhesive properties. In other words fiberboard is made from pulp and not from particles, i.e., its constitutents are not only inter-woven but held together by a natural binder whose main origin is the fiber itself. The fiberboard industry is closely associated with the paper pulp industry, and has nothing in common with particleboard manufacture.

2.3 Background history of prticleboard

Particleboard was developed in the Federal Republic of Germany in 1948 (after the second world war), when the country was short of wood. It was thus possible to put large quantities of sawmill waste to good use. The industry has grown considerably since then. Present world production runs into several million tons of board a year. From being a substitute product, particleboard has come to be regarded as the normal material for a number of uses.

2.4 Advantages and uses of particleboard

Particleboard can take place of wood where timber is in short supply. It can be made from a great number of raw materials such as sawmill and forest waste, wood unsuitable for the sawmill, maize stems, sugar cane residue (bagasse), cotton plant stalks, flax husks and certain wild grasses. A wide range of product may be made, including boards for thermal and acoustic insulation from low-density materials, heavy woods produce harder boards used for many purposes.

Generally speaking, the largest uses of particleboard are the furniture and building industries, there is an infinite range of application in building, such as partitions, doors, flooring, formwork for concerate, etc.

2.5 Some characteristics of particleboard

The following are worth mentioning:-

- Panel sizes, of which there are many ranges from 2 m by 4 m to about 2.5 m by 8 m, they are determined by the size of the press, which in turn, is dependent on production capacity. Thickness runs from 8 mm to 30 mm.

- Density vary from 500 to 900 kgm^{-3}, according to the density of the raw material used.
- Dimensional stability is remarkable and is always superior to that of wood.
- Resistance to water, fire or insects can be obtained by incorporating various substances in the course of manufacture.
- Protection of the outer surface can be achieved in many ways, e.g. by the use of varnish, wood veneer or hard plastic facing, or even printing.

2.6 The principle mechancial properties of particleboard

The following are standard test figures

- Bending strength 200 $kgcm^{-2}$
- Transverse strength (to tearing) 4.5 kg cm^{-2}
- Water content 8 %

2.7 Production process

The manufacture of particleboard is relatively simple: shavings or chips of wood or other ligneous material are coated with a special adhesive, and then hot pressed so as to polymerise and harden the adhesive and then form a rigid board between the particles.

There are two methods of manufacture:

- The extrusion process
- The platen process

In the extrusion process particles are forced into a heated die and leave it in the form of board. Although less costly such extrusion forming has not been widely adopted, owing to the irregular quality and appearance of the board.

In the platen process method, the particles are pressed flat in a horizontal press. There are many variants of their process but the principle remaining the same.

Classification according to the density of the particleboards;

- ✓ Low-density particleboard: A particleboard, with a density of less than 500 kg/m^3 (37 lb/ft^3).
- ✓ Medium-density particleboard: A particleboard, with a density between 500-800 kg/m^3 (37-50 lb/ft^3)
- ✓ High-density particleboard: A particleboard, with a density greater than 800 kg/m^3 (50 lb/ft^3)

2.8 History of production, consumption and use of particleboard

The idea to create particleboard has a long history, but the term "particleboard" was not used for a long time. It is called "artificially board" why such sheetlike boards in large size suitable for building were not produced earlier. The reasons are as follows:

1) There was no proper idea about production of particles, flakes, spliters.
2) Glues for particleboard were available, but proper kind and necessary amount were not known.
3) Pressure cycles were not known.
4) Consumers were reluctant because they were accustomed to solid wood or plywood.
5) Many machines for the production of the new material (chippers, dryers, mixers, chip spreaders, mat prepresses, single and multi-daylight extrusion press etc.) were lacking.
6) Procedures for testing particleboard did not exist, strength values were underestimated, hygroscopicity was overestimated and surfacing and gluing were not experienced.

7) Screw-holding and nail-holding power was not known or underestimated (Kollmann, 1975).

2.9 Comparison of solid wood to particleboard

One of the advantages of particleboard is stability. Solid wood is prone to warping and splitting with changes in humidity, whereas particleboard is not. Untreated particleboard will disintegrate, however, when exposed to high levels of moisture. This problem is somewhat mitigated by laminating the particleboard on both sides with melamine resin to reduce moisture ingress. Solid wood has structural advantages over particleboard. It is stronger, allowing it to support greater weights as shelves or other furniture; unless braced or built with thick material, particleboard shelves may visibly sag over time. Solid wood is also more durable. Most damage to solid wood can be repaired easily, often simply by sanding. Any damage to particleboard is difficult to repair. More people consider solid wood furniture to be more attractive than particleboard. However, the veneer on particleboard is usually cut from wood selected for its appearance and so has the potential of being just as attractive.

2.10 Definitions and classification of wood waste (residues)

Wood residues refer to wood left over from any conversion process. Residues can refer to logging waste or mill waste.

2.10.1 Logging waste

It refers to any wood lying on the ground as a direct result of logging operations and trees severely damaged during logging operations. Approximately one-third of all logging residues originate from felled trees and the balance from residual trees destroyed or damaged during logging and extraction (Andersen, 1999a; FAO, 2001).

The residues may range from portions of the trees including high stumps-to entire trees broken during the logging process and left on the ground. They can be roughly divided into the following categories:-

- High stumps (Leaving usable wood in the stump)
- Stem section above the first branches (Top log)
- Branches
- Off-cuts, rotten parts
- Standing trees broken or severely damaged in the crown
- Standing trees severely damaged (Butt trunk and root damaged)
- Splinter trees and logs
- Logs lost and not recovered

Logging residues can be found directly in the stump area, along skid trails and roadside landings. Damaged trees should also be counted as waste, as they will not contribute to the future crop and could have been harvested during regular felling operations. The composition of the residues in a particular location not only affects technical options for their use but also determines costs and benefits of their extractions.

With respect to logging, the first step is to avoid the generation of residues as far as possible. Applying reduced impact logging (RIL) practices can reduce damage to the residual stand by up to 50 percent, which would have a significant impact on residue volumes while leaving a more productive stand for future wood production. In fact, the increased use of logging residues should only be promoted in combination with improved harvesting techniques.

2,10.2 Wood processing waste

It consists of any wood fiber not used during the conversion process at a mill _ be it a saw mill, veneer mill and plywood mill. The classifications of mill waste are

- o Discarded logs
- o Bark
- o Saw dust

- o Slabs, ribs
- o Peeler cores
- o Grading off-cuts
- o Sander dust
- o Shavings
- o Rejects

Any wood waste management strategy should follow the '4R' approach (i.e., reduce, reuse, recycle and recover) (Wan Tarmeze *et al*., 1999; FAO, 2001)

- ❖ Reduce : minimize waste during primary processing and storage
- ❖ Reuse : use waste in downstream industries without changing its mechanical structure (eg: off-cuts to the joinery)
- ❖ Recycle : use waste for reconstituted panel production such as particleboard
- ❖ Recover : use residues as fuel

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Raw materials

Three types of particleboards, Teak (*Tectona grandis*), In (*Dipterocarpus tuberculatus*) and assorted timber species were tested. Teak-sawdust was collected from No.8 saw mill, Hlaing Township in Yangon, In-sawdust was collected from No.27 saw mill, Thagaya, Yedershe Township, Bago Division and assorted sawdust was collected from No.21 saw mill, Kweshin, Pyinmana Township, Mandalay Division.

3.1.2 Adhesive

Urea-formaldehyde was used as the binder. This adhesive was prepared at the No.1 plywood factory, MTE, Yangon.

3.2 Methods

3.2.1 Board making

The sawdust was air-dried in a controlled laboratory condition for 3 weeks and then oven-dried to 3 to 5 % moisture content before the eventual board formation. Then, sawdust was screened by a sieve through meshes with 0.8 to 3 mm to remove oversize. After screening, 15.2 cm × 15.2cm × 15.2cm (6in × 6 in ×6 in) of sawdust was mixed with 750 ml of urea-formaldehyde adhesive. After mixing with adhesive, the raw materials were laid in an iron mould to form (30 × 30 × 1.2) cm^3 sheets. The consolidated mat was finally pressed between two stainless steel cauls plates which was electrically heated at the temperature 120 ºC for 8 minutes at 110 psi. The tested particleboards were made in Wood Chemistry Laboratory, Forest Research Institute (FRI), Yezin. Fifty particleboards for each type were made and the boards were kept in the air-conditioned room before testing.

3.2.2 Tests on chemical, physical and mechanical properties

To investigate the quality of raw material and variation among different species and variation between boards, tests on some chemical properties, some physical properties and some mechanical properties were conducted.

3.2.2.1. Chemical properties

Some chemical properties such as hot water solubility, 1 % NaOH, alcohol-benzene solubility and lignin content were conducted at the Wood Chemistry Laboratory, FRI. Sample preparation and testing procedure were carried out according to TAPPI (Technical Association of Pulp and Paper Industry) standard methods. Firstly, three different kinds of sawdust were put in a shaker with sieve to pass through a No. 60 (250 µm) mesh size. The sawdust was placed in glass jars, labelled with appropriate code for chemical analysis. Each test was conducted using 3 replications.

