

ADDISABABAUNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CHEMICAL AND BIO ENGINEERING



STUDY ON THE PRODUCTION AND ECONOMIC ANALYSIS
OF PARTICLEBOARD FROM SUGARCANE
BAGASSE

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A Thesis submitted to

The School of Chemical and Bio Engineering

Presented in Fulfillment of the Requirement for the Degree of Master of Science

(Chemical and Bio Engineering Under Process Engineering Stream)

Addis Ababa, Ethiopia

June 2018

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CHEMICAL AND BIO ENGINEERING

This is to certify that the thesis prepared by Komah Berhe, entitled: **production and economic analysis of bagasse particleboard** and submitted in partial fulfillment of the requirement for the degree of Master of Science (Chemical and Bio Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ACKNOWLEDGMENT

First and foremost, I would like to express my sincere gratitude to my advisor, professor (Dr. Ing) belay weldeyes for excellent scientific guidance, kindness, patience, positive criticism and encouragement right from the beginning of this thesis. I would like to acknowledge all my colleagues for their invaluable support and inspiration. Thanks to all staff members of AAiT School of Chemical and Bio-Engineering for their technical assistance. Finally, I wish to express my deepest gratitude to my parents and members of family for all the mental support and encouragement. Thank you, God, for all the strength and support in various means with presence of outstanding people around me.

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ACRONYMS

AAIT	Addis Ababa institute of technology
ANOVA	Analysis of variance
BDF	Bone-dry fiber
CCD	Central composite design
DC	Direct cost
FCIC	Fixed capital investment cost
FSF	Fincha sugar factory
IB	Internal bonding
ID	Indirect cost
MOR	Modulus of rupture
MSF	Methahara sugar factory
OLC	Operating labor cost
PEC	Purchased equipment cost
RC	Resin content
RSM	Response surface methodology
TCD	Tone cane per day
TPC	Total product cost
UF	Urea formaldehyde
UTM	Universal testing machine
WSSF	Wonji/shoa sugar factory

ABSTRACT

The reutilization of sugarcane bagasse residues to obtain an applicable product of particleboard is a very useful practice that generates many advantages in the evaluation of social areas, expanding baselines for economic applications, with a low cost product which is ecological and far less polluting. The objective of this work was to produce and evaluate feasibility of particleboard from sugarcane bagasse. The prepared bagasse was dried. After drying bagasse the true fibers must be separated from the pith component of bagasse. An operation usually known as sieving analysis. The bagasse fibers were mixed with urea formaldehyde resin. The mixture of fibers, resin, and any additives is pressed into boards which are subsequently trimmed and finished to form the final product. From result and discussion, Design-Expert 7.0.0 three-level-three-factor CCD was applied for experimental design and statistical analysis of results. A total of 17 experiments were conducted at conditions of adhesive content 9%, 12 and 15% , targeted density 0.6g/cm³, 0.65g/cm³and 0.7g/cm³ and pressure of 35bar, 40bar and45 bar. From the analysis of experimental results the interaction effects were studied and optimization of process factors was done. Maximum response variables were found. It was observed that mechanical properties of the bagasse particleboard increased with an increase in resin content, density and pressing pressure. The maximum result was obtained with resin content 15%, density 0.7g/cm³ and pressing pressure of 45bar. Under these conditions maximum modulus of rupture and internal bonding was 14.5674Mpa and0.41Mpa respectively, a satisfactory result as compared with literature data. From our preliminary cost analysis, this project is feasible. A payback period of 2 years is an indication of a promising and feasible plant.

Keywords: particle board; sugarcane bagasse; content of adhesive

1 INTRODUCTION

1.1 Background

Particleboard is a new type of engineered wood product which is manufactured from gluing together sawdust, wood chips, sawmill and synthetic resin. This produces a flat hard building material which is commonly used in construction sites. It is denser and cheaper than conventional wood and plywood. It is widely used in the civil construction and furniture sector (Benedito, Júnior, & Cavalcante, 2009). A proposed alternative destination for agricultural wastes is to use them for the manufacture of particulate composites, or particleboards. These particleboards are usually manufactured from wood particles bound together with synthetic adhesives or other binders, which are pressed under heat until the adhesive has cured. Basically, these particleboards can also be made of any lignocellulose material that gives them high strength and a predetermined specific weight, since the chemical composition of lignocellulose materials is similar to that of wood, especially hardwoods which have lower lignin content and higher pentose hemicellulose content (Fiorelli et al., 2013).

Particleboard is used as a generic term for any panel product that is made with wood particles. Of course, there is a great range of particle shapes and size used to make particleboards. The type of particle is therefore used to define the type of particleboard product. For example, following English terminology, chipboard is made with chips, a flake board with flakes, oriented strand board (OSB) with strands and so on. Most European countries use the term particle rather than chip and therefore particleboard as a term for chipboard (Irle, n.d.).

The reutilization of natural organic residues to obtain an applicable product is a very useful practice that generates many advantages in the evaluation of social areas, expanding baselines for economic applications, with a low cost product which is ecological and far less polluting, in order to create a country's sustainable development (Jorge Parga Silva, Antonio Rocco Lahr, Luis Christoforo, & Hallak Panzera, 2012).

The sugar cane bagasse is a residue of cellulose fiber originated from the process of sugar cane. It is often burned in vapor reservoirs to produce energy for industrial use (Eggleston & Lima, 2015). The main components of the smallest particles of sugar cane bagasse fibers are pith and weaker fibers. There are many factors that influence the final mechanical and physical properties of the panels such

as raw material, density of the panels, compaction ratio, types and contents of adhesive, humidity of the particles, pressing temperature and specific pressure. The urea-formaldehyde (UF) and phenol formaldehyde (PF) are the main adhesives used by the wood panel industry. According to Roffael & Schneider (1983), 90% of the particleboards of the world are produced using urea-formaldehyde resin, although this adhesive demonstrates low resistance to humidity (Benedito et al., 2009), Low cost, Rapid cure and Adequate properties for many applications (brittle and susceptible to hydrolysis) (Hughes, 2016), and easy to work with, provide strong, durable bonds and acts as the cross linker or polymerizer (Neml, 2002). The phenol-formaldehyde adhesive, however, is recommended for the production of panels for external use or environments of high relative humidity. The adhesive is the most expensive component of the panels; therefore, the right definition of its type and content is extremely important to optimize the cost/effectiveness ratio (Benedito et al., 2009).

Murakami *et al.* (1999) observed that, increasing the content of adhesive, the mechanical properties and the dimensional stability of the panels increased as well. However, Wu (1999) could not establish a precise relation between the adhesive content and the rupture modulus, elastic modulus and linear expansion. The author says that the effects of the adhesive content on the properties studied are relative and diverse, and thus do not follow a logical pattern.

The density of the panels is affected by many factors of which the most important is the loss of particles. This happens due to the handling of the panels during the stages previous to the consolidation of the panels in the hot press, which compromises the control of density in laboratory conditions and makes necessary the use of a covariance analysis in order to correct the values obtained. This fact is even more evident in the case of sugar cane bagasse, because, compared to the wood; it presents higher amounts of fine particles, and, consequently, loss of material is probably higher. There are other important processing variables of particleboards production such as the type of material and the consequent relation between the density of the panel and the density of the material used. This variable is named compaction ratio. It is recommended a compaction ratio between 1, 3 and 1, 6; the necessary for the right densification and consolidation of the panel. It is also evident that the panels made of low density material often present higher resistance to bending and internal bonding if compared to panels made of high density material. The water absorption and thickness swelling usually present higher values in case of low density material. However, Vital *et*

al., (1974) concluded that panels in which was attested a high compaction ratio (1, 6) presented lower water absorption than panels in which was attested a low compaction ratio (1, 2). They attributed the probable causes of the lower water absorption rate to the reduction in porosity and to the increase in woody material (Benedito et al., 2009).

1.2 Statement of Problem

In recent years, there is a growing tendency towards recycling of the waste and using it for producing the composite wooden products like Particle Board. On the other side depletion of forest resources has increased demand for these kinds of products. Use of renewable materials for manufacturing particleboards could contribute the solution of raw material shortage for the particleboard industry. Environmentally friendly or green building materials are becoming more widely used as our society becomes aware of harmful consequences associated with the use of standard practices in industrial production. These materials are nontoxic and are made from renewable or recyclable resources. Nowadays, many manufacturing units all over the country are in the production of particle board in small scale sector (Muruganandam, et.al.,2016) .

In Ethiopia, particleboard produces from eucalyptus as a raw material. But trees as a row material are not preferable both in ecological effects and cost for utilization. In addition now the cost of chipboard dramatically increases with proportional demand of the customer due to the expansion of Ethiopian city furniture's to achieve sustainable growth. Then, the production of particleboard panels with sugarcane bagasse may be able to satisfy the growing demand in the wood panel industry for raw materials. Furthermore, the production of particleboard panels with sugarcane bagasse may allow the industry to expand, reduce the use of eucalyptus and timber (and thereby, reduce the pressure on forests), and reduce the costs of panel production; these properties have the potential to make such boards very competitive. This is the reason why we consider doing particleboard production using sugarcane bagasse at different qualities and minimum cost for construction, furniture purposes

1.3 Objectives

1.3.1 General objective

The main objective of this study is production and techno-economic analysis of particleboard from sugarcane bagasse

1.3.2 Specific objective

- To investigate effects of processing variables on the product (adhesive content, target density and pressure)
- To specify the optimal operating conditions for sugarcane bagasse particleboard
- To determine economic analysis for the production of bagasse particleboard.

1.4 Significance of the study

The main advantage of selecting particleboard is that its cost effective option against plywood or MDF. It provides smooth and flat surface for sticking decorative laminates or wood veneer. This particle board is stronger and aesthetically attractive. Thus laminated particleboard and veneered particle board are now used in mass production of office furniture. It is an eco- friendly material as it uses bagasse which is residue of sugarcane after the juice is extracted. And have thermo acoustic insulation properties, they are very much useful in speakers and in false ceiling of auditoriums, theaters etc.

Particleboard is a common building material used in almost all types of construction projects. It can be utilized for housing, industries and in commercial buildings as partition walls, window entryway boards, table tops, board sheets and so on. Particleboard is commonly used for cabinetry, tabletops, shelving, wall and floor panels, doors, furniture, and other non-structural architectural applications (Muruganandam et al., 2016).The best uses of Particleboard is

Market furniture

Any time we buy a dresser or entertainment center we usually purchasing a product made from particle board this is because of particle board is very inexpensive and easy to work with. Furniture that costs more can use a variety of fiber board and natural milled wood. The same look can be accomplished with basic particleboard and several main stream furniture companies have lead great successes using it as their main material.

2 LITERATURE REVIEW

2.1 Introduction

Many developing countries with inadequate or under-utilized forest resources have readily available large quantities of natural fibers which occur as agricultural wastes. In recent years the technology for the manufacture of soft board, hardboard, particle board and related building components from sugar cane bagasse has been perfected. Bagasse is the residue of fiber, pith, and moisture remaining after the sugar cane has been shredded and crushed and its sugar-laden juices extracted. Many developing countries have well established sugar industries which harvest several million tons of sugar cane annually, and approximately one-third to one-half of this tonnage becomes the waste product bagasse (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

In the industrial sector, there is also potential for substituting indigenous sources for wood and imported fuels. The Ethiopian Pulp and Paper Share Company use imported pulp as its sole feedstock to produce different grades of paper (Manyuchi, 2015). This entailed a foreign exchange cost of approximately \$7 million in 1984 which will increase with a planned expansion of capacity unless local sources of pulp can be used. ECAFCO, the Ethiopian particle board company, currently uses 6,000 tons of scarce eucalyptus wood annually, which further exacerbates the deforestation problem. Additionally, demand for a minimum of 21,000 tons of a densified fuel wood substitute to feed industrial boilers has been identified (Report, n.d.).

Bagasse, a by-product of, sugar cane processing, has the potential to significantly substitute for wood and imported materials in the domestic and industrial sectors. In densified form, bagasse could replace fuel wood in house hold or industrial use. Depithed bagasse could be used as a pulp feedstock in the local paper industry and as a substitute for wood feedstock in the manufacture of particleboard. In raw form, bagasse also could be burned by sugar mills to generate surplus electricity for sale to the national grid (O'Hara, 2011).