3.2.2.1.1 Determination of alcohol-benzene solubility

Oven-dried sample 5 g was weighed and placed in a previously oven-dried, cooled and weighed thimble. Then, thimble was placed in a soxhelt apparatus and extracted with (250-300 ml) alcohol-benzene mixture (33 parts of ethyl alcohol and 67 parts of benzene) for six hours or until the color of mixture was clear. After then, thimble was removed from the soxhelt apparatus and dried in the oven at (105 ± 2 ºC) for constant weight. After drying, it was cooled in descitor and weighed. Alcohol-benzene solubility percent was calculated when the constant weight of thimble with content was obtained.

$$\text{Alcohol-benzene solubility \%} = \frac{(C - B)}{A} \times 100$$

where,

A = OD wt of sample in gram (before extraction)

B = OD wt of thimble in gram

C = OD wt of thimble with sample in gram (after extraction)

3.2.2.1.2 Determination of hot water solubility

Oven- dried sample (2 ± 0.1 g) was weighed and placed in a flask and 100 ml of distilled water was added. A reflex condenser was attached to the flask and the apparatus was placed in a gently boiling water bath at (100 ºC) for three hours. Special attention was given to ensure that the level of the solution in the flask remained below that of the boiling water. Samples were then removed from the water bath and filtered with 1-G-1crucible. The residues in the flask were washed with hot distilled water until the flask has no residues. The 1-G-1crucible with the content was kept in the oven at (105 ± 2 ºC) for constant weight. After drying, it was cooled in the desicator and weighed. Material dissolved in the hot water solubility was calculated when the constant weight of cotton bag with content was obtained. And then, hot water solubility percent was calculated.

$$\text{Hot water solubility \%} = \frac{(C-B)}{A} \times 100$$

where,

A = ODW of sample in gram (before extraction)

B = ODW of 1-G-1crucible in gram

C = OD wt of 1-G-1crucible and sample in gram (after extraction)

3.2.2.1.3 Determination of 1 % NaOH solubility

Oven-dried sample (2 ± 0.1 g) was weighed and placed in beaker, and 100 ml of NaOH solution was added into it and stirred. After stirring well, the covered beaker was placed in the water bath, which will be boiling steadily for exactly 1 hour, stirring the content three times, at periods of 10, 15 and 25 min after the beaker was placed in the boiling bath. After 1 hour, the contents of the beaker were filtered by a cotton bag and washed by 100 ml of hot water, then with 50 ml of acetic acid (10 %), and then thoroughly with hot water. The cotton bag with content was dried to constant weight at (105 ± 2 ºC), cooled in desicator and weighed.

$$1\ \%\ \text{NaOH} = \frac{(C-B)}{A} \times 100$$

where,

A = ODW of sample in gram (before extraction)

B = ODW of cotton bag in gram

C = ODW of cotton bag with sample in gram (after extraction)

3.2.2.1.4 Determination of lignin content

Oven-dried and extracted free sample (1g) was weighed and placed in a pestle and motor. Then 15 ml of 72% H_2SO_4 acid was added. The mixture was stirred at 20 ºC for two hours. After two hours, the mixture was transferred into a conical flask and 665 ml of distilled water was added to obtain 3 % acid concentration. And then, the flask was connected with condenser to attain constant solution level and heated at 100 ºC for four hours. After four hours, the flask was cooled at the room temperature. The samples were filtered into the 1-G-3 crucible. The content in the 1-G-3 crucible was washed with hot water until it was free from acid. Then it was dried in the oven at (105 ± 2 ºC) for two hours. After OD, it was cooled in desicator and weighed. Lignin content was calculated when the constant weight of 1-G-3 crucible with content was obtained.

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

where,

A = ODW of sample in gram (before testing)

B = ODW of 1-G-3 crucible in gram

C = ODW of 1-G-3 crucible with sample in gram (after testing)

3.2.2.2 Physical properties

Tests on some physical properties such as moisture content, density, specific gravity, shrinkage, thickness swelling and water absorption were carried out in this study. All tests were conducted at the Timber Physics Laboratory, FRI. Sample preparation and testing procedure were conducted according to ASTM (American Society for Testing and Material) standard D 1037-64. All the tested samples were prepared at the FRI Wood Workshop. The size and number of samples for each test were shown in Table 3.1. Twenty-five boards of each species were used for testing physical properties. Density, specific gravity and volumetric shrinkage were tested from one single sample, and similary, thickness swelling and water absorption were also tested from one sample. Therefore, two samples were cut from each board for testing. For weighing samples, an electrical digital balance was used and for measuring the thickness of the samples, a digital caliper was used.

Table 3.1 Size and total number of specimens for physical properties

Sr No.	Name of Test	Width and Length of specimen(mm)	N
1	Density	20 × 80	25
2	Specific Gravity	20 × 80	25
3	Volumetric shrinkage	20 × 80	25
4	Thickness swelling	76.2 × 76.2	25
5	Water absorption	76.2 × 76.2	25

3.2.2.2.1 Moisture content

The test specimens were weighed to the accuracy of 0.01 g and then, they were dried in an oven at (103 ± 2 ºC) until they had attained the constant weight. The moisture content of each test specimen was determined as the loss in weight, expressed as a percent of the OD weight.

$$\text{MC \%} = \frac{(IW - ODW)}{ODW} \times 100$$

where,

IW = initial weight of sample in gram

ODW = oven-dried weight of sample in gram

3.2.2.2.2 Density and specific gravity

The test specimen was weighed and its volume was determined by water displacement method. Then, they were dried in an oven at (103 ± 2 ºC) until they had attained the constant weight. During drying, weighing and measuring the specimens were carried out every day. After attaining a constant weight, the volume was measured again.

$$\text{Density} = \frac{M}{V}$$

where,

M = weight of the specimen

V = volume of the specimen

For specific gravity, the test specimens were weighed to an accuracy of not less than ± 0.02%. It is the ratio of the density of the board to the density of water at 4 ºC.

$$\text{Specific gravity} = \frac{\text{ODW}}{\text{V}} \times \frac{1}{\text{density of water}}$$

where,

ODW = oven-dried weight of sample

V = volume at test

3.2.2.2.3 Shrinkage

The specimens were weighed for determination of volumetric shrinkage and the data were recorded. For weighing specimens, an electrical digital balance was used and two decimal places were read. To determine volumetric shrinkage, water displacement method was used in determining volume. Then, they were oven-dried at a temperature of 103 ± 2 ºC until they had attained constant weights. During oven drying, weighing the specimens were carried out every day. The volumetric shrinkage from test to oven-dry was determined by the formula,

$$V_o\% = \frac{(V_1 - V_2)}{V_1} \times 100$$

where,

V_o = volumetric shrinkage of a specimen from initial volume to oven-dry volume

V_1 = the initial volume of the specimen

V_2 = the volume of the specimen after oven-drying

3.2.2.2.4 Thickness swelling and water absorption

The test specimen was conditioned as nearly as deemed practical to constant weight and moisture content in a conditioning chamber maintained at a temperature of 20 ± 3 ºC. After conditioning, the specimen was weighed to the accuracy of not less than ±0.2 % and the thickness was measured to an accuracy of not less than ±0.3%. The thickness was measured to an accuracy of ±0.3% at three points along each side. After that, the specimens were submerged horizontally under 1 in (25 mm) of distilled water maintained at the room temperature. After 24-hours submersion, the specimen was suspened to drain for 10 minutes, the excess surface water was removed and the specimen was weighed and its thickness was measured immediately.

$$\text{Thickness swelling }\% = \frac{(FT - IT)}{IT} \times 100$$

where,

FT = final thickness of specimen

IT = initial thickness of specimen

$$\text{Water absorption }\% = \frac{(FW - IW)}{IT} \times 100$$

where,

FW = final weight of specimen

IW = initial weight of specimen

3.2.2.3 Mechanical properties

Some mechanical properties such as static bending, compression parallel to surface and compression perpendicular to surface were conducted at Timber Mechanics Laboratory, FRI. Sample preparation and testing procedure were conducted according to ASTM D 1037-64. Thirty boards for each species were used for testing mechanical properties. Ninety samples for each of the tested species were cut from these boards. The size and number of samples for each test are given in Table 3.2. Table 3.2

Table 3.2 Size and total number of specimens for mechanical properties

Sr No.	Name of Test	Width and Length of specimen (mm)	N
1	Static Bending	76 × 230	30
2	Compression parallel to surface	20 × 60	30
3	Compression perpendicular to surface	20 × 60	30

For testing mechanical properties, a Shimadzu Autograph Universal Testing Machine was used.

3.2.2.3.1 Static bending

For static bending, the test piece of size 12 mm × 76 mm × 230 mm was supported and center loading was used with a span length of 210 mm. The load was applied to the center of the specimen at a constant rate of 6.5 mm / min. Before testing, the actual dimensions of specimens were taken.

The following common properties are evaluated from the test results:

1. FS@PL $= \frac{1.5P'L}{bd^2}$

2. MOR $= \frac{1.5PL}{bd^2}$

3. MOE $= \frac{P'L^3}{4Dbd^3}$

where,

. FS@PL = Fiber stress at proportional limit

MOR = Modulus of rupture

MOE = Modulus of elasticity

P' = Load at proportional limit

P = Maximum load

b, d, l = breath, depth and span length of the specimen

D = Total deflection at proportional limit

3.2.2.3.2 Compression parallel to surface

For compression parallel to surface, the load was applied continuously throughout the test to cause the movable crosshead of the machine to travel at a constant of 0.6 mm / min. Before testing, the actual dimensions of specimens were measured. Testing was continued until the specimens came across with failure.

The following properties are evaluated:-

Where,

1. MCS $= \frac{P}{A}$

2. FS@PL $= \frac{P'}{A}$

where,

MCS	=	Maximum crushing strength
FS@PL	=	Fiber stress at proportional limit
A	=	Area of cross section
L	=	Length of the specimen
D	=	Total deflection or compression at proportional limit
P	=	Maximum load
P’	=	Load at proportional limit

3.2.2.3.3 Compression perpendicular to surface

For compression perpendicular to surface, the load was applied through a metal plate about 20 mm in width, which was placed on the upper surface of the specimen at equal distance from the ends at right angle to the length. The load was applied through the bearing plate to a radial surface at a rate of 0.3 mm / min. Also, before testing, the actual dimensions of specimens were measured. Testing was continued until the specimens came to be failure.

The fiber stress at the proportional limit is the only strength value evaluated.

$$\text{FS@PL} = \frac{P'}{A}$$

where,

FS@PL	=	Fiber stress at proportional limit
P’	=	Load at proportional limit
A	=	Cross sectional area

3.3Data analysis

In this study, the data obtained from chemical, physical and mechanical tests were subjected to ANOVA test and LSD (0.05) mean comparison test in order to evaluate the significance of the board properties.

The experimental design was a completely randomized one-factorial model:

$$\mathbf{Y_{ij} = \mu + \alpha_i + e_{ij}}$$

where,

Y_{ij} = the value of the j^{th} individual unit belonging to the i^{th} species

μ = mean value

α_i = the effect of beginning in the i^{th} species

e_{ij} = the random error attached to the ij^{th} observation

Table 3.3 Format of the analysis of variance

Source of variation	df	Sums of squares	Mean squares	F ratio
Among treatments	t-1	TXX= $\frac{\sum_{i}^{t} X_i^2}{r}$ - CF	MST	$\frac{MST}{MSE}$
Within treatments	t(r-1)	EXX = SXX - TXX	MSE	
Total	tr-1	SXX = $\sum_{i}^{t}\sum_{j}^{r} X_{ij}^2$ -CF	–	–

Thirty samples for mechanical properties, twenty five samples for physical properties and three samples for chemical properties were used for each test. The research data were entered into Microsoft Excel worksheets as the basic format for analysis, thereafter, transformed into the software used. Data for each test were statistically analyzed and multifactor analysis of various was used (α = 0.05). In this analysis, Statistica Version 6.0 and Microsoft Excel 2003 were used.

4. RESULTS AND DISCUSSION

4.1 Chemical properties

4.1.1 Alcohol-benzene solubility

Alcohol-benzene solubility of raw material consists of all components soluble in organic solvent. It principally consists of resins, fatty acid, their esters, and waxes. The three kinds of raw materials contained high concentration of alcohol-bezene solubility. Alcohol-bezene solubility of raw material exceeds 10 % cause pitch troubles in paper production. Alcohol-bezene solubility percent of three kinds of raw material is shown in Table 4.1 and Figure 4.1.

Table 4.1 Alcohol-bezene solubility of three kinds of raw material (%)

Species	Mean	N	Std Dev.	Min	Max	95% Conf.	CV%
Teak	16.983	3	0.479	16.6	17.52	1.189	2.82
In	13.073	3	0.424	12.78	13.56	1.098	3.25
Assorted	15.92	3	0.442	15.44	16.31	1.054	2.78

The test of significance of the effect of raw materials is conducted by the use of one-way ANOVA (see Table 4.2).

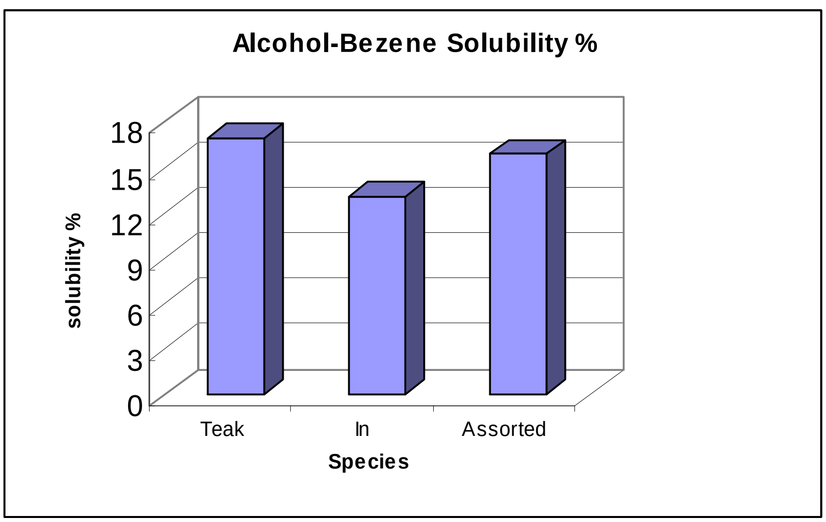

Fig 4.1 Alcohol-bezene solubility of three kinds of raw material (%)

According to the ANOVA table, F= 60.83, the p – value is less than 0.05. Therefore, there is significant effect among the raw materials at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted. It was found that three kinds of raw material are significantly different from each other.

Table 4.2 The ANOVA table for alcohol-bezene solubility

Source of variation	SS	df	MS	F	p
Effect	24.522	2	12.261	60.83	0.000104*
Error	1.209	6	0.202	-	-
Total	26.031	8	12.463	-	-

(Note: "*" means significant at 95 % probability level)

4.1.2 Hot water solubility

The extractive contents, particularly the cold and hot water soluble are important in the predetermination of water-soluble extractives such as tannin, starch, sugar, pectin and phenolic compounds within the woody materials (Khin May Lwin, 2006). The results in Table 4.3 showed that the three kinds of raw material contained high concentration of hot water soluble.

Table 4.3 Hot water solubility of three kinds of raw material (%)

Species	Mean	N	Std Dev.	Min	Max	95% Conf.	CV%
Teak	22.943	3	0.245	22.66	23.09	0.61	1.07
In	21.027	3	0.266	20.8	21.32	2.2	1.27
Assorted	22.823	3	0.884	22.02	23.77	0.66	3.87

If hot water solubility percent of raw material exceeds 10 %, it is unsuitable for pulp production. But these extractives are binding materials and they improve the adherent quality in particleboard-making.

Table 4.4 The ANOVA table for hot water solubility

Source of variation	SS	df	MS	F	p
Effect	6.916	2	3.458	11.37	0.009094*
Error	1.824	6	0.304	-	-
Total	8.740	8	3.762	-	-

(Note: "*" means significant at 95 % probability level)

The test of significance of the effect of raw materials is conducted by the use of one-way ANOVA (see Table 4.2). According to the ANOVA table, F= 11.37, the p – value is less than 0.05. Therefore, there is significant effect among the raw materials at 5 % level of significance.

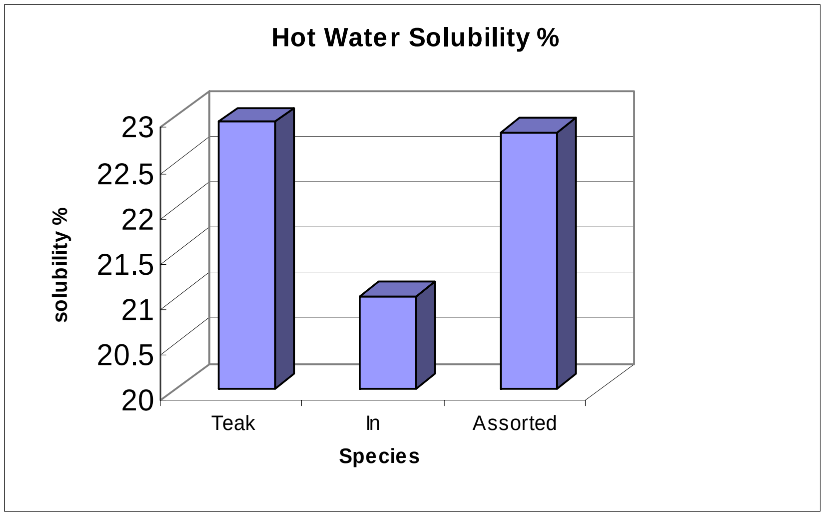

Fig 4.2 Hot water solubility of three kinds of raw material (%)

To investigate which species are significantly different from each other, LSD test is conducted. In this study, LSD test is used because the number of treatment is not too large, say, less than six. It was found that Teak and assorted species are differing significantly from In, wheares there is no significant difference between Teak and assorted.

4.1.3 1% NaOH solubility

The three kinds of raw materials contained high concentration of 1 % NAOH solubility percent. The extractives soluble in this solubility are also binding materials and used to improve the adhesive quality. 1 % NaOH solubility percent of three different kinds of raw material are shown in Table 4.5.

Table 4.5 1% NaOH solubility of three diff: kinds of raw material (%)

Species	Mean	N	Std Dev.	Min	Max	95% Conf.	CV%
Teak	34.573	3	0.402	34.11	34.83	1.00	1.16
In	30.33	3	0.263	30.03	30.52	1.54	0.87
Assorted	35.813	3	0.619	35.1	36.21	0.65	1.73

The test of significance of the effect of raw materials is conducted by the use of one-way ANOVA (see Table 4.6). According to the ANOVA table, F= 121.20, the p – value is less than 0.05. Therefore, there is significant effect among the raw materials at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted. It was found that three kinds of raw materials are significantly different from each other.

Table 4.6 The ANOVA table for 1% NaOH solubility

Source of variation	SS	df	MS	F	p
Effect	49.61	2	24.81	121.20	0.000014*
Error	1.23	6	0.20	-	-
Total	50.84	8	25.01	-	-

(Note: "*" means significant at 95 % probability level)

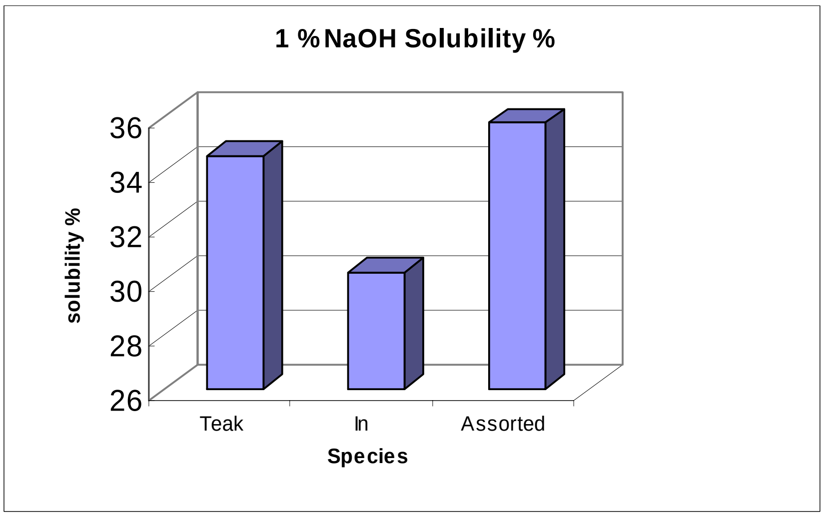

Fig 4.3 1% NaOH solubility of three kinds of raw material (%)

4.1.4 Lignin content

A chemical property of lignin content in raw material is needed to find out for its pulping characteristics. High amount of lignin content in raw materials causes difficulty in pulping and bleaching because lignin possesses resin-like properties. Therefore, high amount of lignin content can cause the adherent quality in particleboard-making.

Table 4.7 Lignin content of three kinds of raw material (%)

Species	Mean	N	Std Dev.	Min	Max	95% Conf.	CV%
Teak	29.023	3	0.081	28.95	29.11	0.201	0.28
In	22.36	3	0.062	22.29	22.41	0.19	0.28
Assorted	23.027	3	0.076	22.96	23.11	0.16	0.33

Ammong the three tested species, Teak has the highest (29.023%) amount of lignin content. Lignin content of three kinds of raw material is as given in Table 4.7.

The test of significance of the effect of raw materials is conducted by the use of one-way ANOVA (see Table 4.8).

Table 4.8 The ANOVA table for lignin content

Source of variation	SS	df	MS	F	p
Effect	80.804	2	40.402	7451	0.000000*
Error	0.033	6	0.005	-	-
Total	80.837	8	40.407	-	-

(Note: "*" means significant at 95 % probability level)

According to the ANOVA table, F= 7451, the p – value is less than 0.05. Therefore, there is significant effect among the raw materials at 5 % level of significance.