2.2 Nature of bagasse and bagasse board

2.2.1 Bagasse: -

Bagasse is the name given to the fibrous residue of the sugar cane stalk after the cane has been crushed in the roller mills and most of the sugar-laden juices extracted (Briones, Colín, & Diazsolano, 2010). Fresh bagasse from a sugar mill contains water (moisture), fiber, pith, and soluble solids (mostly sugar) in the following proportions (by weight) (Lois-Correa, Flores-Vela, Ortega-Grimaldo, & Berman-Delgado, 2010)

Moisture	42-54%
Fibers	31-37%
Pith	12-15%
Soluble solids	2-6%

The moisture content of the bagasse is essentially a function of the manner in which the cane is milled, since water is added to the cane in the milling process. The fiber and pith content depends mainly on the variety of cane being milled. The soluble solids are principally sugar, and the extent of its occurrence in bagasse is inversely related to the thoroughness with which the cane is milled. The principal distinction between the so-called "fibers" and "pith" is the length of the fibers present in each (Rezende, Lima, Maziero, & Ribeiro, 2011). The pith fibers are, in effect, too short in relation to their width to be suitable for fibrous reinforcement of a composite such as particle board (a composite of fibers and binding resin). The pith does, however, have the property of being highly absorptive, being capable of absorbing many times its own weight in liquids. For this reason, the principal use of pith is as a carrier for liquids, for example, as a carrier of molasses in the preparation of animal feeds. The fibers proper in sugar cane are comparable in geometry and composition to wood and certain other cellulose fibers. The chemical composition of dry bagasse is similar to that of most hardwoods, consisting of approximately 45-60% cellulose, 20-30% pentosans, and 15-22% lignin (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

The principal use of bagasse presently is as a fuel in bagasse furnaces at sugar mills. Its usefulness in this respect is based on its fuel value, which has been found to be approximately 7700 BTU/pound in the dry state. The fuel value of fresh bagasse (as it comes from the sugar mill) is considerably less about 3400 BTU/pound, on the average since the bagasse contains a large percentage of moisture (Rezende et al., 2011)(“L. S. Polanco, D. F. Day – Audubon Sugar Institute - AgCenter V.

Kochergin – Amalgamated Research LLC. J. Alvarez – Sugar Cane Growers Cooperative of Florida,” 2014).

2.2.2 Properties of Bagasse Boards

Three types of board can be produced from bagasse fibers: (1) soft board, used principally for insulation board and acoustic panels; (2) hardboard, used in furniture manufacture and in the interior parts of buildings; (3) particle board, used principally as an exterior and interior structural component in frame construction, and in the manufacture of furniture. The essential difference in these boards lies in their methods of production; the production of particle board, in particular, is quite different from the production system for soft board and hardboard, which have similar means of production. The emphasis in this thesis on particle board is based on its considerably greater usefulness in housing and other construction.

Bagasse soft board is a low-density board most notable for its good heat insulation properties, its heat transmission coefficient typically being only 0.320-0.330 BTU/ft²/hr/in/^oF. The strength of bagasse soft board is not very great, however, with the modulus of rupture usually ranging between 380 and 470 psi (27-33 kg/cm²). Bagasse soft board is, in fact, useful only as a decorative or finishing material (such as acoustic panels), and is not to be considered a primary or structural building material.

Bagasse hardboard is basically similar to the well-known "Masonite" panels in appearance, properties, and uses. The dimensions of the panels most commonly produced are 4 feet by 8 feet by 1/8 to 1/4 inch thick. The density of the various types of bagasse hardboard currently being manufactured varies from 45 to 70 pcf. The strength of bagasse hardboard, moreover, varies directly with the density of the board, ranging from a modulus of rupture of 3000 psi for a board with density of 45 pcf to a modulus of 7400 psi for a board of 70 pcf (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

Hardboard may also be tempered with an application of oil to improve its water resistance. While untempered hardboard deteriorates rapidly on exposure to water, oil tempered hardboard shows a somewhat improved resistance. Nonetheless, oil-tempered hardboard, when exposed to water, still shows significant levels of water absorption, panel swelling, and panel deterioration.

In spite of its adequate strength and as a result primarily of its poor ability to resist deterioration under exposure to water, bagasse hardboard does not find significant use as a primary construction material, but does enjoy fairly wide use in finishing applications for the interior of buildings.

Bagasse particle boards are in general appearance and usefulness closely related to wood-chip particle boards. Bagasse particle board is usually manufactured in panels 4 feet wide by 8 or 10 feet long by 1/2, 5/8, or 3/4 inch thick. The bagasse particle board compares very favorably with wood particle board, being in general lighter, stronger, and less susceptible to swelling and warping in water (Wu, 1989).

Bagasse particle board which is made with a phenolic resin binder is highly resistant to water and is suitable for exterior as well as interior applications. The high strength of bagasse board makes it an excellent structural component in walls, floors, and roofs of frame-type construction. Highly effective insecticides and fungicides, moreover, have been developed for use in bagasse board and render the boards virtually immune to attack by insects and fungus.

2.3 Surplus Bagasse Potential and the Sugar Industry in Ethiopia

Ethiopia has a well-established cane sugar industry, which is owned and operated by the Ethiopian Sugar Corporation (ESC). Sugar industry in Ethiopia was pioneered by the Dutch management and consultancy firm called Hangler Vondr Amsterdam (**HVA**) **International** in the early 1950s. This firm established the three sugar mills of Ethiopia, namely Wonji, Shoa and Metahara in 1954, 1960 and 1968 respectively. When built, the sugar factories had a combined milling capacity of 6500 TCD and a total cane plantation area of 13,000 hectares. Ethiopia has also another sugar mill called Finchaa Sugar Factory that was built in 1998. Wonji and Shoa sugar factories are now merged under one management institute. All of the three factories employ cogeneration technology to get heat and power for the sugar processing. In addition, the mills obtain national grid power for irrigation pump stations and domestic purposes (P. Report, 2009).

Wonji-Shoa Sugar Factory (WSSF)

The factory is found at Oromiya Regional State near Nazareth City at 112 Kilo Meters from Addis Ababa. WSSF consists of two sugar factories Wonji and Shoa and it has a total sugar plantation farm of about 7,022 ha. Wonji sugar factory was commissioned in 1954, with a capacity of 1,450 TCD and Shoa sugar factory was commissioned in 1962 with a capacity of 1,650 TCD.

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Table 2. 1: Annual production capacity of WSSF

Factory	Nominal crushing Capacity	Annual production capacity		
		Sugar (tons)	Cane (tons)	Plantation (ha.)
Wonji	1450	70,000	593,000	7,022
Shoa	1650			

Bagasse production at WSSF

Bagasse is co-generated for the internal electrical power generation of the sugar mills. Research studies show that the estimated production of bagasse at WSSF to be around 30.29 % of the cane crushed. That means bagasse production a WSSF = $0.3029 \times 593,000 = 179619.7$ ton/yr (Semret, 2014).

Table 2. 2: Bagasse and Cane composition at WSSF

Component	Parameter	Amount
Bagasse	Himudity (% on total basis)	50
	Fiber (% on total basis)	46.9
Cane	Fiber(% on total basis)	14.2
	Bagasee (%)	30.29

Due to long years of operation and obsolete technology, the performance of the WSSF is not satisfactory hence feasibility studies were conducted with the aim of investigating the possibility of long-term operation, rehabilitation, and expansion of the plant for maximum sugar output. The study results have not yet been implemented. WSSF has a milling season of about 220 days with duration from October to May.

In a bid to replace these two oldest factories with a new and modern one, an expansion project had been carried out both in the cane cultivation field and the factory since 2010. And, the factory plant expansion project has come into its completion in July, 2013. Accordingly, the newly built and modern Wonji/Shoa Sugar Factory has currently a design capacity of crushing 6,250 tons of cane a day and producing over 174,000 tons of sugar per annum. The new ethanol plant planned to be built,

will have a capacity of producing 12,800 meter cube. The Factory is currently contributing 20 megawatt electric powers to the national grid in addition to satisfying its own demand which is around 11 megawatt.

Its agricultural expansion project is currently being carried out around the areas known as Wakie Tiyo, Welenchiti and North Dodota areas. The total cane cultivation field of the factory has currently reached 12,800 hectares. And, the 7,000 hectares of the factory's sugarcane field cultivated with the agricultural expansion project is owned by out grower farmers of the surrounding area. There are 32 Sugarcane out Growers associations which in total have 9,100 member farmers. The Factory, beyond supplying the farmers with selected seeds, and rendering professional as well as technical support to them, has made irrigable land.

Metehara Sugar Factory (MSF)

MSF is located at about 220 km from the capital city of Ethiopia, Addis Ababa and about 100 km below Awash Hydropower Plant. The factory was built in 1968 and it has a crushing capacity of 5,000 TCD and a production capacity of 120,000 ton white sugar per annum with a plantation area of about 8507 ha. Process steam is produced by bagasse burning in the four boilers of the factory that have a total capacity of 125 t/hr of steam which is supplemented by fuel oil burning (Semret, 2014). Same as Wonji Shoa Sugar Factory its construction was carried out by H.V.A. Company of the Netherlands. Formed as Share Company between the Ethiopian government and the constructing company, it was the third sugar mill to the nation. It currently has more than 10,000 hectares of land covered with sugarcane. Its average production capacity is 136,692 tons of sugar a year.

Finchaa Sugar Factory (FSF)

This factory is found in Oromiya Regional State in Horro Guderru Wellega Zone, Abay Chomen District in Fincha Rift Valley around 350 Kilo Meters away from the capital Addis Ababa.

The milling section is equipped with 4 sets of roller mills through which the prepared cane passes and the juice in the cane is extracted by means of applying hydraulic pressure on top of the milling rollers. Bagasse is obtained from the milling process after extraction of the juice and to enable more extraction of the juice, imbibition water is spread on the bagasse in the last roller mill. Then a mixture of the extracted juice (called "mixed juice") from the different steps of set of the roller mills

is obtained and mixed together in a trough. The Bagasse obtained after the last set of roller mill is known as “**Mill Wet Bagasse**”. The amount of bagasse produced is about 1,280 ton per day or 467200ton per year (P. Report, 2009).

Feasibility study including the topography and soil content of the area was conducted by Bukers Agricultural International Ltd. of Britain since 1978 while the project work had started in 1989. The finance needed to construct the factory was secured from the African Development Bank & African Development Fund; governments of Australia & Spain and domestic banks of the nation. Fincha River which is generating hydroelectric power and then made reach the rift valley to water the sugarcane plantation field of Fincha Sugar Factory finally goes to Nile River as a tributary. The Factory’s command area is 67,098 hectares.

The factory started production in 1998 and till July, 2013 the average annual production capacity of Fincha Sugar Factory was 110,000 tons of sugar while it had the capacity of producing 8,000 meter cube ethanol. Till the last months of 2010 it had been the only factory in the country that produces ethanol.

The factory has carried out expansion projects both on its sugarcane plantation field and its sugar mill. Hence it has come up with a plant of 12,000 TCD design capacity capable of annually producing 270,000 tons of sugar and 20,000 meter cube ethanol. The Mill’s previous design capacity was 5,000 TCD. To acquire and cultivate cane cultivation field capable enough to feed the expanded plant with more than double crushing capacity.

The factory’s agricultural expansion project has been carried out around the areas known as East Bank (eastern side of Fincha River) , Neshie and also on the idle areas found on the Western side of the river. The factory, therefore, in near future will bring its total sugarcane plantation land which had been only 12,170 hectares close to 21,000 hectares. The cultivation land expansion job has enabled the factory to expand its cane covered land to more than 19,000 hectares till 2016. The Factory produces 31 Mega Watt electric powers out of which 10 Mega Watt is exported to the national grid (<http://ethiopiansugar.com/index.php/en/factories/fincha-sugar-factory>).

In general in the milling season of 2007/2008, Metahara, Fincha and Wonji-Shoa sugar factories have crushed 1,130,541, 779,549 and 488,039 t of cane, respectively. The commercial sugar % cane (yield) of the cane at each factory was 11.52, 11.34 and 11.75 %, respectively. Metahara sugar

factory, which was the leading in production season, produced 130,266.1 t of plantation white sugar which was followed by Finchaa sugar factory with production of 88,367.4 t and Wonji-Shoa was in the third position with the production of 57,375.8 t of sugar. At Metahara sugar factory, the cane crushed was slightly lower than the previous year by about 3% but the sugar production was higher than the previous year by about 3 % which is the outstanding achievement in the production history of the factory. This could be attributed to the improvement of cane quality and overall factory performances with lowest losses, lowest down time and highest recovery. The production of Finchaa sugar factory was 88.21 % of the set target, though the factory has performed slightly over the designed capacity. The factory also produced ethanol from the factory by-product (molasses), its yield being 5,330,337 liters in the production year under discussion (P. Report, 2009).