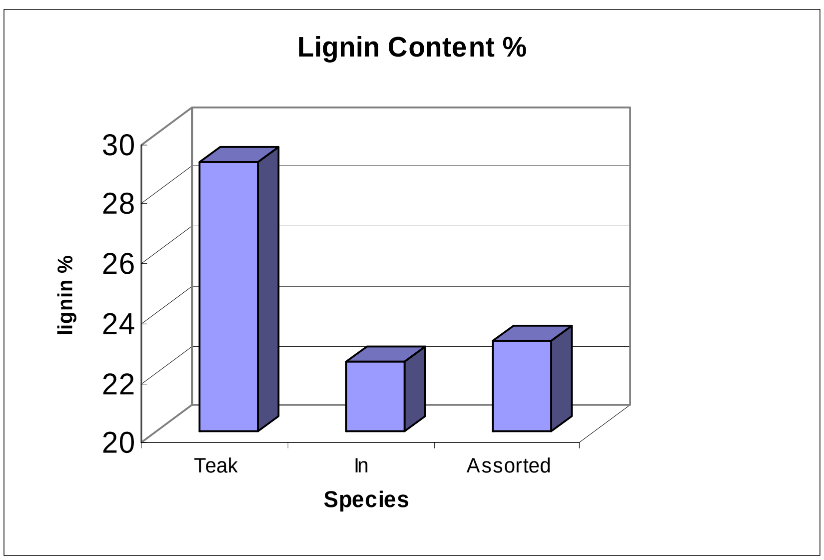

Fig 4.4 Lignin content of three kinds of raw material (%)

To investigate which species are significantly different from each other, LSD test is conducted. It was found that three kinds of raw material are significantly different from each other.

4.2 Physical properties

4.2.1 Moisture content (MC)

The mean MC of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.9.

Table 4.9 Moisture content of particleboards (%)

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	5.193	25	0.248	4.850	5.870	0.102	4.779
In	10.007	25	0.301	9.500	10.640	0.124	3.010
Assorted	10.695	25	0.336	9.590	11.220	0.139	3.145

It ranges from 5.09 to 5.30 % in Teak, from 9.88 to 10.13% in In particleboard and 10.56 to 10.83 % in assorted particleboard at 95 % probability level.

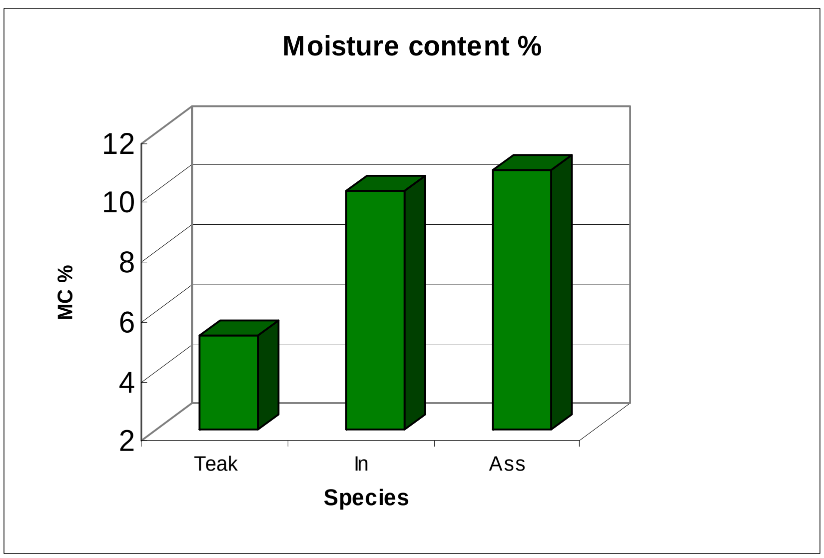

Fig 4.5 Moisture content of particleboards (%)

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.10).

Table 4.10 The ANOVA table for moisture content

Source of variation	SS	df	MS	F	p
Effect	449.402	2	224.701	2539.06	0.00000*
Error	6.372	72	0.088	-	-
Total	455.774	74	224.789	-	

(Note: "*" means significant at 95 % probability level)

According to the ANOVA table, F= 2536.06, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted. It was found that three different kinds of tested boards are significantly different from each other.

According to (As/ NZS 1859:1 2001, Int) the MC of standard particleboards ranges from 5 to 8 %. It can be seen that, mean MC of the tested Teak particleboard lies in the range of standard limit at 95 % probability level. However, the mean MC of In-particleboard and assorted particleboard are found to be higher than the MC of standard particleboard.

4.2.2 Density of particleboards

4.2.2.1 Oven-dried density of particleboards

It is the ratio of oven-dry weight to oven-dry volume of a specimen. The mean oven-dried density of each species, the number of specimens, standard deviation within species, coefficient of variation, maximum and minimum values and 95 % confidence limit are given in Table 4.11.

Table 4.11 Oven-dried density of particleboards (kgm^{-3})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	766.9	25	15.0	735.0	791.0	6.17	1.95
In	828.7	25	23.4	788.0	881.0	9.68	2.83
Assorted	807.1	25	13.6	785.0	845.0	5.63	1.69

It ranges from 760.7 to 773.1 kgm^{-3} in Teak, from 819.0 to 838.4 kgm^{-3} in In particleboard and 801.5 to 812.8 kgm^{-3} in assorted particleboard at 95 % probability level.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.12). According to the ANOVA table, F= 76.9, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance.

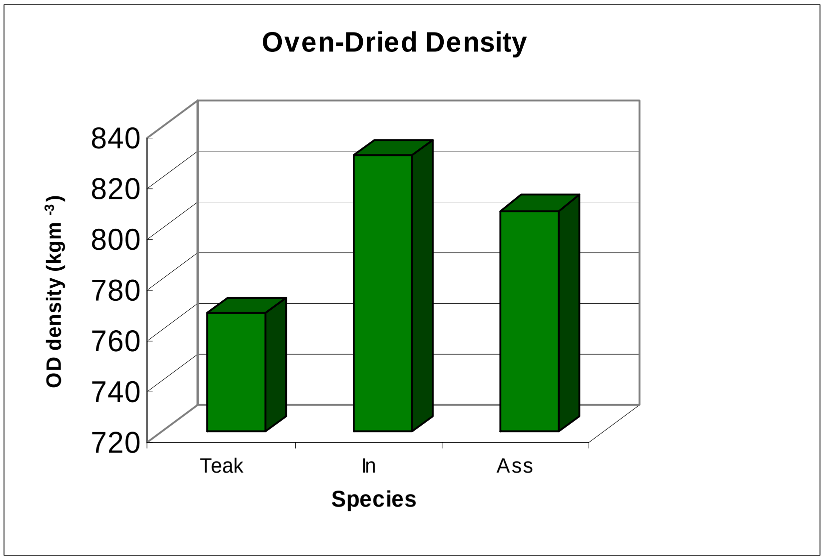

Fig 4.6 Oven-dried density of particleboards (kgm^{-3})

To investigate which species are significantly different from each other, LSD test is conducted . It was found that three different kinds of tested boards are significantly different from each other.

Table 4.12 The ANOVA table for oven-dried density

Source of variation	SS	df	MS	F	p
Effect	49182	2	24591	76.9	0.00000*
Error	23020	72	320	-	-
Total	72202	74	24911	-	-

(Note: "*" means significant at 95 % probability level)

4.2.2.2 Density at test of particleboards

It is the ratio of weight at test to volume at test. The mean density at test of each species, the number of specimens per board, standard deviation within species, coefficient of variation, maximum and minimum values and 95 % confidence limit are given in Table 4.13. It ranges from 766.37 to 778.91 kgm^{-3} in Teak, from 861.66 to 878.82 kgm^{-3} in In particleboard and 817.18 to 827.22 kgm^{-3} in assorted particleboard at 95 % probability level.

It was noted that, the coefficient of variation within trees can be high up to 10 % (Anon, 1974). The CVs of the three tested boards are less than the standard

CV %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise.

Table 4.13 Density at test of particleboards (kgm^{-3})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	772.64	25	15.19	739	795	6.27	1.97
In	870.24	25	20.80	844	919	8.58	2.39
Assorted	822.20	25	12.17	802	846	5.02	1.48

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.14).

Table 4.14 The ANOVA table for density at test

Source of variation	SS	df	MS	F	p
Effect	119082	2	59541	220.1	0.0000*
Error	19474	72	270	-	-
Total	138556	74	59811	-	-

(Note: "*" means significant at 95 % probability level)

According to the ANOVA table, F= 220.1, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance.

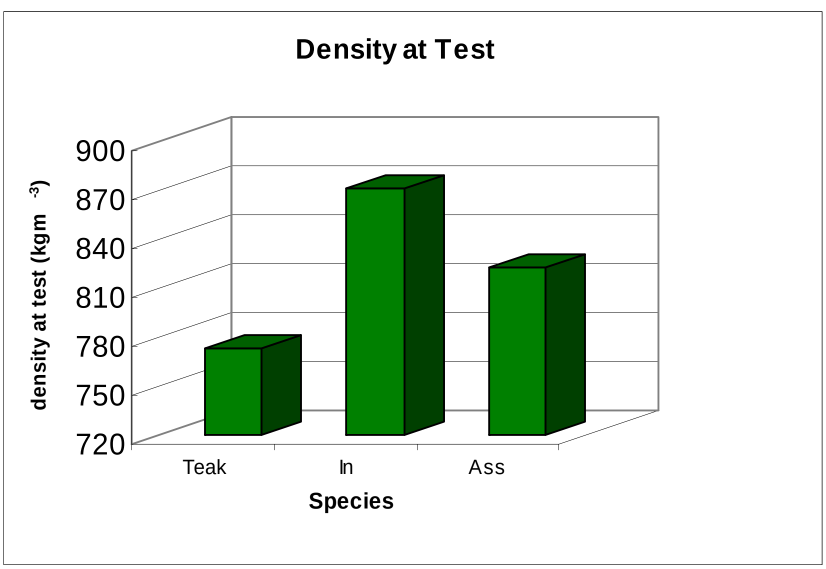

Fig 4.7 Density at test of particleboards (kgm^{-3})

To investigate which species are significantly different from each other, LSD test is conducted. It was found that three different kinds of tested boards are significantly different from each other.

4.2.3 Specific gravity

It is the ratio of the density of the board to the density of water at 4ºC. Specific gravity of wood and wood-products are always based on oven-dried weight. This property is an important parameter in determining the strength of a particular species in the absence of actual strength test results.

4.2.3.1 Oven-dried specific gravity of particleboards

The mean oven-dried specific gravity of each species, the number of specimens, standard deviation within species, coefficient of variation, maximum and minimum values and 95 % confidence limit are given in Table 4.15.

Table 4.15 Oven-dried specific gravity of particleboards

Species	Mean	N	Std Dev	Min	Max	95 % Conf.	CV%
Teak	0.767	25	0.015	0.735	0.791	0.006	1.95
In	0.829	25	0.023	0.788	0.881	0.010	2.83
Assorted	0.807	25	0.014	0.785	0.845	0.006	1.69

It ranges from 0.761 to 0.773 in Teak, from 0.819 to 0.838 in In particleboard and 0.801 to 0.813 in assorted particleboard at 95 % probability level.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.16). According to the ANOVA table, F= 76.9, the p – value is less than 0.05.

Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted . It was found that three different kinds of tested boards are significantly different from each other.

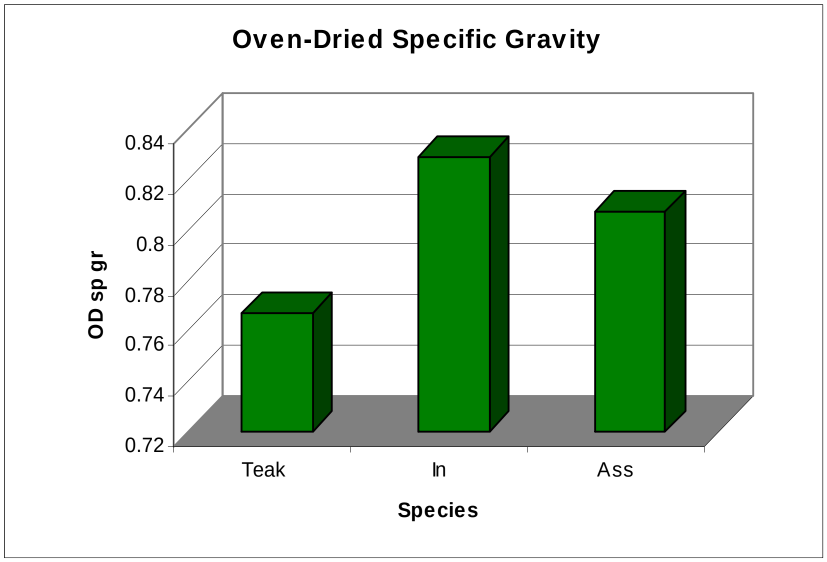

Fig 4. 8 Oven-dried specific gravity

Table 4.16 The ANOVA table for oven-dried specific gravity

Source of variation	SS	df	MS	F	p
Effect	0.04918	2	0.02459	76.9	0.00000*
Error	0.02302	72	0.00032	-	-
Total	0.0722	74	0.02491	-	-

(Note: "*" means significant at 95 % probability level)

4.2.3.2 Specific gravity at test

The mean specific gravity at test of each species, the number of specimens, standard deviation within species, coefficient of variation, maximum and minimum values and 95 % confidence limit are given in Table 4.17.

Table 4.17 Specific gravity at test of particleboards

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	0.732	25	0.016	0.693	0.757	0.007	2.15
In	0.792	25	0.020	0.761	0.838	0.008	2.48
Assorted	0.745	25	0.009	0.725	0.759	0.004	1.24

It ranges from 0.726 to 0.739 in Teak, from 0.784 to 0.800 in In particleboard and 0.741 to 0.749 in assorted particleboard at 95 % probability level.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.18). According to the ANOVA table, F= 103.4, the p – value is less than 0.05.

Table 4.18 The ANOVA table for specific gravity at test

Source of variation	SS	df	MS	F	p
Effect	0.04969	2	0.02485	103.4	0.0000*
Error	0.01730	72	0.00024	-	-
Total	0.06699	74	0.02409	-	-

(Note: "*" means significant at 95 % probability level)

Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted . It was found that three different kinds of tested boards are significantly different from each other.

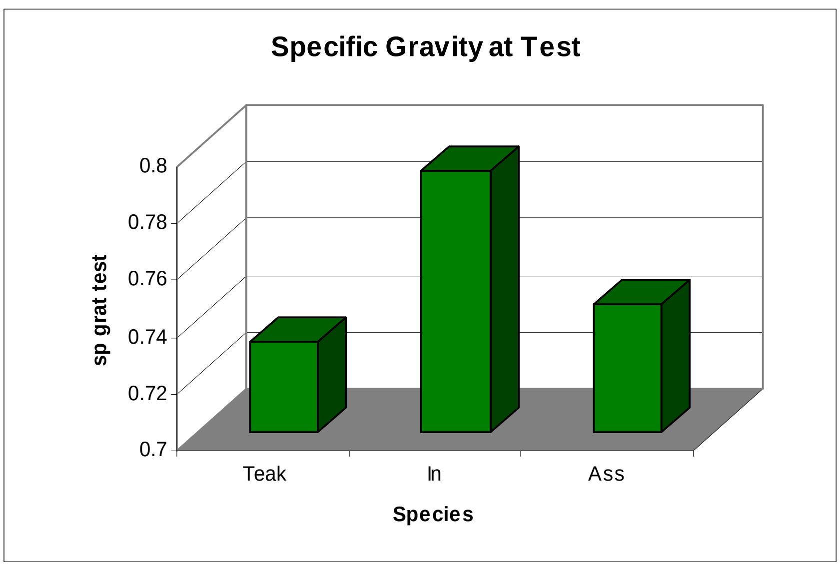

Fig 4. 9 Specific gravity at test

4.2.4 Volumetric shrinkage

The mean volumetric shrinkage of each species, the number of specimens, standard deviation within species, coefficient of variation, maximum and minimum values and 95 % confidence limit are given in Table 4. 19.

Table 4.19 Volumetric shrinkage (%)

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	4.802	25	0.276	4.400	5.310	0.114	5.75
In	4.895	25	0.340	4.520	6.000	0.140	6.95
Assorted	7.911	25	0.297	7.560	8.530	0.123	3.75

It ranges from 4.688 to 4.916 % in Teak, from 4.755 to 5.036 % in In particleboard and 7.789 to 8.034 % in assorted particleboard at 95 % probability level. The coefficients of variation within trees can be high up to 15 % (Anon, 1974). It can be seen that, the coefficient of variation of three different kinds of particleboard is less than 7 %, which might point out that the result is to be reliable.

Table 4.20 The ANOVA table for volumetric shrinkage

Source of variation	SS	df	MS	F	p
Effect	156.410	2	78.205	837.65	0.0000*
Error	6.722	72	0.093	-	-
Total	163.132	74	78.298	-	-

(Note: "*"means significant at 95 % probability level)

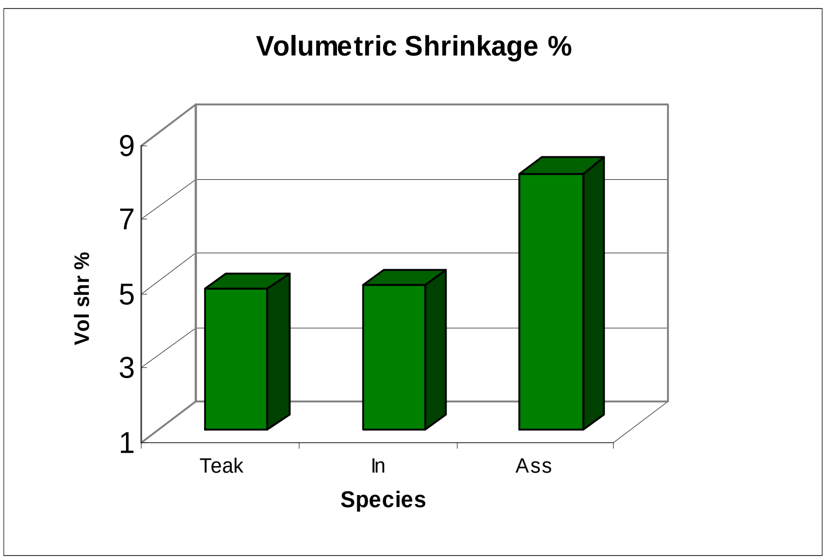

Fig 4.10 Volumetric shrinkage (%)

It was noted that, volumetric shrinkage of Myanmar's hardwood species lies between 6.1 to 21.9 % (Cho Cho Win and Win Kyi, 2008). The volumetric shrinkage of Teak and In particleboard are less than that of hardwood species. The volumetric shrinkage of assorted particleboard is higher than that of some hardwood species because it is combining with so many species and they have different chemical content, moisture content and other factors.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.20).

According to the ANOVA table, F= 837.65, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance.

To investigate which species are significantly different from each other, LSD test is conducted . It was found that both Teak and In particleboard are differing significantly from assorted particleboard, wheares there is no significant difference between Teak and In.

4.2.5 Thickness swelling and water absorption

4.2.5.1 Thickness swelling

The mean thickness swelling of each species, the number of specimens, standard deviation within species, coefficient variation, maximum and minimum values of each species and 95 % confidence limit are given in Table 4.21.

Table 4.21 Thickness swelling for 24 hour water submersion (%)

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	1.785	25	0.054	1.620	1.850	0.022	3.02
In	2.042	25	0.063	1.890	2.120	0.026	3.07
Assorted	2.294	25	0.092	2.120	2.450	0.038	4.00

After 24-hour water submersion, it ranges from 1.763 to 1.807 % in Teak, from 2.016 to 2.068 % in In particleboard and 2.256 to 2.332 % in assorted particleboard at 95 % probability level. The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.22).

According to the ANOVA table, F= 318.49, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted .

It was found that three different kinds of tested boards are significantly different from each other. According to British Standard Institution (BS), 5669-1977, the thicknesses swelling of standard particleboard is 12%, for flooring, the swelling is 10% and for moisture resistance particleboard is 8%.

So the three sampled particleboard; Teak particleboard, In particleboard and assorted particleboard can be compared with the standard particle board in terms of thicknesses swelling.