Tendaho sugar factory

It is found at the lower Awash River Basin of Afar Regional State around Millie, Doubti, Assaeitta and Affambo Districts at a distance of 670 km from Addis Ababa. It is located at 300 k.m. distance from Djibouti Port which makes it more fit to export sugar. The project was started in 2006 with 50,000 hectares of land to be cultivated and will have a factory with a design capacity of 13,000 TCD a day. The factory construction contractor is OIA (Overseas Infrastructure Alliance) of India. The first phase of the factory has started trial production in October, 2014. It is currently in regular operation. Upon coming to its maximum crushing capacity, the factory will be able to produce more than 3 Million Quintals of sugar and 31,000 meter cube ethanol annually.

Out of the total hectares of the cane farm land the factory will cultivate 25,000 hectares sugarcane plantation field by its own while the rest 25,000 hectares are to be cultivated by surrounding out grower pastoralists. The factory has cultivated sugarcane over 20,866 hectares of land. The cane cultivation field is getting its water supply from Tendaho Dam and it is capable of irrigating 60,000 hectares of land having a capacity of holding more than 1.8 billion cubic meter water. Irrigable land has reached 22,835 hectares while construction of main canal and other canal structures are already built. The factory has made irrigable land available to pastoralists around which enable them to become semi pastoralist. 175 residence houses and 429 buildings are built at the factory command area.

It is the hugest plant in the country and it will take the lion's share of the total amount of sugar produced in the nation. Out of the total 60 megawatt electric power it will be generating from its

sugar bi-product it will export 38 Mega Watt electric powers to the national grid while the rest is consumed for its own regular operation.

Wolkaiyt sugar factory

It is the other sugar development project located at 1,300 kilo meters from Addis Ababa in the Western Zone of Tigray Regional State at Welkayit District. One sugar factory with 24,000 TCD is found under construction by Chinese Company - CAMC. When it reaches its maximum production capacity, the factory will be capable of producing 484,000 tons of sugar and 41,654 meter cube ethanol a year. The project's total area of land for sugarcane cultivation is 50,000 hectares.

It will get its water supply from the river called Zareima upon which the construction of a dam named "May-Day" is in progress. The dam which is under construction by a local construction company-Sur Construction will have 840 meters width and 135.5 meters height. When completed, May-Day Dam will have a capacity of containing 3,497,000,000 meter cube water. Vis-à-vis the dam construction a drip irrigation scheme is in operation reaching at a contractual agreement with an Israeli Company known as NETAFIM so as to cultivate sugarcane at 7,000 hectares of land of the project. A 10 kilo meters long canal construction work is completed. A canal structure work capable of cultivating 3,000 hectares of land is underway. As cane cultivation needs water supply all throughout the year, the project is currently cultivating cotton till cultivating sugarcane with irrigated water supply is possible. 261 hectares of land is made irrigable while 220 hectares are covered with cane. 800 residential and 36 non-residential houses are constructed at the project.

In general, these new sugar factories under construction together with Tendaho, Kesseem and Arjo Diedessa sugar factories which already commence production at different levels are expected to create direct and indirect job opportunities to more than 600,000 citizens in various fields of work. Moreover, as the sectors' development activities are mainly carried out at the various remote areas of the nation, local people of these areas are enabled to get access to various social services and infrastructures including irrigable farm lands.

Arjo Dediessa sugar factory

It is located at Western Ethiopia of Oromiya Regional State in eastern Wollega, Eilu Ababora and Jimma Zones at the Didessa Rift Valley at a distant of 540 kilo meters from the capital through the route of Addis Ababa-Jimma-Beddelie-Nekemet Road. The altitude of the area is 1,350 meters above sea level while its annual rainfall is 1,400 millimeter. Its rainy season is extends from May to October. The soil content which is usually black in color and rarely blue together with its climate makes the area suitable to sugarcane cultivation.

The Factory had been owned by a Pakistan company called Al-Habasha P.L.C. which had been unable to proceed the business. Therefore, the company had been transferred to the ownership to the Ethiopian government and was made to operate as a property of Sugar Corporation as of August, 2012. Over 90% of the construction of the plant was completed when it was transferred to the Corporation.

The Factory is inaugurated by FDRE Prime Minister Hailemariam Desalegne on May, 2015. Commencing production by mid-2015, it is in operation with a design crushing capacity of 8,000 tons of cane a day. Equipped with necessary facilities, it is expected to produce electric power from its by-product which enables it satisfy its own power demand as well as export some to the national grid and also produce ethanol in the future.

The Factory in total will have 20,000 hectares of land cultivated with cane. Its source of water is the Didessa River. Currently, 1,660 hectares of land is made irrigable area. And, has 3,448 hectares of land covered with cane. 64 residential houses and two service giving buildings are constructed.

Kassem sugar factory

The Factory is found at Zone Three in Awash Fentallie and Dulecha districts of Afar Regional State, 50 kilo meters from Metehara Sugar Factory and 250 kilo meters from Addis Ababa. It is a project which has a total of 20,000 hectares of land to be cultivated with cane & its plantation stretches to the areas known as Kesseem and Bolhomon. The Kesseem Dam which has a capacity of holding 500 cubic meters water is the source from which sugarcane cultivation is being carried out. Irrigable land has reached 2,946 hectares while the construction of 20.5 kilo meters of main canal is completed. Currently, the factory has 8,413 hectares of land covered with cane among which 6,000 hectares

cultivated by a private company known as Amibara Agricultural Development with which Sugar Corporation has signed contractual agreement.

Earlier the Kessem project was part of the expansion project of Metehara Sugar Factory. It was after the establishment of Sugar Corporation that the project was made to proceed as an independent entity. The construction contractor of this Factory is a Chinese company – COMPLANT. 517 residential and 20 service giving buildings or blocks are constructed.

The Factory making trial production by March, 2015 is now in regular operation. And, it will also be a factory with ethanol and co-generation facilities. The Factory is expected to start crushing 6,000 tons of sugarcane per day soon which will later on will develop to 10,000 TCD making it capable of producing 153,000 tons of sugar & 12,500 meter cube ethanol a year at the start and when it later reaches its maximum crushing capacity it will produce 260,000 tons of sugar and 30,000 meter cube ethanol annually. Moreover, the Factory out of the total 26 megawatt electric power it is expected to produce through its cogeneration facility, will contribute 15 megawatts to the national grid satisfying its own demand.

Omo-kuraz sugar factory

- The factory started trial sugar production since March 27, 2017.
- The factory while entering regular production crushes 6 thousand to 6 thousand 500 tons of sugar cane a day. When it operates with its full capacity it will crush 12 thousand tons of sugar cane a day.
- When it starts working with its full gear it will have a capacity of producing 2.5 Million quintals of sugar and 28 Million liters of ethanol a year.
- It will also produce 60 Mega Watts of electricity and sends 40 of it to the national power grid using only 20 megawatts to itself.

The source of this 6.67 Billion Birr sugar development project is the Chinese Development Bank. Its construction officially started in July, 2014 following an agreement signed between Sugar Corporation and the Chinese Company- Complant,

2.4 Bagasse particle board production system

Bagasse particle board production is divided into five operational areas:

- 2.4.1 Obtaining Bagasse from Sugar Mills;
- 2.4.2 Fiber Storage and Handling;
- 2.4.3 Fiber Preparation;
- 2.4.4 Mixing, Pressing, and Finishing; and
- 2.4.5. Administrative and Other Functions

2.4.1 Obtaining Bagasse from Sugar Mills

To undertake the production of bagasse particle board, it is essential that an adequate supply of suitable bagasse be obtainable at reasonable cost. Since the bagasse is likely 'to be obtained from one or more sugar mills located relatively near the bagasse board plant, the characteristics of each sugar mill operating system will determine the suitability and the cost of the bagasse to be used in the board (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

The physical characteristics of bagasse are in large part determined by the methods of harvesting and milling the sugar cane from which the bagasse is made. Bagasse made from harvested cane which contains large amounts of silt or clay, as often found with mechanized harvesting methods, will also generally have high levels of clay or silt. The removal of such impurities is usually possible, but at some added cost. A persisting discoloration due to fine clay particles may be found, however, and bagasse with such a "tint" may be unsuitable for use in particle board. Bagasse which contains carbonized matter left from partially burnt trash is particularly objectionable, since it results in the discoloration of the particle board in the form of small but visible carbon specks. Such carbonized impurities, moreover, are virtually impossible to remove from bagasse. Other impurities in bagasse include unextracted sugar. Reasonable levels of unextracted sugar up to about 5% do not ordinarily interfere with particle board production (Fiorelli et al., 2013).

Bagasse of virtually any degree of coarseness may be used in particle board manufacture, but in general the finer the bagasse arriving from the mill, the less difficult and more uniform is the depithing process at the board plant. The coarseness of the bagasse is determined by the milling pressure, the milling rate, the condition of the roller mills, and other factors. As a result of the progressive wearing of the milling equipment during the course of the milling season, the coarseness of the bagasse can be expected to increase as the milling season progresses. Normal' equipment wear, however, will not usually affect the suitability of the bagasse produced. In general, bagasse

from any sugar mill with normal operations will be an acceptable raw material for particle board manufacture (Semret, 2014).

Since bagasse is almost universally used as a fuel in the bagasse-fired boilers of sugar mills, its release for use in particle board production must be made possible by effecting significant changes in the sugar mill operating system. Two major modes of change are possible. First, a mill or group of mills may be able to reduce considerably their own bagasse requirements by improving their overall thermal efficiencies. Mills at high levels of thermal efficiency may be able to supply a surplus of bagasse adequate to meet the needs of a bagasse particle board plant.

Alternatively, the second method of releasing bagasse is the burning of supplemental or alternate fuels in the boilers of the sugar mill or mills. This strategy involves either the conversion of the existing bagasse furnace to accept supplemental fuels, or the outright replacement of the bagasse furnace with a furnace which accepts only the alternate fuel. The capital and operating costs incurred in such conversions, or in programs to improve mill thermal efficiency, will be the principal determinants in the cost of the bagasse used by the particle board plant (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

Under most conditions, the cost of the bagasse will be about \$3 to \$5 per ton, fresh basis, or \$6 to \$10 per ton, dry basis, at the sugar mill. Transport of the bagasse to the board plant, plus a profit margin for the cooperating sugar mill, will usually raise the final cost to \$7 to \$12 per ton, dry basis, at the board plant. On the basis of a 25% (by weight) fiber extraction from the bagasse, as explained below under Fiber Storage and Handling, the cost of bagasse fibers as a raw material becomes \$14 to \$24 per ton, not including processing and preparation costs (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

2.4.2 Fiber Storage and Handling

The production of bagasse particle boards requires the handling and storage of large amounts of bagasse fibers. The storage requirement is clearly significant, for example, when the year-round operation of a board plant is to be based on bagasse produced during a short cane-milling season. The storage capacity required under such conditions may easily reach 30,000 tons of bagasse, dry basis, or 15,000 tons of prepared fiber. The costs and requirements for storage of bagasse fibers will vary significantly according to the production sequence followed. Since the moisture, fiber, and pith fractions in bagasse may vary considerably from region to region or mill to mill. It will prove useful to base further discussions of the quantities and costs relating to this raw material on a bone-dry fiber

(BDF) quantity basis. In general, one ton of fresh bagasse contains about 50% moisture, 35% fibers, 12% Pith, and 3% soluble solids, by weight. Taking into account fiber losses due to decay, handling, and depithing, one can reasonably expect a yield of about 25% BDF, by weight, from one ton of fresh bagasse. One ton of BDF therefore requires an average of 4 tons of fresh bagasse. A more accurate determination of BDF yield must be made on the basis of local conditions (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

1 Fiber Storage before Depithing (Path 1)

There are three methods of storing unprocessed bagasse in current use. The first two methods discussed below are based on the bulk storage of fresh bagasse. The third method requires the compression of bagasse into bales prior to storage.

1. (A) Simple Bulk Storage

Under most climatic conditions, bagasse cannot be kept in unprotected storage areas, since it will ferment and decay, thereby causing damage to the bagasse fibers and also reducing considerably the fuel value of the bagasse. Hugot reports, "however, that bagasse may be safely stored in the open in very dry climates" (1960). He recommends that the tops of bagasse bulk storage piles be provided with a thatch cover made from cane leaves, in case rain should occur.

The principal requirement of this storage method is a large storage area, as bagasse is a material with a low bulk density. Stacked bagasse with a moisture content of 45% will have a bulk density in the range of 10-15 lbs/ft³; dry bagasse will be about half this value, or 5-8 lbs/ft³. One ton of dry bagasse will therefore require about 350 ft³ of storage space. The storage requirements for 30,000 tons of dry bagasse, or 15,000 tons of BDF, are then 30,000 tons X 350 ft³/ton = 10,500,000 ft³. If the bagasse is stored in piles with a mean height of 40 feet, for example, then the total storage area needed becomes 10,500,000 ft³ / 40 ft. = 262,500 ft², or about 6 acres. Thus, in the simple bulk storage of bagasse, 5000 tons of dry bagasse, or about 2500 tons BDF, will require about one acre of land.

The transfer of bagasse into and out of this bulk storage area must be accomplished by means of mechanized equipment such as front-end loaders and trucks or railroad cars. If the bagasse is stored in bulk at the particle board plant (the bulk storage of at least some bagasse will be inevitable), additional equipment such as heavy conveyor systems and metering stations will be required.

One potential danger associated with the open storage of loose bagasse, or with any handling operation which creates bagasse dust, is the health hazard related to the disease bagassosis. Workers who are exposed to prolonged inhalation of bagasse dust may contract a lung disease, which is

similar to silicosis in effect. Hence, in the open storage and other handling of bagasse, care must be taken to avoid the creation of bagasse dust. In addition, the open storage of bagasse in windy areas will generally result in the blowing about of large numbers of bagasse particles. These wind-borne particles are a definite hazard to the eyes and are a general nuisance to employees and adjacent properties. Covering of the bagasse storage piles may be advisable or necessary, as a result, during windy periods (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

1. (b) Bulk Storage with Preservatives - the "Ritter Method"

As mentioned previously, the simple bulk storage of bagasse is not usually feasible or desirable, except in dry climates. To allow the bulk storage of bagasse in normal or wet climates, a system was devised by Ritter in South Africa whereby bulk piles of bagasse are continually sprayed with biological liquor which prevents the decay of the bagasse. The spray liquor, consisting mainly of lactic-acid producing bacteria in a nutritive molasses medium, prevents the growth of micro-organisms which would cause fiber deterioration.

In this system, fresh bagasse or partially-depithed bagasse is mixed with the biological liquor and conveyed to a large concrete slab which constitutes the storage area.' This slab has several parallel channels which permit the drainage and recirculation of the biological liquor. The removal of the bagasse from the storage area may be accomplished by means of flumes built into the concrete slab or by the ordinary mechanical systems used for the bulk transfer of bagasse. The advantages of the Ritter method are claimed to be the following:

- (1) Labor and handling costs are lower than in the baling of bagasse.
- (2) Dust problems and the potential danger of bagassosis are eliminated.
- (3) The quality of the bagasse stored by this method is excellent.

The cost of the Ritter method of storage is approximately \$3 per ton of dry bagasse, or \$6 per ton of BDF, not including land and major capital equipment costs. The storage area requirements of this method are similar to those for the simple bulk storage of bagasse, with the exception that stack heights of 75-80 feet are reported as common in highly mechanized operations. Thus, one acre of storage area in a highly mechanized Ritter method operation can accommodate about 10,000 tons of dry bagasse, or about 5000 tons of BDF.

1. C Baling

Fresh bagasse may also be baled in a special press which resembles an enlarged and reinforced hay baler. The bagasse is pressed into bales 12 inches by 12 inches by 24 inches or 18 inches by 24

inches by 24 inches, on the average, which are then tied with two or three baling wires. The bagasse bales are then stacked on clean, high, and well-drained areas in such a way as to allow for the circulation of air through the stacks to remove the moisture in the bales (Bs, Rosettenstein, & Dv, 2013). These stacks must be protected from exposure to rain by being covered with asbestos sheets or galvanized-steel sheets dipped in asphalt (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968). Typical bagasse bale stacks are approximately 30 feet high. One ton of dry bagasse stored by this method requires about 720 ft³ of space, so that $720 \text{ ft}^3 / 30 \text{ ft} = 24 \text{ ft}^2$ of area are required for one ton of baled dry bagasse. On this basis, -one acre can accommodate slightly less than 2000 tons of dry baled bagasse, or about 1000 tons of BDF (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968). The operating costs incurred in baling bagasse are approximately \$15-\$20 per ton BDF. Capital investment costs for a baling station for 30,000 tons dry bagasse (15,000 tons of BDF) annual capacity are about \$500,000-\$600,000 (Joel, 2016).

2. Fiber Storage after Depithing (Path 2)

It should be evident that the storage requirements and handling costs for bagasse fibers could be lowered significantly if the bagasse fibers were depithed before storage. This depithing process involves the separation of most of the pith and very small fibers from the true bagasse fibers, leaving relatively clean bagasse fibers for use in particle board (or paper) production. Since one ton of BDF is normally obtained from about two tons of dry bagasse, handling and storage costs for depithed fibers should offer considerable economies. At least three methods for the storage of depithed fibers are in current use, as described below. According to the literature of the field (“Queensland University of Technology,” n.d.), simple bulk storage of bagasse fibers in the depithed state has not been attempted, probably because of the high bulk density and combustibility of the depithed fibers.

2. (A) Baling of Depithed Fibers

The baling operation for depithed fibers is similar to that for fresh bagasse, except that the bagasse is passed through depithing machines before entering the baling machine. Keller reports that “savings of about 25% in overall handling and processing costs result from the use of bagasse depithed prior to storage, compared with bagasse depithed after storage. On this basis, operating costs in the range of \$10-\$15 per ton of BDF can be expected. Storage area requirements will also be reduced by about 50%, so that one ton of baled depithed fibers would require about 360 ft of storage space. In this case, one acre will accommodate slightly less than 2000 tons of BDF (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

2. (B) Briquetting

Depithed bagasse fibers may be compressed to 1/6 to 1/10 of their loose volume by briquetting machines such as those commonly used for the briquetting of sawdust, peat, metal chips, etc. A highly successful briquetting machine manufactured is by SPM (Swiss Precision Machinery) found in Basle, Switzerland. Bagasse briquettes may be produced in densities ranging from 40-70 lbs/ft³, with resulting bulk densities of 30-40 lbs/ft³. These briquettes are then stored in large enclosures. The briquette storage building for example, contains approximately 1,000,000 ft³ of storage space and has a capacity in excess of 12,000 tons of depithed bagasse briquettes (Review, 2012), or 12,000 tons of BDF.

Operating costs for a SPM briquetting machine of 10,000 tons BDF annual capacity are about \$5.50 per ton of BDF, based on 200 days per year operation. Such a machine also represents an investment of about \$215,000, including conveyors for the briquette transport, but not including the storage building (Patil, Patil, & Kulkarni, 2014).

2. (c) Matting

Another method of storing bagasse fibers, which has reportedly been successful with bagasse fibers containing as little as 3% pith by weight, involves the pressing of fibers into large mats. These fiber mats are then stored without binding wires. It has not been possible to obtain details on this method of storage. The system was originally designed.

2.4.3 Fiber Preparation

To obtain bagasse fibers suitable for bagasse board manufacture, it is necessary to separate the true fibers from the pith. The pith is objectionable in particle board because it is highly absorptive and thus increases the amount of binding resin which must be used. At the same time, pith does not contribute to the strength of the board; indeed, pith will seriously impair the strength of the particle board if it is present in levels exceeding 5-7% by weight (Bates, Carolina, North, Natural, & Program, 2001).

The process whereby true fibers are separated from pith is generally referred to as depithing. The depithing process may be accomplished by any of the three methods which follow (Atchison, Joseph E., 1963):

(1) Dry depithing methods, involving separation of the pith after the bagasse has dried in storage or has been dried in special-purpose dryers.

(2) Moist or humid depithing methods, in which the bagasse is depithed as it leaves the sugar mill or at other times when its moisture content has been restored to about 50% by weight.

(3) Wet depithing methods, which are carried out with the bagasse in a dilute suspension, typically 4%-8% bagasse in water, by weight.

The available machinery for depithing bagasse and their possible arrangements in a depithing operation are discussed below.

1. Depithing Machines and Costs

Depithing of bagasse is normally accomplished by beating the bagasse in hammer mills or agitators and subsequently or simultaneously screening the material to allow the pith, dirt, and other fines to separate from the larger bagasse fibers (Aplicada & E-mail, 2012).

Investments required for complete depithing machinery vary according to the capacity and type used, but in most cases, will range from \$1000-\$1500 per ton of BDF daily capacity, including installation costs. Operating costs for the production of clean, pith-free fiber for use in particle board or paper pulp manufacture will be approximately \$4-\$5 per ton of BDF.

2. Depithing Station Arrangements

Arrangements currently in use for the preparation of paper pulp could also be adapted for use in bagasse board production. The particular characteristics of bagasse as a raw material have led to unforeseen and often insurmountable difficulties for the personnel involved. The successful depithing of bagasse will therefore ordinarily require personnel with previous experience in depithing bagasse (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

2.4.4 Mixing, Pressing, and Finishing

Once bagasse fibers have been freed from the pith component of bagasse, they are ready for use in the actual manufacture of bagasse particle boards. The production of bagasse particle boards involves three steps: A. Mixing the fibers with binding resins and other additives; B. Pressing the mats formed from the fiber-resin mixture; and C. Finishing the pressed boards to standard sizes, thicknesses, and surface smoothness's (Irle, n.d.).

Mixing

Depithed bagasse fibers are brought from the storage area or from the depithing station to the mixing station, passing through dryers which ensure a uniform moisture level of 12-16% by weight. Fibers which have been baled, briquetted, or matted must be returned to a free, loose condition by appropriate mechanical processes. The flow of bagasse fibers into the mixing station must be

carefully controlled for uniformity and continuity. Special intermediate storage bins are installed to fill in any gaps in the supply of fibers from the depithing station or storage area. The flow of fibers is metered by weight, and the addition of resin binders and other additives is accurately controlled (U. F. Service & Report, 1977).

The binding resins used in bagasse particle board are of two types -- urea formaldehyde or phenolic resins. Urea resins are soluble in water both before and after setting, and boards made with urea resins are suitable only for interior uses. Urea-formaldehyde (UF) resins are the main binders for wood composite boards, such as particleboards, fireboards, or hardwood plywood. In the use of UF resins, water solubility, good adhesion, high curing rate, and low cost are the attractive properties (Christjanson, Pehk, & Siimer, 2006) (Nasser, 2012) . Phenolic resins are highly water resistant and produce boards which are suitable for all types of exterior applications. Either resin will typically comprise 8-10% of the final weight of the finished particle board. The cost of the resins will vary depending on whether the resins are bought or imported "ready to use," or whether they are made at the board plant from their basic components. Imported ready-to-use resins of either type will cost about \$0.20-\$0.30 per pound under most conditions. If the board plant is equipped to produce its own resins from imported phenol, then the cost of the resin produced at the plant can be lowered to about \$0.15 per pound. A phenolic resin production facility for a 100 tons-per-day board plant will cost about \$500,000 initial capital investment, including the required transfer vehicles and stainless steel storage tanks (Ronald Allen Sanchez & Ronald Allen Sanchez, 1968).

Pressing

The pressing operation is obviously an extremely critical step in particleboard production. It is during this step that many of the physical properties are determined, especially those properties influenced by the vertical density gradient (F. Service, 1972). Mat moisture content, press closing speed, and press time and temperature are the most significant pressing conditions affecting the properties of particleboard (U. F. Service & Report, 1977).

Bagasse particle boards may be formed by three processes:

- a. Multiplaten Hot Press Process; b. Continuous Pressing or Bartrev Process; c. Extrusion Process.

A, Multiplaten Hot Press Process

In this process the mixture of fibers, resin, and other additives is sent to a mat-forming station, where carefully metered amounts of the mixture are placed on a large conveyor belt. The mat formed at this station may be one homogeneous layer of fiber-resin mixture. Alternatively, mats with three distinct layers may be formed; the outer layers are made of fine fibers and/or fibers mixed with phenolic resin, while the core layer is made of coarser fibers and/or fibers mixed with urea resin. A third type of mat is a graded density mat incorporating a uniform gradation in fiber fineness from the exterior to the core of the board, the core again containing the coarser fibers.

The mat is formed into overall dimensions that are somewhat larger than the dimensions of the board that will ultimately be produced. The length and width of the mat will each be about one inch greater than the final dimensions of the finished board. This one-inch oversizing is generally adequate to avoid under sizing of the board when it is pressed and to allow for trimming to the final finished size. The thickness of the mat will be determined by the desired thickness and density of the finished board. A mat formed to a 3 1/2 to 4 inch thickness initially will typically yield a finished board 5/8 inch to 3/4 inch thick in the 50-60 lbs/ft³ density range.

The machinery used in the mat-forming operation is large and is usually closely integrated in design and operation with the board press.