Table 4.22 The ANOVA table for thickness swelling

Source of variation	SS	df	MS	F	p
Effect	3.2407	2	1.6203	318.49	0.0000*
Error	0.3663	72	0.0051	-	-
Total	3.6070	74	1.6254	-	-

(Note: "*" means significant at 95 % probability level)

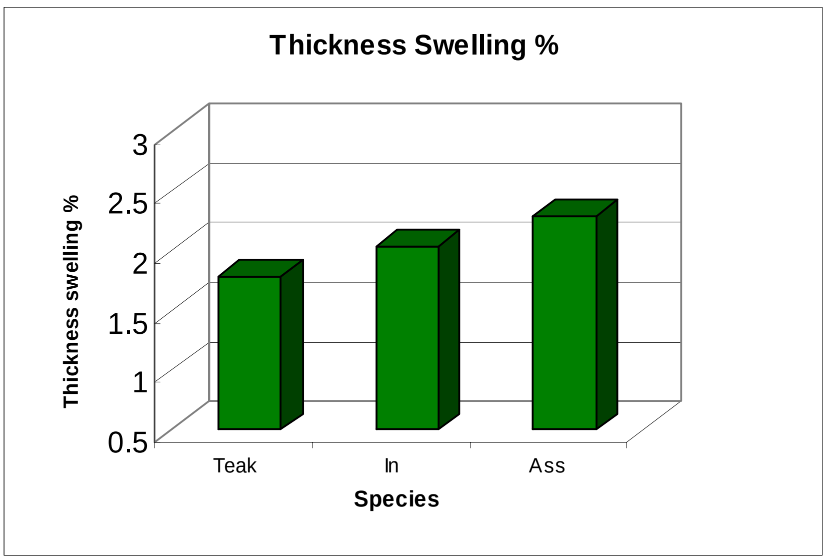

Fig 4. 11 Thickness swelling for 24 hour water submersion (%)

4.2.5.2 Water absorption

The mean water absorption of each species, the number of specimens, standard deviation within species, coefficient variation, maximum and minimum values of each species and 95 % confidence limit are given in Table 4.23.

Table 4.23 Water absorption for 24 hour water submersion (%)

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	6.059	25	0.171	5.770	6.420	0.070	2.82
In	8.088	25	0.133	7.680	8.310	0.055	1.65
Assorted	12.857	25	0.251	12.280	13.210	0.104	1.95

After 24-hour water submersion, it ranges from 5.989 to 6.13 % in Teak, from 8.033 to 8.143 % in In particleboard and 12.754 to 12.961 % in assorted particleboard at 95 % probability level.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.24).

Table 4.24 The ANOVA table for water absorption

Source of variation	SS	df	MS	F	p
Effect	608.933	2	304.466	8314.3	0.0000*
Error	2.637	72	0.037	-	-
Total	611.570	74	304.503	-	-

(Note: "*" means significant at 95 % probability level)

According to the ANOVA table, F= 8314.3, the p – value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted . It was found that three different kinds of tested boards are significantly different from each other.

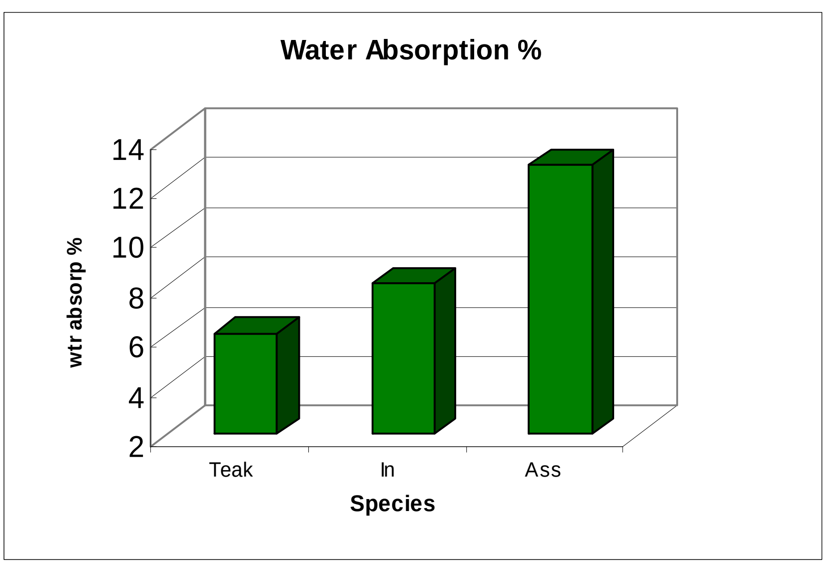

Fig 4.12 Water absorption for 24 hour water submersion (%)

According to BS, 5669-1977, water absorption of medium-density particleboard ranges from 10 to 50 % and high-density particleboard ranges from 15 to 40 %. It can be seen that, mean water absorption of the tested Teak particleboard, In particleboard and assorted particleboard are less than the standard limit at 95 % probability level.

4.3 Mechanical properties

These properties are taken into consideration in the use of material where strength is essential. The manifold applications of particleboard in furniture manufacture, for building purposes and for other uses, for instance in shipbuilding, for containers, as parts of railway-carriages, automobiles, trucks, etc, require adequate elasticity, rigidity, strength and hardness. Particleboard was not used for load-bearing or highly stressed structural elements. Particleboard was mainly used for core board in the manufacture of furniture, for paralleling ceilings, partitions and sub-flooring. The various mechanical properties are correlated to the type and structure of particleboards, to their density, moisture content, and particularly to the nature of overlays glued to their surface. There exist many types of particleboard with various thicknesses. Therefore, the mechanical and related properties must be interpreted as wide ranges (Kolmann, 1975).

4.3.1 Static bending

The properties from the static bending play an important role in the uses of wood as beams. For static bending, two properties are usually measured: modulus of rupture (MOR) and modulus of elasticity (MOE). The bending strength or modulus of rupture is the most important mechanical property of particleboard with respect to their practical application with them. It is not known that neither in beams or plates of solid wood nor in comparable samples of wood based materials the stress distribution over the cross section in linear (Kollmann, 1975).

4.3.1.1 Fiber stress at proportional limit (FS@PL)

It is a stress set up in a specimen by loading it to the proportional limit. It is the maximum stress to which the material can be subjected under a given type of load without being permanently deformed. According to the investigations carried out for this research, the average fiber stresses at proportional limit of three tested species of particleboard are shown in Table 4.25. The mean FS@PL of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.25.

Table 4.25 Fiber stress at proportional limit (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	9.728	30	0.503	8.647	10.455	0.188	5.17
In	8.564	30	0.673	7.574	9.718	0.251	7.86
Assorted	9.243	30	0.712	7.678	10.575	0.266	7.70

It ranges from 9.540 to 9.916 Nmm^{-2} in Teak, from 8.313 to 8.815 Nmm^{-2} for In and 8.977 to 9.509 Nmm^{-2} in assorted particleboard at 95 % probability level. The coefficient of variation of FS@PL of solid timber can be high up to 22 % (Anon, 1999). The CVs of the three tested boards are less than the standard CV % of solid timber.

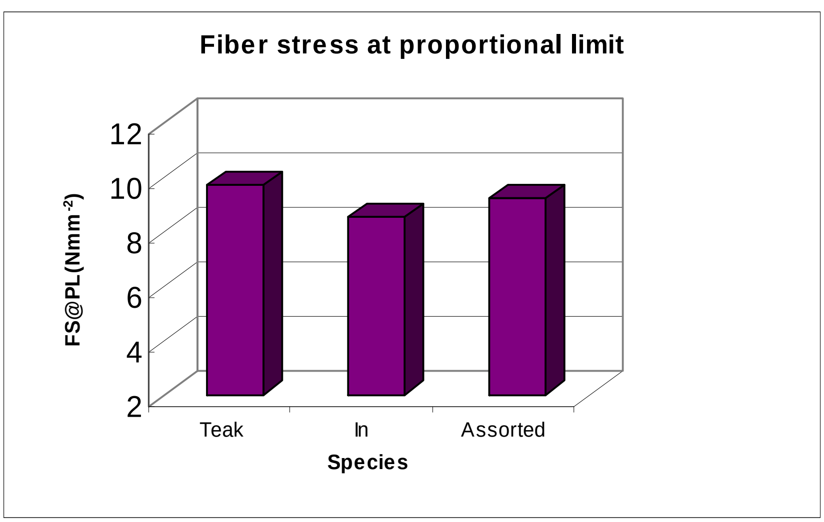

Fig 4.13 Fiber stress at proportional limit in static bending test

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.26). According to the ANOVA table, F = 25.37, the p - value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted .

Table 4.26 The ANOVA table for FS@PL

Source of varation	SS	df	MS	F	p
Effect	20.511	2	10.256	25.37	0.00000*
Error	35.171	87	0.404	-	-
Total	55.682	89	10.660	-	-

(Note: "*" means significant at 95 % probability level)

It was found that three tested particleboards are significantly different from each other.

The FS@PL of sawdust board is 6 Nmm^{-2} (EN 312-2, 1996). Assume that we want to find out, whether the test means are against reference value or not. So one-sample t-test was used . According to t-test, a small p-value ($p<0.05$) indicates a significant deviation of the sample mean from the reference value. The values of three tested boards are larger than the standard value.

4.3.1.2 Modulus of rupture (MOR)

In technical terms, the modulus of rupture is computed as maximum fiber stress in the extreme upper and lower surface fibers of the specimen under test. It is an approximation of the true stress, as the formula for computing it makes assumptions that are valid only up to the proportional limit. In simple terms, this value is regarded as the breaking strength of the product under test (Maloney, 1977).

According to the investigations carried out for this research, the average MORs of three tested species of particleboard are shown in Table 4.27. The mean MORs of each species together with the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are also given in that table. It ranges from 10.96 to 11.08 Nmm^{-2} in Teak, from 9.94 to 10.07 Nmm^{-2} for In and 10.88 to 11.04 Nmm^{-2} in assorted particleboard at 95 % probability level. The coefficient of variation of MOR of solid timber's can be high up to 16 % (Anon, 1999). The CVs of the three tested boards are less than the solid timber standard cv %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise.

Table 4.27 Modulus of rupture (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	11.017	30	0.720	10.658	11.256	0.058	6.54
In	10.006	30	0.878	9.654	10.354	0.067	8.78
Assorted	10.960	30	0.725	10.547	11.321	0.084	6.61

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.28).