The pre-sized mats leave the mat-forming station and enter the pressing station where they receive a cold pressing which reduces their thickness to 1 1/2 to 2 inches. The mats are then individually loaded into a large stack of loading trays; when all loading trays contain mats, the trays move forward into the press itself and deposit the mats between the plates of the press. The multiplaten hot press consists of a series of stacked steel plates which can be heated (generally by steam) and hydraulically actuated to squeeze together, thereby simultaneously heating and compressing the mats placed between the plates. The mats are kept under pressure for a period of time varying according to the desired thickness and density of the board, but in most instances averaging 7-15 minutes. The temperature of the plates will ordinarily be about 275-300°F. After the period, the pressed boards are loaded into discharge trays. New mats are then loaded into the press for a new pressing cycle.

B, Continuous Pressing or Bartrev Process

This process resembles the multiplaten hot press process described above, except that the mats are pressed into boards one at a time in a semi-continuous Bartrev-Bison Press (also known as the Baehre-Bison Press). The mats are formed on a continuous steel belt which passes directly through

the press. The mats pass through the press one at a time and are individually pressed at a temperature and duration comparable to the multiplaten hot press. The loading and unloading of this single-press unit is very rapid, and a production rate of 12 tons of board (approximately 120-150 boards) per day is possible for each press of this type. These presses have been used by the National Bagasse Products Corporation of Vacherie,-Louisiana, but no detailed information on capital and operating costs of this press are available for this study.

C, Extrusion Process

The third process for the production of bagasse particle board has not yet been perfected for use with bagasse fibers, although it is in current use with wood fibers. When perfected, however, this process will offer the means to produce a variety of bagasse board types not possible with pressing methods. The upgrading of bagasse boards into complete pre-fabricated or multi-use sections will be greatly facilitated by this method when it is available.

In brief, the extrusion process begins with the introduction of resin-coated fibers into an extrusion press where a ram forces the mixture between heated plates. The mixture, after being compressed in this manner, becomes an increment to the board section being extruded. Repetitions of this cycle produce a continuous length of board which can be cut to desired lengths. Daily production rates of 20 tons are possible if current wood fiber extruding machines are adapted to bagasse fiber use.

Finishing

As boards leave the pressing station, they are transferred manually or by machine to a finishing station. This station provides for the sanding of the surface of the board to a prescribed smoothness and thickness.

2.4.5. Administrative and Other Functions

The operation of a bagasse particle board plant includes several functions in addition to the simple functioning of the production equipment described in the preceding parts of this section. 'General administrative and engineering needs must also be met. Administrative costs and personnel requirements must also include provision for the marketing and distribution of the particle board. In addition, some effort should be made in the area of product development. The development of plastic laminated particle boards, for example, could lead to a significant local or regional demand for this type of board. Innovative uses for particle board within the local building industry should also be explored and encouraged by the particle board producer. Standard Building Products, Ltd for example, is devoting considerable resources to developing and promoting complete prefabricated

housing units made from bagasse particle board. Product development costs such as these should be included in normal operating costs and will no doubt prove a profitable allocation of resources in the long run.

2.5 Physical and mechanical properties of bagasse particle board

The statistics relating to physical and mechanical properties of the particle board are major concern to guarantee the right application where the product or material is being utilized and to give important data for the use in new applications. Data on the effects of moisture content, water absorption, thickness swelling, internal bonding strength, tensile strength, compressive strength, Flexural strength, hardness, rate of loading, press temperature and pressing time are very much essential for the analysis of physical and mechanical properties of the particle board made from any kind of the material (Muruganandam et al., 2016).

2.5.1 Physical properties

A) Moisture Content

Equilibrium moisture content for the Particle board is 8% and average moisture content of all boards is 9%. Equilibrium moisture content is mainly depends on relative humidity. Particle Boards should be conditioned to reach equilibrium with the humidity level in which it is to be used. Measurement of moisture content can be achieved by weighing or by using electric moisture meter. Linear dimensions and thickness will change if there is change in moisture content (Muruganandam et al., 2016).

$$\text{Moisture content (\%)} = (W_a - W_o/W_o)*100$$

W_a- air dried weight and W_o- Oven dried weight of the particle board

The sugarcane bagasse may have presented the lowest average value of moisture for two reasons. The first is related to the type of additives used for panel production; for example, the chemical formula of the urea-formaldehyde adhesive used in the production of particleboard panels made from sugarcane bagasse. The second is related to the chemical composition of the raw material, as the sugarcane bagasse in general presents higher values of extractives than wood, and this chemical compound may have decreased the moisture of panels.

Barros Filho assessed the chemical composition of the sugarcane bagasse from a cachaça distillery and cane sugar mill for the production of particleboard panels and obtained average values of extractives of 11.1% and 9.1%, respectively. These values are above those commonly found for softwood (coniferous wood; $5\% \pm 3\%$) and hardwood (locally known as Madeira de folhosas; $3\% \pm 2\%$) (Muruganandam et al., 2016) (Oliveira et al., 2016).

B) Water Absorption Test

For water absorption, the test piece is cut and immersed in distilled water in a glass vessel at room temperature 20-30°C 2 and 24 hr. The effect of water on the properties like bending strength and bending stiffness is very severe. There is a chance of strength reduction of boards because of the water. So, water absorption is a most important property for any type of Particle Boards (Iswanto, 2014).

Water absorption (%) = $(W_f - W_i / W_i) * 100$, since W_f – final weight and W_i – initial weight

Okino et al (1997), studying the effect of acetylation of the sugar cane bagasse particles without the pith on the physical-mechanical properties of panels, and using the resins urea-formaldehyde and tannin-formaldehyde in the contents of 8 and 12%, obtained an average value of water absorption that varied from 21.3 to 95,2% and from 38.1 to 118.8% for 2 and 24 for hours of immersion respectively (Benedito et al., 2009). Pedreschi assessed the properties of industrial panels made from sugarcane bagasse and found average values of 10.7% for WA2h and 40.6% for WA24h (Oliveira et al., 2016).

C) Thickness Swelling

The effect of thickness swelling in the Particle boards is because of the moisture and absorption properties. Thickness swelling should not be more than 2-3%. Thickness swelling is very much lower after drying. For Thickness swelling, the specimen is immersed in distilled water at room temperature .(Jorge Parga Silva et al., 2012)

Thickness swelling (%) = $(T_f - T_i / T_i) * 100$ (4) T_i = initial thickness T_f = final thickness

Tabarsa et al. assessed the potential use of bagasse as an alternative raw material for the production of panels and obtained values ranging between 15.1% and 18.1% for TS2h, and 22.6% and 24.5% for TS24h (Oliveira et al., 2016).

But Okino et al. (1997), studying the effect of the acetylation of sugar cane bagasse particles without the pith on the physical-mechanical properties and using the resins urea formaldehyde and tannin-formaldehyde in the contents of 8 and 12%, obtained average values of thickness swelling that varied from 2.50 to 44.40% and from 4.70 to 55.30% for 2 and 24 hours respectively (Benedito et al., 2009).

2.5.2 Mechanical properties

A) Tensile Strength or Internal Bond Strength

Internal bond strength is commonly examined property for any type of Particle Boards. In terms of strength properties, this is one of the properties which have lot of significance. Tensile strength test is a mechanical test performed on packaging materials to determine the maximum load that can be applied to a material before it ruptures or tears. Tensile testing machine is used to calculate the tensile strength. The sample was placed on the machine and anchored at both ends. As the machine was pumped manually, both tensioned ends were stretched till it failed. Failure occurred by splitting. The tensile strength was calculated using the formulae $\delta t = Wt / b \times t$ Where, δt = Tensile stress (N/mm²), Wt = Failure tensile load (N) b = Breadth of the specimen (mm) and t = Thickness of the specimen (mm) (Muruganandam et al., 2016). The internal bond (IB), or tensile strength perpendicular to the board surface, is a widely determined property in all particleboard research. A particleboard with a well-cured adhesive will normally fail when stressed in tension perpendicular to the board surface, near the midpoint of the thickness. This is the lowest density region in a hot-pressed panel particleboard and consolidation of the mat to obtain intimate particle contact is lowest in this region. Most researchers have found higher IB values with increasing board density, increasing resin content, and increasing press time and temperature (U. F. Service & Report, 1977).

Mendes et al. found average values of internal bond of 0.5 MPa for industrial panels made from Pinus, 0.6 MPa for panels made from Eucalyptus, and 0.2 MPa for panels made from sugarcane bagasse. Barros Filho et al. assessed the quality of particleboard panels made from sugarcane bagasse mixed with Eucalyptus and by using urea-formaldehyde and melamine-formaldehyde as

adhesives, and they obtained average values of internal bond ranging between 0.20 and 0.63 MPa .(Oliveira et al., 2016)

B) Bending Stiffness or modulus of Elasticity (MOE)

Modulus of elasticity (MOE), also known as tensile modulus, is a number that measures an object or substance's resistance to being deformed elastically when a force is applied to it. The modulus of elasticity of an object is defined as the slope of its stress-strain curve in the elastic deformation region. The higher modulus of elasticity the material has, the stiffer it is (Zhu, 2017).

Modulus of elasticity is an important property because of its measure of stiffness or resistance to bending when stress is applied.

$$MOE = PbpL^3/4bh^3Yp$$

Where Pbp – load at the proportionality limit

L – Span length in mm, b – Width of the specimen in mm, h – Thickness of the specimen in mm and Yp –deflection corresponding to Pbp (mm)

Mendes et al. assessed different types of lignocellulosic materials produced in Brazil for the production of particleboard panels with urea-formaldehyde adhesive. For static bending, they obtained average MOE value of 1643.2Mpa for panels produced with sugarcane bagasse

C) Bending Strength or modulus of rupture (MOR)

Modulus of rupture (MOR), also known as flexural strength is a mechanical property, defined as the stress in a material just before it yields in a flexure test. By using a three point flexural test technique, a specimen having either a circular or rectangular cross-section is bent until fracture or yielding for modulus of rupture test. The modulus of rupture represents the highest stress experienced within the material at its moment of failure or breaking (Zhu, 2017).

Modulus of rupture is an important property determining the application of the product for structural components. This property results will depend according to the board density. A concentrated bending load was applied at the center with a span of 15 times the thickness of the Specimen (Muruganandam et al., 2016).

MOR can be calculated by load deflection curves using the formula

$$\text{MOR} = 3PbL/2bh^2$$

Where Pb – Maximum load, L – Span length in mm, b – Width of the specimen in mm and h – Thickness of the specimen in mm

Both Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) shows the effect based on the moisture content, particle size and type of raw material used.

Mendes et al. assessed different types of lignocellulosic materials produced in Brazil for the production of particleboard panels with urea-formaldehyde adhesive. For static bending, they obtained average MOR value of and 20.9 MPa for panels produced with sugarcane bagasse.

Okino et al. (1997), studying the effect of the acetylation of sugar cane bagasse particles without the pith on the physical mechanical properties of panels and using the resins urea formaldehyde and tannin-formaldehyde in the contents of 8 and 12%, obtained average values of RM that varied from 97 to 232 Kgf/cm².

3 MATERIALS AND METHODS

The experimental procedure for the development of particleboard is depicted in the figure 3.1 below.

Detail description of the process is given in the text that follows.