Table 4.28 The ANOVA table for MOR

Source of variation	SS	df	MS	F	p
Effect	19.36	2	9.68	273.0	0.0000*
Error	3.09	87	0.04	-	-
Total	22.45	89	9.72		-

(Note: "*" means significant at 95 % probability level)

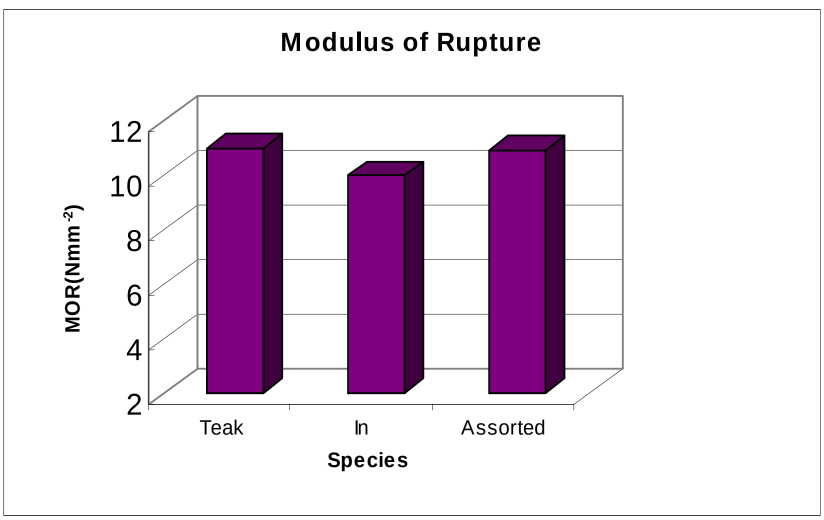

Fig 4.14 Modulus of rupture in static bending test

According to the ANOVA table, F = 273, the p - value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significant. To investigate which species are significantly different from each other, LSD test is conducted .

It was found that both Teak and assorted particleboards are different significantly from In particleboard, wheares there is no significant difference between Teak and assorted particleboard. The MOR of standard particeboard is 11 Nmm^{-2} (EN 312-2, 1996). Assume that we want to find out, whether the test means are against reference value or not. So using one-sample t-test (Appendix-IV), only the value of In particleboard is significantly different from the standard value (9.940 to 10.07 Nmm^{-2}). It was less than the standard value, whereas Teak and assorted boards were not different significantly from the standard value at 95 % probability level. Therefore, it was found that Teak and assorted boards can be compared with the standard board in terms of MOR.

4.3.1.3 Modulus of elasticity (MOE)

The stiffness of a solid body, used either as a beam or a long (or intermediate) column, is a measure of its ability to resist deformation or bending. It is expressed in terms of the modulus of elasticity and applies only within the proportional limit (Kollmann,1975). Modulus of elasticity refers to the stiffness of the material. Modulus of elasticity is a value indicative of stiffness, not of strength. This property is useful in calculating the deflection of the product under stress (Maloney,1975). The mean MOE of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.29.

Table 4.29 Modulus of elasticity (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	2147.296	30	112.88	1946.63	2351.61	42.150	5.26
In	2037.228	30	120.17	1818.25	2396.83	44.874	5.90
Assorted	2229.963	30	152.60	1915.62	2497.10	56.983	6.84

It ranges from 2105.13 to 2189.45 Nmm^{-2} in Teak, from 1992.35 to 2082.10 Nmm^{-2} for In and 2172.981 to 2286.95 Nmm^{-2} in assorted particleboard at 95 % probability level. The coefficient of variation of MOE of solid timber can be high up to 22 % (Anon, 1999). The CVs of the three tested boards are less than the solid timber's standard CV %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.30). According to the ANOVA table, F = 16.67, the p - value is less than 0.05.

Table 4.30 The ANOVA table for MOE

Source of variation	SS	df	MS	F	p
Effect	560960	2	280480	16.67	0.00000*
Error	1463665	87	16824	-	-
Total	2024625	89	297504	-	-

(Note: "*" means significant at 95 % probability level)

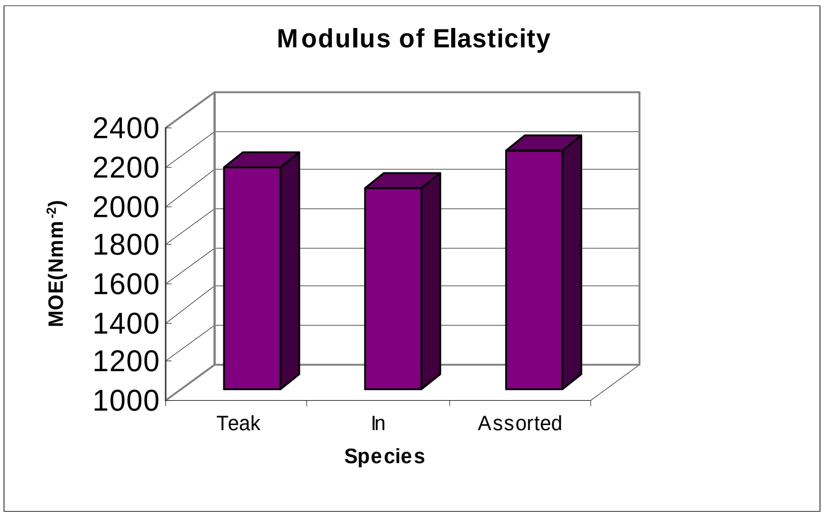

Fig 4.15 Modulus of elasticity of static bending test

Therefore, there is significant effect among the species at 5 % level of significance. To investigate which species are significantly different from each other, LSD test is conducted . It was found that three tested particleboards are significantly different from each other. The MOE of particle board is 2000 N/mm^2 (EN 312-2, 1996).

Assume that we want to find out, whether the test means are against reference value or not. So one-sample t-test was used . According to t-test, only the value of In particleboard is not different significantly from the standard value whereas Teak and assorted boards are significantly different from the standard value at 95 % probability level. They are larger than the standard value. Therefore, it was found that three tested boards can be compared with the standard board in terms of MOE.

4.3.2 Compression parallel to surface

A relatively complicated procedure is necessary for determining the compression strength parallel to surface because of the large variation and the character of the wood-based fiber and particle panel products. It is one that is not used widely in the industry; however, as new products move into structural applications, the determination of this property and the development of design information on it should become more important (Maloney, 1975).

4.3.2.1 Fiber stress at proportional limit (FS@PL)

The mean FS@PL of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.31.

Table 4.31 Fiber stress at proportional limit (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	14.206	30	1.038	11.795	16.419	0.388	7.31
In	12.012	30	0.799	10.820	13.645	0.298	6.65
Assorted	15.418	30	1.115	13.424	17.989	0.416	7.23

It ranges from 13.82 to 14.59 Nmm^{-2} in Teak, from 11.71 to 12.311 Nmm^{-2} for In and 15.00 to 15.83 Nmm^{-2} in assorted particleboard at 95 % probability level. The coefficient of variation of FS@PL of solid timber can be high up to 24 % (Anon, 1999).

Table 4.32 The ANOVA table for FS@PL

Source of variation	SS	df	MS	F	p
Effect	178.83	2	89.41	90.60	0.0000*
Error	85.86	87	0.99	-	-
Total	264.69	89	90.40	-	-

(Note: "*" means significant at 95 % probability level)

The CVs of the three tested boards are less than the solid timber's standard CV %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise. The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.32). According to the ANOVA table, F = 90.60, the p - value is less than 0.05.

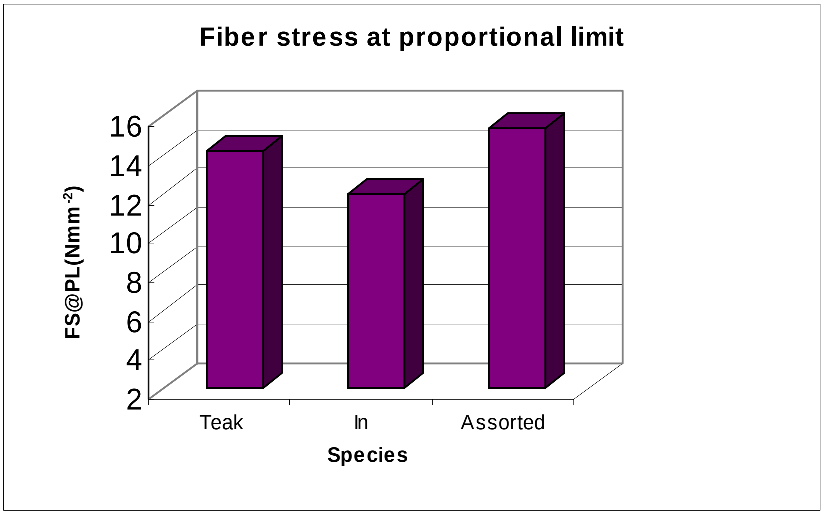

Fig 4.16 Fiber stress at proportional limit in compression parallel to surface

Therefore, there is significant effect among the species at 5 % level of significance.

To investigate which species are significantly different from each other, LSD test is conducted . It was found that three tested particleboards are significantly different from each other.

4.3.2.2 Maximum crushing strength (MCS)

It is the maximum stress sustained by a compression parallel to surface specimen. The mean MCS of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.33.

Table 4.33 Maximum crushing strength (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	16.816	30	1.521	14.096	19.473	0.568	9.05
In	12.883	30	1.281	10.666	17.179	0.478	9.95
Assorted	17.723	30	1.130	15.654	20.409	0.422	6.37

It ranges from 16.25 to 17.38 Nmm^{-2} in Teak, from 12.40 to 13.36 Nmm^{-2} in In particleboard and from 17.30 to 18.14 Nmm^{-2} in assorted particleboard. The coefficient of variation of FS@PL of solid timber can be high up to 18 % (Anon, 1999). The CVs of the three tested boards are less than the solid timber's standard CV %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.34). According to the ANOVA table, F = 113.83, the p - value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance.

Table 4.34 The ANOVA table for MCS

Source of variation	SS	df	MS	F	p
Effect	397.10	2	198.55	113.83	0.0000*
Error	151.76	87	1.74	-	-
Total	548.86	89	200.29	-	-

(Note: "*" means significant at 95 % probability level)

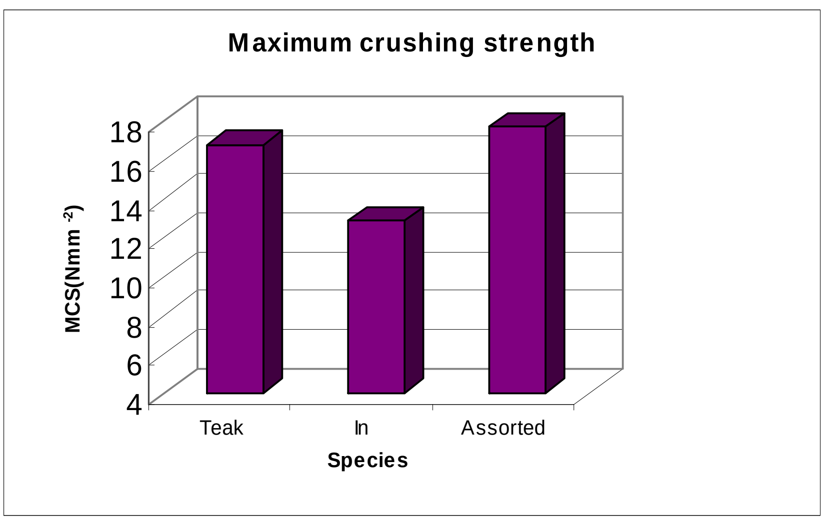

Fig 4.17 Maximum crushing strength in compression parallel to surface

To investigate which species are significantly different from each other, LSD test is conducted . It was found that three tested particleboards are significantly different from each other. It was noted that the maximum crushing strength of particleboard ranges from 8 to 20 N/mm^2 (Kollmann, 1975). The three tested boards lie in the range of standard limit at 95 % probability level.

4.3.3 Compression perpendicular to surface

4.3.3.1 Fiber stress at proportional limit (FS@PL)

The compressive strength perpendicular to the board plane is of minor importance except when particleboard are applied as sub-floors, or if the pressure applied veneering or laminating operations, cause deformation in thicknesses (Kollmann, 1975).

The mean FS@PL of each species, the number of samples, standard deviation, minimum and maximum values, coefficient of variation and 95 % confidence limit are given in Table 4.35.

Table 4.35 Fiber stress at proportional limit (Nmm^{-2})

Species	Mean	N	Std Dev.	Min	Max	95 % Conf.	CV%
Teak	18.115	30	1.029	17.015	20.648	0.384	5.68
In	18.136	30	1.090	16.472	20.284	0.407	6.01
Assorted	18.975	30	1.665	15.685	23.194	0.622	8.77

It ranges from 17.73 to 18.50 Nmm^{-2} in Teak, from 17.73 to 18.54 Nmm^{-2} in In particleboard and from 18.35 to 19.60 Nmm^{-2} in assorted particleboard. The coefficient of variation of FS@PL of solid timber can be high up to 28 % (Anon, 1999).

The CVs of the three tested boards are less than the solid timber's standard CV %. Thus, the individual values of each board are not much dispersed and the results are assumed to be precise.

The test of significance of the effect of species is conducted by the use of one-way ANOVA (see Table 4.36). According to the ANOVA table, F = 4.31, the p-value is less than 0.05. Therefore, there is significant effect among the species at 5 % level of significance.

To investigate which species are significantly different from each other, LSD test is conducted (Appendix- IV). It was found that both Teak and assorted particleboards are different significantly from In particleboard, wheares there is no significant difference between Teak and assortd particleboards.

The compression perpendicular to surface of particleboard ranges from 9 to 14 N/mm^2 (Kollmann, 1975). The three tested boards are higher than the standard limit at 95 % probability level.

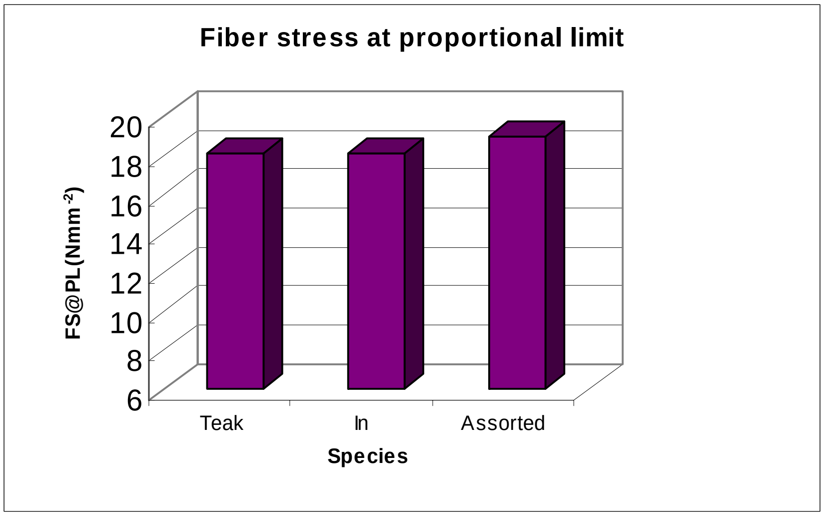

Fig 4.18 Fiber stress at proportional limit in compression perpendicular to surface

Table 4.36 The ANOVA table for FS@PL

Source of variation	SS	df	MS	F	p
Effect	14.44	2	7.22	4.31	0.016344*
Error	145.56	87	1.67	-	-
Total	160.00	89	8.89	-	-

(Note: "*" means significant at 95 % probability level)

4.4 Potential availability of sawmill residues

Average outturn percentage of MTE sawmills for Teak and other non-teak hardwoods together with the otturn percentage of different types sawmill residues are shown in Table (37).Sawn timber production and mill residues under Myanma Timber Enterprise (MTE) for the last 7 years are detailed in Tables 38 and 39, respectively. Estimating the volume of mill waste available for further processing is difficult.

Table 4.37 Throughput, outturn and sawmill residues

Timber species	Throughput (%)	Outturn (%)	Sawmill residues (%)			
			Fuel wood	Sawdust	Slabs	Shaving
Teak	100	45	37	13	4	1
Hardwood*	100	60	30	10	-	-

"*"Hardwoods other than Teak

Recovery rates vary within and among sawmills depending on log sizes, dominant species processed and processing equipment, etc. (FAO, 2001).

There are 10 teak saw mills and 80 hardwood saw mills under MTE. Based on the statistics reported by MTE (2007), the annual average of Teak sawlogs (from 2000-01 to 2006-07) was about 45,043 ton and that of non-teak hardwood sawlogs was about 340,794 ton (see Table 4.38 to 4.39). And, the average rate of recovery is round about 45 % for teak logs and 60 % for other hardwood logs (see Table 4.37). Therefore, about one-half (169,071 ton) of the valuable resources are being discarded as residues such as fuelwood, sawdust, slabs and shaving. Out of these sawmill residues, the total amount of sawdust will be about 39,934 ton.

Table 4.38 Potential availability of hardwood sawmill residues (Ton)

Financial Year	Round log	Sawn Timber	Sawmill residues
2000-01	312277	178963	133314
2001-02	371279	215250	156029
2002-03	341267	201440	139827
2003-04	314902	183321	131581
2004-05	362066	211961	150105
2005-06	376750	224195	152555
2006-07	307018	188326	118692
Average	**340794**	**200494**	**140300**

(Source : MTE)

Rather, the residues are likely to be used by local people as fuelwood or claimed for further industrial processing.

Table 4.39 Potential availability of Teak sawmill residues (Ton)

Financial Year	Round log	Sawn Timber	Sawmill residues
2000-01	60083	25023	35057
2001-02	17800	31319	40481
2002-03	64120	29366	34754
2003-04	65714	30802	34912
2004-05	52878	24966	27912
2005-06	32389	15464	16925
2006-07	22315	10958	11357
Average	**45043**	**23985**	**28771**

(Source: MTE)

This indicates that, although primary processimg may produce huge volumes of residues, in many countries they are not viewed as 'waste' but as by-products that are already used by the urban and rural populations and secondary wood-based industries (FAO, 2001).

4.4.1 Costs of raw materials

To form (30 × 30 × 1.2) cm^3 sheet, 15.2 cm × 15.2cm × 15.2cm (6in× 6 in ×6 in) of sawdust was mixed with 750 ml of urea-formaldehyde adhesive. The targeted board's thickness was 12 mm. For the determination of variations in thickness; each board was measured at four points, near each corner and near the center. The average thicknesses of Teak, In and assorted particleboards are approximately found to be 12 mm, 13 mm and 13 mm, respectively. There are different types and different sizes of particleboards for finalized uses. The most common size of the particleboard used in furniture-making and construction is 8′× 4′× 12 mm . To get one particleboard of size 8′× 4′× 12 mm, 4ft^3 of sawdust was mixed with 24 liter of UF. Based on the total amount of sawdust (39,934 ton) which can be obtained from MTE sawmills, 499,175 sheets (17,808 m^3)of particleboards could be produced annually. The estimated cost of one sheet of Teak particleboard (8′× 4′× 12 mm) based on the costs of sawdust and UF adhesive is about 3,700 Kyats. One bag of Teak sawdust is about 1,500 Kyats in Yangon and one ton of UF adhesive is 98,000 Kyats (Official Rate). Since the cost of one bag of hardwood sawdust is 300 kyats, the same size of hardwood sawdust particleboard will cost about 2,600 Kyats. This study is only on an experimental scale, thus it is difficult to estimate the investement costs for land, building, machines, operating costs and overhead charges.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the results obtained from the present study, the following conclusions can be drawn.

i. Among the three kinds of tested sawdust, Teak sawdust has high chemical content, especially in lignin content and it enhances better quality.

ii. The average moisture content of Teak particleboard (5.2%) lies in the range of standard limit (5-8%) whereas the average moisture content of In and assorted particleboards are higher than the standard limit.

iii. In accordance with the classification of their densities, Teak particleboard can be classified as medium-density particleboard. And In and assorted particleboards can be classified as high-density particleboard.

iv. Thickness swelling and water absorption of three types of board lie in the range of standard limits.

v. Modulus of rupture of Teak and assorted boards are close to that of the standard board. However, MOR of In particleboard is less than the standard value.

vi. Moduli of elasticity of three kinds of tested particleboard are higher than the standard MOE.

vii. The properties of the tested particleboards are found to be within the acceptable limit.

viii. By using sawdust obtained from MTE saw mills, about 499,000 sheets of particleboard (8′ ×4′×12 mm) could be produced annually.

ix. Utilization of sawmill residues in terms of sawdust has a significant potential for particleboard manufacturing in the future.

x. Based on the findings of this study, it is possible to produce partricleboards in the country using the tested raw materials.

xi. The purchase of machines and glue or binding materials should be considered seriously because it takes most of the investment capital.

5.2 Recommendations

Based on the results obtained from the present study, the following recommendations are made and should be considered for further research works.

1. More research is needed to improve the quality of the particleboard and production of adhesives.
2. Emphasis should be placed on research and developmemt programmes aimed to improve both quality and quantity of wood-based products.
3. Research on utilization not only the amount of industrial residues but also in increasing logging residues and other lesser-used species in particleboard manufacturing process should be carried out.
4. Research on different types and ratio of adhesives, different thicknesses and layers (3-layer or multi-layer) of particleboard and different sizes of raw materials in particleboard manufacturing process should be carried out.
5. Further investigations on other properties such as hardness test, nail and screw holding power test, durability and drying properties of particleboard should be carried out.
6. Training on production engineers and skilled labour are needed.
7. Based on the findings of this research, it is suggested that large scale particleboard production should be started in the country using the available raw materials.

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