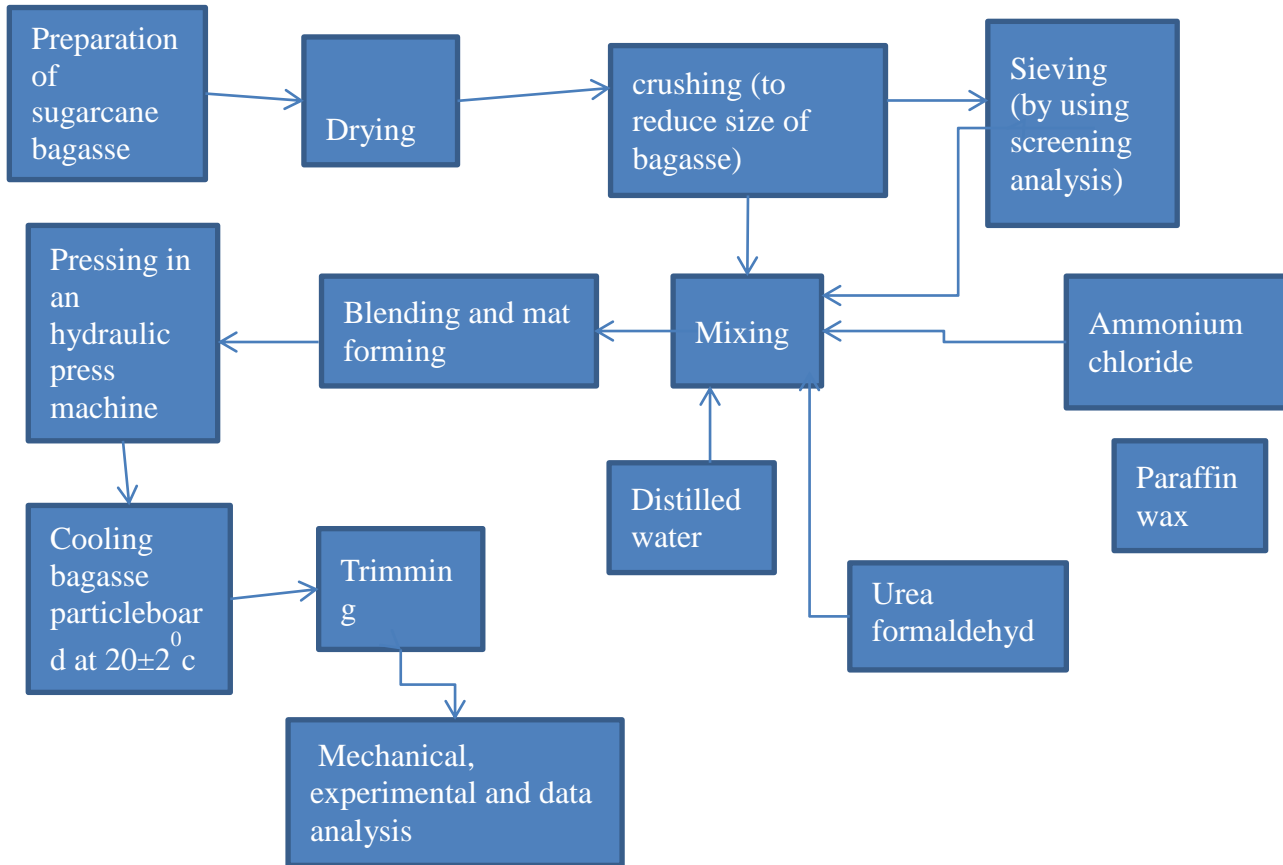


Figure 3. 1: The experimental procedure for the production of particle board from sugarcane bagasse

3.1 Experimental location

Development of particleboard and evaluation of its physical and mechanical properties were conducted at Addis Ababa University Addis Ababa institute of technology (AAIT) college of natural science (mechanical laboratory) and maichew particle production respectively.

3.2 Materials required

Raw materials used for this research were locally available sugarcane bagasse fiber.

3.2.1 Laboratory equipment's

Laboratory equipment for conducting mechanical and physical testing was: analytical weighing balance, thermo meter, viscometer, test tubes, oven dryer, physical testing equipment (universal testing machine).

Same functions of these materials are:

Type	Used
Test tubes	To measure the liquid ingredients
Mixer	To mix the ingredients and reduced the amount of unconverted ingredient by producing perfect mixing.
Thermo meter	To measure to the temperature
Analytical weighing balance	used to measure the required amount of ingredient that used to produce the product
Physical testing equipment (Universal testing machine)	To measure the mechanical properties of particleboard, like modulus of rapture, modules of elasticity and internal bonding.

3.2.2 Chemicals

Chemicals used and their functions in this study were:-

- Urea-Formaldehyde: - Used for increase the binding effect of the particle
- Wax: -it is also used as an additive
- Ammonium chloride: used as an hardener
- Distilled Water: used to dilute the ingredients and act as the reaction media.

3.3 Procedures

3.3.1 Raw material preparation

The raw materials used for this study were Sugarcane bagasse fiber, it was kindly supplied by wonji/shoa sugar factory located in Oromiya Regional State near Nazareth City, which is the most important by-product of sugar and obtained by the milling of green cane in a mill.

After collected the raw material, drying crushing and screening operation were performed directly.

3.3.2 Particle drying, crushing and screening

a) Drying

1, Sun Drying

Sun drying is very simple and ancient skill used for drying of bagasse. It is only possible in areas where in an average year the weather allows the bagasse to be dried immediately. The bagasse that brought from wonji/shoa sugar industry was dried for two days. The main advantage of sun drying is low capital and operating cost and also the fact that little expertise is required. Hence, it is primarily preferred for drying of raw materials for particle board making to reduce water content (Muruganandam et al., 2016).

2, Oven Drying

The greater part of the furnish delivered to the mill needs to dry until the moisture content of the particle come in the order of (2-3)% for the purpose of bonding with liquid resins. Therefore it was tried to use an oven dry to get the required moisture level. A 50 g sample of bagasse were dried at 105°C for 4 hours in a standard laboratory oven and the moisture content calculated from the mass loss observed (Excell, 1983).

The moisture content of the particle is determined by:

$$Mc = ((w1-w2)/w1)*100, \text{ (Labotec, 2005)}$$

M_c – Moisture content of the particle and

W_1 and w_2 are weights of particle before and after drying respectively.

b) Crushing

The dried bagasse was crushed in a laboratory size reduction by 5cm size of sieve crusher. It is (Retsch GmbH 5657 HAAN WEST GERMANY) standard.

c) Sieving

Then the required size material was separated in a vibrating screen shaker. Screening the material to allow the pith, dirt, and other fines to separate from the larger bagasse fibers. All material which passed through 750 micrometers standard window screen was discarded while all material remaining on the screen were utilized in the project with the exception of extremely large. The size of particle 750micrometer up to 1cm was used as the core of the board and (1-4) cm of the particle size was used to the inner side of the board. Once you do not forage Screening normally takes place after the dryers as moist particles tend to stick together, plugging screen plates and lowering the overall efficiency of the screening process.

Experimental setup

From ANOVA the design experiment was used three variables with three levels of each variable listed below by using central composite method.

- 1) Concentration in (%), (9, 12 and 15)
- 2) Target Density bagasse particle board in gram per centimeter cube (0.6, 0.65 and 0.7) and
- 3) Pressure in bar (35, 40 and 45)

Table 3. 1: design experiment

Sample No.	Resin content (%)	Density (g/cm ³)	Pressure (bar)
1	9	0.6	35
2	15	6	35
3	9	0.7	35
4	15	0.7	35
5	9	0.6	45
6	15	0.6	45
7	9	0.7	45
8	15	0.7	45
9	9	0.65	40
10	15	0.65	40
11	12	0.6	40
12	12	0.7	40
13	12	0.65	35
14	12	0.65	45
15	12	0.65	40
16	12	0.65	40
17	12	0.65	40

3.3.3 Mixing

To mix the dried particle with adhesive the target density were (0.6-0.7)g/cm³, thickness of the board was 0.8cm and adhesive concentration were (9-15) %.

Blending may either take place in large vats at slow speed, or in small blenders with rapid mixing and shorter blending times. But in this laboratory test the mixing process were applied manually. After perfect mix, it was put in a mat forming box, which in the dimensions of: 20cm x 20 x 1.5cm. After this transportation of the mats to the pre-press and hot press were undertaken.

3.3.4 Pressing

Pre-pressing of the mats prior to the introduction in the main hot presses, is now becoming a common feature in the pressing operation, due to the consolidation and reduction in mat width. This allows for ease of handling and the use of narrower openings in the hot-press, thereby considerably reducing pressing time.

A pre-pressing was used at 10bar. It was used cold type. The main press is always heated, by passing hot water, steam or oil through the platens at constant temperatures. Then the box were put in a hydraulic press machine and the boards were making by using an 8-minute press closing time, with pressure of 35bar, 40bar, and 45bar and constant temperature of 160°C for the Urea Formaldehyde adhesive.

3.3.5 Board finishing

On leaving the hot press the boards were separated from the mold by mechanically by means of turning devices. The mold was stacked, the boards in turn, were cool and conditioning at temperature ($20\pm 2^\circ\text{C}$), so as to avoid degradation of the urea resins. Trimming saws were used to cut the boards to size, with the edge trimmings. In order to meet set standards as to thickness and surface quality knife planers were used. These knife planers were (hw-top line kreissaege blatt 3555*4, 4*80z=72ws revpr 1) standard.

3.4 properties of developed particle board

The parameters were evaluating in this experiment included of modulus of rupture (MOR) and internal bond (IB).

3.4.1 Evaluation of mechanical properties of developed particle board

A) Bending Strength or modulus of rapture (MOR)

Modulus of rapture is widely important mechanical property of particle board. So as it is favored to characterize the prepared particleboard with the aspect of its bending strength.

Apparatus and equipment: apparatus used for this test were: weighing balance, steel ruler, and thickness gauge, universal testing machine (UTM) and PC system.

Methods

For this testing ziwick/ Roell type z1-mm14450zw04 standard test method was used.

Procedures:-

- To test the developed particleboard, it was cut in to pieces and it was take two samples from each board.
- The thickness of each test pieces were measured using thickness gauge at four places on gain side of the particleboard test specimen and record the average thickness.
- The width of the board was 5cm; the height and the mass of the particleboard were measured using steel ruler and weighing balance respectively.
- The volume of the board was calculated on the test specimen by multiplying height, width and average thickness.
- The density of the board was calculated by dividing mass to the calculated volume.
- The distance between the grips of the bending tester (support separation) was set as 150mm for standard test specimen.
- The test specimens were inserted between the grips and then tighten the grips with sufficient pressure, and the calculated average thickness and density were inserted in to the PC.
- The tensile testing machine was operated at a speed of 100mm/minute until the board sample breaks. Then the modulus of rapture was recorded from the PC.

Production and economic analysis of particleboard from sugarcane bagasse

Table 3. 2:- Laboratory data for density testing

Sample No.	Variables	mass(g)	thickness of the sample				Thickness Average	volume	Height	density
			T1	T2	T3	T4				
1	c (9%),d (0.6) and p(35)	35.64	0.732	0.74	0.69	0.75	0.73	68.54	18.73	0.52
		38.93	0.64	0.62	0.71	0.63	0.65	68.83		0.64
							0.69			0.58
2	c (15%),d (0.6) and p(35)	39.57	0.78	0.7	0.76	0.72	0.74	64.87	17.6	0.61
		38.22	0.93	0.93	0.95	0.95	0.69	60.67		0.63
							0.715			0.62
3	c (9%),d (0.7) and p(35)	44.87	0.7	0.64	0.65	0.69	0.67	62.32	18.7	0.72
		42.56	0.78	0.68	0.74	0.7	0.72	66.92		0.636
							0.695			0.678
4	c (15%),d (0.7) and p(35)	44.03	0.69	0.63	0.69	0.63	0.66	62	18.8	0.71
		46.83	0.71	0.62	0.7	0.63	0.664	62.44		0.75
							0.662			0.73
5	c (9%),d (0.6) and p(45)	35.46	0.79	0.71	0.8	0.7	0.75	65.67	18.2	0.54
		37.7	0.62	0.68	0.64	0.66	0.65	58.91		0.64
							0.7			0.59
6	c (15%),d (0.6) and p(45)	40.68	0.72	0.7	0.73	0.69	0.71	65.6	18.5	0.62
		37.76	0.67	0.61	0.66	0.62	0.64	59		0.64
							0.675			0.63
7		42.3	0.68	0.64	0.72	0.6	0.66	61.57	18.6	0.687
8	c (15%),d (0.7) and p(45)	39.71	0.54	0.62	0.56	0.6	0.58	52.25	18	0.76
		45.89	0.7	0.72	0.74	0.68	0.71	63.74		0.72
							0.645			0.74
9	c (9%),d (0.65) and p(40)	39.85	0.7	0.64	0.71	0.63	0.67	62.27	18.7	0.64
		44.82	1	0.99	0.91	1.02	0.73	68.12		0.658
							0.7			0.649

Production and economic analysis of particleboard from sugarcane bagasse

Table 3.2 Laboratory data sheet for density testing continue

Sample No.	Variables	mass(g)	thickness of the sample				Thickness	volume	Height	density
			T1	T2	T3	T4	Average			
10	c (15%),d (0.65) and p(40)	40.16	0.55	0.62	0.57	0.6	0.585	56.56	19	0.71
		43.76	0.77	0.75	0.8	0.72	0.76	72.21		0.606
							0.673			0.658
11	c (12%),d (0.6) and p(40)	37.79	0.74	0.68	0.72	0.7	0.71	66.3	18.7	0.57
		41.08	0.67	0.75	0.69	0.73	0.71	66.3		0.62
							0.71			0.595
12	c (12%),d (0.7) and p(40)	43.71	0.66	0.64	0.7	0.6	0.65	61.56	18.9	0.71
		47.07	0.62	0.74	0.64	0.72	0.68	64.48		0.73
							0.67			0.72
13	c (12%),d (0.65) and p(35)	42.14	0.71	0.75	0.76	0.7	0.73	69.1	19	0.61
		36.98	0.62	0.58	0.61	0.59	0.6	56.9		0.65
							0.67			0.63
14	c (12%),d (0.65) and p(45)	42.23	0.67	0.65	0.69	0.63	0.66	62	18.7	0.68
		43.61	0.75	0.69	0.74	0.7	0.72	67.1		0.65
							0.69			0.665
15	c (12%),d (0.65) and p(40)	41.84	0.73	0.71	0.75	0.69	0.72	67.48	18.8	0.62
		44.17	0.73	0.69	0.72	0.7	0.71	66.92		0.66
							0.716			0.64
16	c (12%),d (0.65) and p(40)	41.84	0.73	0.71	0.75	0.69	0.72	67.48	18.8	0.62
		44.17	0.73	0.69	0.72	0.7	0.712	66.92		0.66
							0.716			0.64
17	c (12%),d (0.65) and p(40)	41.84	0.73	0.71	0.75	0.69	0.72	67.48	18.8	0.62
		44.17	0.73	0.69	0.72	0.7	0.712	66.92		0.66
							0.716			0.64

Where c: - Resin content (%), d: - density (g/cm³) and P: - pressure (bar)

Table 3. 3: Laboratory Data test for modulus of rapture (MOR)

Sample No.	Variables	Average thickness (cm)	Average density (g/cm ³)	Grip separation(m m)	Bending strength(MOR) N/MM ²
1	c (9%),d (0.6) and p(35)				5.637
					5.7
		0.69	0.58	150	5.6637
2	c (15%),d (0.6) and p(35)				9.1053
					10.4851
		0.715	0.62	150	9.7952
3	c (9%),d (0.7) and p(35)				7.65
					7.91
		0.695	0.678	150	7.78
4	c (15%),d (0.7) and p(35)				11.982
					13.6492
		0.662	0.73	150	12.8156
5	c (9%),d (0.6) and p(45)				7.05
					7.117
		0.7	0.59	150	7.0835
6	c (15%),d (0.6) and p(45)				10.965
					11.084
		0.675	0.63	150	11.0245
7		0.66	0.687	150	9.8129
8	c (15%),d (0.7) and p(45)				14.512
					14.6228
		0.645	0.74	150	14.5674
9	c (9%),d (0.65) and p(40)				7.0623
					7.9903
		0.7	0.649	150	7.5263

Table 3. 4: Laboratory Data test for MOR continue

Sample No.	Variables	Average thickness (cm)	Average density (g/cm ³)	Grip separation(m m)	Bending strength(MOR) N/MM ²)
10	c (15%),d (0.65) and p(40)				11.523
					12.4156
		0.673	0.658	150	11.9693
11	c (12%),d (0.6) and p(40)				8.5
					8.04
		0.71	0.59	150	8.27
12	c (12%),d (0.7) and p(40)				10.325
					11.829
		0.67	0.72	150	11.077
13	c (12%),d (0.65) and p(35)				8.7621
					9.1477
		0.67	0.63	150	8.9549
14	c (12%),d (0.65) and p(45)				9.879
					11.2024
		0.69	0.665	150	10.5407
15	c (12%),d (0.65) and p(40)				9.5
					9.92
		0.716	0.64	150	9.71
16	c (12%),d (0.65) and p(40)				9.23
					9.79
		0.716	0.65	150	9.51
17	c (12%),d (0.65) and p(40)				9.15
					9.25
		0.716	0.63	150	9.2

B) Internal bonding test

It has the same procedure with modulus of rupture; the only difference is based on the dimensions used. For IB test, the dimensions of specimens were 5 by 5 cm². For internal bonding test it was take two samples from each board.

Table 3. 5: Laboratory data sheet for internal bonding testing

sample No.	Variables	Mass	Average thickness	volume	Density	IB (N/mm2)
1	c (9%),d (0.6) and p(35)	8.97	0.73	18.25	0.491507	0.3
		9.31	0.65	16.25	0.572923	0.2
			0.69		0.53	0.26
2	c (15%),d (0.6) and p(35)	10.45	0.74	18.5	0.564865	0.214
		10.2	0.69	17.25	0.591304	0.246
			0.715		0.578	0.28
3	c (9%),d (0.7) and p(35)	10.73	0.67	16.75	0.640597	0.319
		10.7	0.72	18	0.594444	0.31
			0.695		0.62	0.315
4	c (15%),d (0.7) and p(35)	11.7	0.58	14.5	0.806897	0.329
		10.08	0.71	17.75	0.567887	0.313
			0.645		0.687	0.321
5	c (9%),d (0.6) and p(45)	9.22	0.75	18.75	0.491733	0.25
		9.75	0.65	16.25	0.6	0.29
			0.7		0.55	0.27
6	c (15%),d (0.6) and p(45)	10.06	0.71	17.75	0.566761	0.31
		10.06	0.64	16	0.62875	0.27
			0.675		0.598	0.29
7		10.89	0.66	16.5	0.66	0.3055
8	c (15%),d (0.7) and p(45)	12.84	0.66	16.5	0.778182	0.38
		11.64	0.664	16.6	0.701205	0.44
			0.662		0.74	0.41

Table 3.5: Laboratory data sheet for internal bonding testing continue

sample No.	Variables	mass	Average thickness	volume	Density	IB (N/mm)
9	c (9%),d (0.65) and p(40)	9.56	0.585	14.625	0.654	0.35
		10.28	0.76	19	0.541	0.256
			0.673		0.597	0.278
10	c (15%),d (0.65) and p(40)	10.71	0.67	16.75	0.64	0.36
		11.46	0.73	18.25	0.63	0.33
			0.7		0.634	0.345
11	c (12%),d (0.6) and p(40)	11.06	0.71	17.75	0.623	0.31
		10.23	0.71	17.75	0.58	0.22
			0.71		0.5997	0.265
12	c (12%),d (0.7) and p(40)	12	0.65	16.25	0.74	0.32
		11.78	0.68	17	0.693	0.305
			0.67		0.72	0.3625
13	c (12%),d (0.65) and p(35)	11.15	0.73	18.25	0.611	0.29
		9.92	0.6	15	0.661	0.281
			0.67		0.64	0.2855
14	c (12%),d (0.65) and p(45)	10.76	0.66	16.5	0.652	0.38
		11.68	0.72	18	0.65	0.3
			0.69		0.651	0.34
15	c (12%),d (0.65) and p(40)	10.92	0.72	18	0.607	0.35
		11.49	0.71	17.75	0.65	0.292
			0.718		0.626	0.321
16	c (12%),d (0.65) and p(40)	10.92	0.72	18.1	0.603	0.32
		11.49	0.712	17.8	0.65	0.304
			0.716		0.621	0.312
17	c (12%),d (0.65) and p(40)	10.92	0.72	18	0.61	0.31
		11.49	0.712	18	0.64	0.28
			0.715		0.615	0.295

3.5 Experimental design and data analysis

Response surface methodology (RSM) was adopted in the design of experimental combinations. The main advantage of RSM is to reduce the number of experimental runs needed to provide sufficient information for statistically acceptable results. A three variable (three levels of each) central composite experimental design was employed.

The first task before conducting the experiments was selection of potential parameters to be varied. The three main factors selected in this study were adhesive content, targeted density and pressure. The level of the selected factors was determined from the literature research and is resented in table below. The experiment performed as a completely randomized design with three main factors, three levels and two response variables. The processing variables (adhesive content, density and pressure) were optimized using RSM to study their effect on the functional properties of prepared particleboard. The responses that were considered during the optimization of the processing variables were modulus of rapture and internal bonding.

Table 3. 6:- : levels of independent variables for the development of particleboard based on central composite design

Independent variables	Units	Coded symbol	Coded levels		
			-1	0	+1
Adhesive content	%	A	9	12	15
Density	g/cm ³	B	0.6	0.65	0.7
Pressure	Bar	C	35	40	45

Data analyses have performed by DESIN EXPERT® 7.0.0 software using response surface methodology design method and randomize the runs. Randomization ensures that the conditions in one run neither depend on the conditions of the previous runs nor predict the conditions in the subsequent runs. Randomization is essential for drawing conclusions from the experiment .in correct, unambiguous and defensible manner.

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This design of the experiment helps us to differentiate the significance of the main and the interaction factors. This program software also used to develop the mathematical model that will describe the effects of the main and interaction factors on the response.

The proposed RSM design required 17 runs. Detail of the experimental runs with the set of input parameters that were conducted at a given in table 3.7

Table 3. 7:- : three factors, three levels face centered quadratic design model with three center point formulation

Standard order	A: adhesive content	B: density	C: pressure
1	9.00	0.60	35.00
2	15.00	0.60	35.00
3	9.00	0.70	35.00
4	15.00	0.70	35.00
5	9.00	0.60	45.00
6	15.00	0.60	45.00
7	9.00	0.70	45.00
8	15.00	0.70	45.00
9	9.00	0.65	40.00
10	15.00	0.65	40.00
11	12.00	0.60	40.00
12	12.00	0.70	40.00
13	12.00	0.65	35.00
14	12.00	0.65	45.00
15	12.00	0.65	40.00
16	12.00	0.65	40.00
17	12.00	0.65	40.00

4 RESULT AND DISCUSSION

The determination of mechanical properties involves not only scientific but also technological and practical aspects. Thus, the mechanical properties of the boards were studied to determine the values of important parameters such as modulus of rupture (MOR) and internal bonding. The value of MOR and IB for particle board at a given level of three factors is depicted in table 4.1 below. The resulting data, table 4.1; were analyzed using DESIGN EXPERT® 7.0.0 software to determine the effect of adhesive content, density and pressure. The dependent variables used as a response parameter were the modulus of rupture and internal bonding. All experiments were carried out in a randomized order to minimize the effect of unexpected variability in the observed response due to extraneous factors.

From table 4.1 it can be seen that the maximum value of the mechanical properties of the board (MOR and IB) were 14.5674Mpa and 0.41Mpa respectively. From this result increasing the adhesive content, density and pressure, MOR and IB also increased. Range of MOR is approximately from 5.664-14.5674 Mpa and for IB its range is 0.26-0.41 Mpa. The average values are for MOR 9.7Mpa and for IB 0.31Mpa.

Widyorini et al (2005) assessed the quality of particleboard panels produced with sugarcane bagasse with resin content of 8%-10% and obtained MOR values between 2 and 11 MPa for static bending and Mendes et al (2007), he is found average values of internal bond of 0.2 MPa for panels made from sugarcane bagasse. This agrees with present study.

Table 4. 1: experimental design and response

Standard order	Factor 1	Factor 2	Factor 3	Response 2	Response 3
	Adhesive content (%)	Density(g/cm ³)	Pressure (Bar)	MOR (N/mm ²)	IB (Mpa)
1	9.00	0.60	35.00	5.6637	0.26
2	15.00	0.60	35.00	9.7952	0.264
3	9.00	0.70	35.00	7.78	0.3
4	15.00	0.70	35.00	12.8156	0.35
5	9.00	0.60	45.00	7.0835	0.27
6	15.00	0.60	45.00	11.0245	0.29
7	9.00	0.70	45.00	9.8129	0.32
8	15.00	0.70	45.00	14.5674	0.41
9	9.00	0.65	40.00	7.5263	0.278
10	15.00	0.65	40.00	11.9693	0.345
11	12.00	0.60	40.00	8.27	0.265
12	12.00	0.70	40.00	11.077	0.3625
13	12.00	0.65	35.00	8.9549	0.2855
14	12.00	0.65	45.00	10.5407	0.34
15	12.00	0.65	40.00	9.71	0.321
16	12.00	0.65	40.00	9.51	0.312
17	12.00	0.65	40.00	9.2	0.295

The design summary for the experiment is shown in table 4.2

Table 4. 2: design summary

Study type	Central composite
Initial design	Response surface
Center point	0
Design model	Quadratic
Runs	17

Factor	Name	Unit	Type	Low actual	High actual	Level
A	Adhesive content	%	Quadratic	9	15	3
B	Density	g/cm ³	Quadratic	0.6	0.7	3
C	Pressure	Bar	Quadratic	35	45	3

4.1 Development of regression model equation

Table 4.1 summarizes the result obtained with the experimental design which was aimed at increasing processing variables determining the condition that favors maximum MOR and IB occurs. A quadratic model equation 4.1, 4.3 shown below was fitted the data model for predicting responses; modulus of rapture (MOR) and internal bonding (IB) respectively. F ratio is calculated for 95% of confidence level.

4.1.1 Modulus of rapture for the prduced particleboard

The Model F-value of 316.45 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant

model terms (not counting those required to support hierarchy), model reduction may improve your model. Values of R^2 and adjusted R^2 were 0.9975 and 0.9944 respectively.

The "Lack of Fit F-value" of 0.17 implies the Lack of Fit is not significant relative to the pure error. There is a 94.92% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit. The "Pred R-Squared" of 0.9943 is in reasonable agreement with the "Adj R-Squared" of 0.9944.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 70.564 indicates an adequate signal. This model can be used to navigate the design space.

As depicted equation 4.3 in terms of coded factors the response MOR affect by all linear terms (A, B, C) and quadratic terms (pure quadratic) (A^2 , B^2 , C^2) and interaction terms (AB, AC, BC). As expressed in equation 4.3 MOR was positively affected by all linear terms (A, B, C), interaction terms except (AB, BC) and pure quadratic term (A^2 , B^2, C^2) and also negatively affected by interaction term (AC). For linear terms adhesive content (A) had a highest positive effect on the response of MOE whereas from quadratic terms B^2 had the highest positive effect on the response.

Final Equation in Terms of Coded Factors:

$$\begin{aligned} \text{MOR} = & +9.56 + 2.23 * A + 1.42 * B + 0.80 * C \\ & + 0.21 * A * B - 0.059 * A * C + 0.14 * B * C \\ & + 0.11 * A^2 + 0.041 * B^2 + 0.11 * C^2 \end{aligned} \quad 4.1$$

Final Equation in Terms of Actual Factors:

$$\begin{aligned} \text{MOR} = & +15.84314 - 0.33608 * A - 32.57459 * B - 0.52924 * C \\ & + 1.43133 * AB - 3.93000E-003 * AC + 0.56780 * BC \\ & + 0.012768 * A^2 + 16.24507 * B^2 + 4.59651E-003 * C^2 \end{aligned} \quad 4.2$$

4.1.2 Internal bonding of the developed particleboard

The Model F-value of 17.46 implies the model is significant. There is only a 0.05% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 0.95 implies the Lack of Fit is not significant relative to the pure error. There is a 58.33% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 16.046 indicates an adequate signal. This model can be used to navigate the design space.

equation 4.5 in terms of coded factors represents the response IB affect by all linear terms (A, B, C) and quadratic terms (pure quadratic) (A^2 , B^2 , C^2) and interaction terms (AB, AC, BC). As expressed in equation 4.5 IB was positively affected by all linear terms (A, B, C), interaction terms and also negatively affected by pure quadratic term (A^2 , B^2, C^2). For linear terms and the interaction terms density (B) had a highest positive effect on the response of IB whereas from quadratic terms A^2 had the highest negatively effect on the response.

Final Equation in Terms of Coded Factors:

$$\begin{aligned} \text{IB} = & +0.31+0.023 * A+0.040 * B+0.017* C \\ & +0.015* A * B+7.500E-003 * A * C+5.000E-003* B * C \\ & -2.500E-003 * A^2-2.500E-004* B^2-1.250E-003 * C^2 \end{aligned} \quad 4.3$$

Final Equation in Terms of Actual Factors:

$$\begin{aligned} \text{IB} = & +0.94260 -0.070767 * A-1.07500 * B -0.011510* C + \\ & 0.10000 * A* B+5.00000E-004 * A * C +0.020000 * B * C \\ & -2.7778E-004* A^2-0.100000 * B^2 -5.00000E-005* C^2 \end{aligned} \quad 4.4$$

4.2 Effect of individual processing variable

The effect of each independent variable on mechanical properties of the particleboard was investigated by keeping other variables constant. More ever, from the model equation, the coefficients of independent variables show the effect of each independent variable on mechanical properties of the particleboard.

4.2.1 Effect of adhesive content on modulus of rapture for particleboard

The measured values of the MOR are shown in Figures 4.1. The MOR increased as the resin content increased. An increase of the adhesive content from 9% to 15% resulted in a substantial improvement of MOR for bagasse particle boards. It can be seen that higher adhesive content levels resulted in improved mechanical properties. The MOR values obtained in this study are in

general agreement with previous studies, Bekalo S and Reinhardt H-, (2009), Blanchet P, Cloutier A and Riedl B. (2000). Post (1958) found that resin content has only a slight effect on the modulus of rupture (MOR) values with urea-formaldehyde adhesive (U. F. Service & Report, 1977).

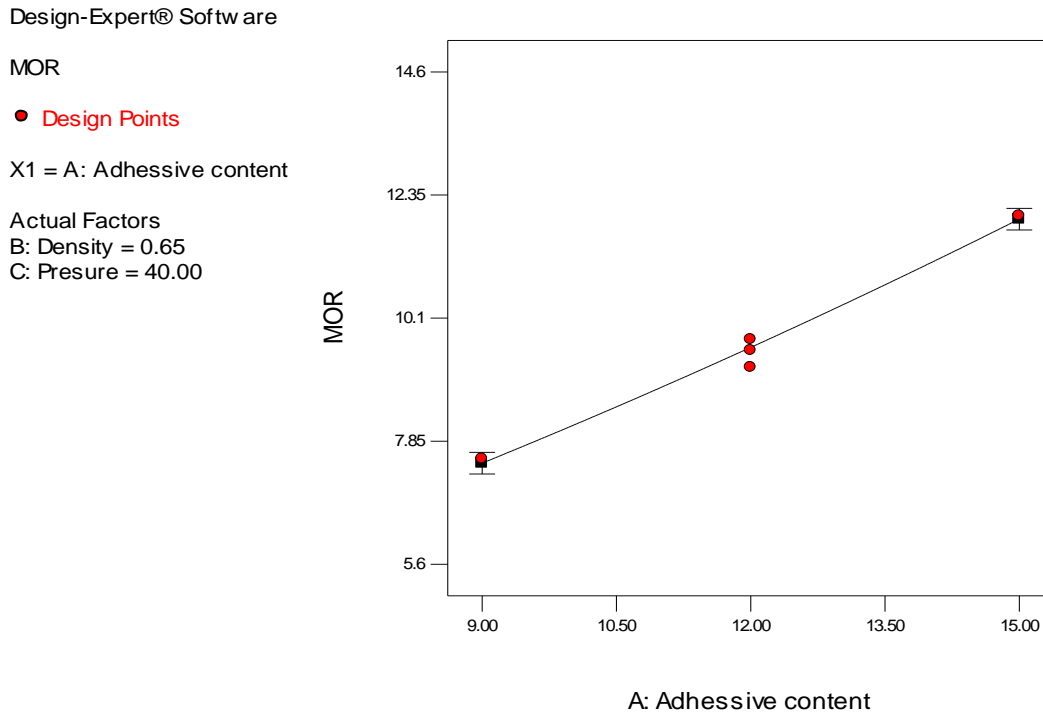


Figure 4. 1: Effect of adhesive content on modulus of rupture (MOR) for the produced particleboard.

4.2.2 Effect of density on modulus of rupture of particleboard

As shown figure 4.2 with increasing MOR density of the particleboard increased from lower (-1) to higher coded (+1) or from 0.6g/cm^3 to 0.7g/cm^3 . Moreover, the MOR value of the particleboards increased with increasing board density, which is a similar trend to that observed for conventional particleboards (Iswanto, 2014; Rachtanapun & Sattayarak, 2012). According to Malonney, (1977) the MOR are strongly influenced by the particleboard's density. The higher the overall density of particleboard from a given raw material, the greater the strength (Particleboards, n.d.).

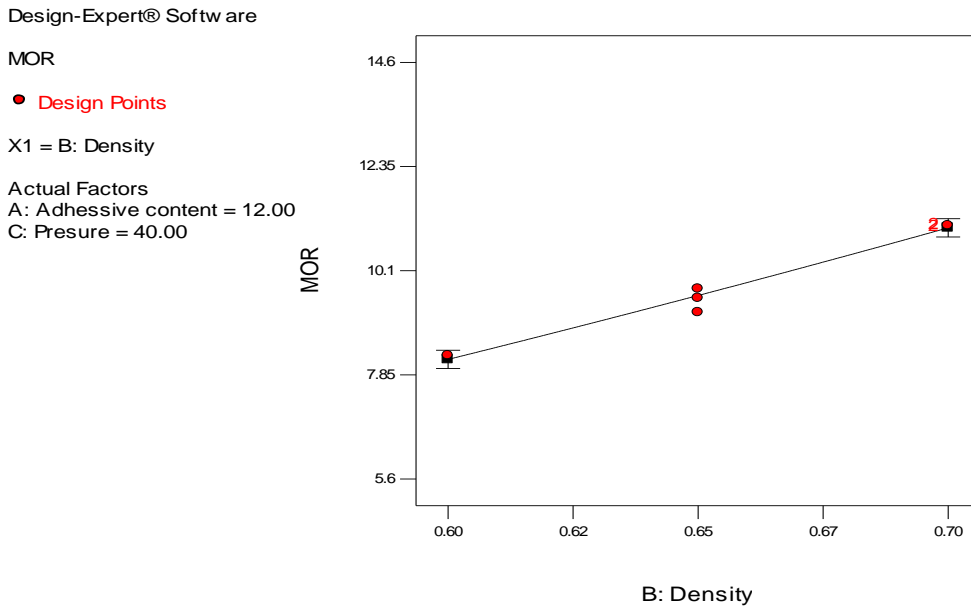


Figure 4. 2: Effect of density on modulus of rapture

4.2.3 Effect of pressure on modulus of rapture (MOR) of the produced particleboard

The effect of pressing pressure on modulus of rapture was shown in figure 4.3 below. From the graph it can be observed that the pressure start to increase from low coded (-1) to high coded (+1) or from 35bar to 45bar, modulus of rapture also increase slightly. I.e., at high pressing pressure, porosity between particles decreased and it occurs high density (Of, Duration, Physical, Of, & Clones, 2011). Modulus of rapture (MOR) could be improved when refining steam pressure increases (Nayeri, Tahir, Jawaid, & Harun, 2014).

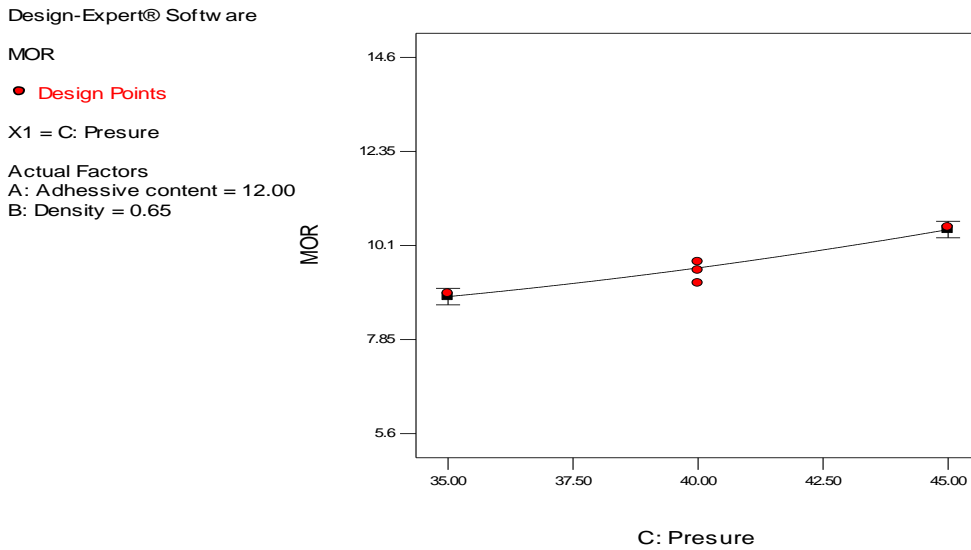


Figure 4. 3: Effect of pressure on modulus of rapture

4.2.4 Effect of adhesive content on internal bonding of particle board (IB)

Internal bonding is an essential factor in particleboards which controls the quality of internal connections in the middle layer. It can be enhanced by adequate pressing of particles and full utilization of resin in inner layers of particle cake (Dahmardehghalehno & Bayatkashkoli, 2013).

As depicted in figure 4.4 below the effect of adhesive content on internal bonding of the particleboard can be observed that as adhesive content increase the value of internal bonding also increasing linearly. Most researchers have found higher IB values with increasing board density, increasing resin content, and increasing press time and temperature (U. F. Service & Report, 1977).

Design-Expert® Software

IB

● Design Points

X1 = A: Adhesive content

Actual Factors

B: Density = 0.65

C: Pressure = 40.00

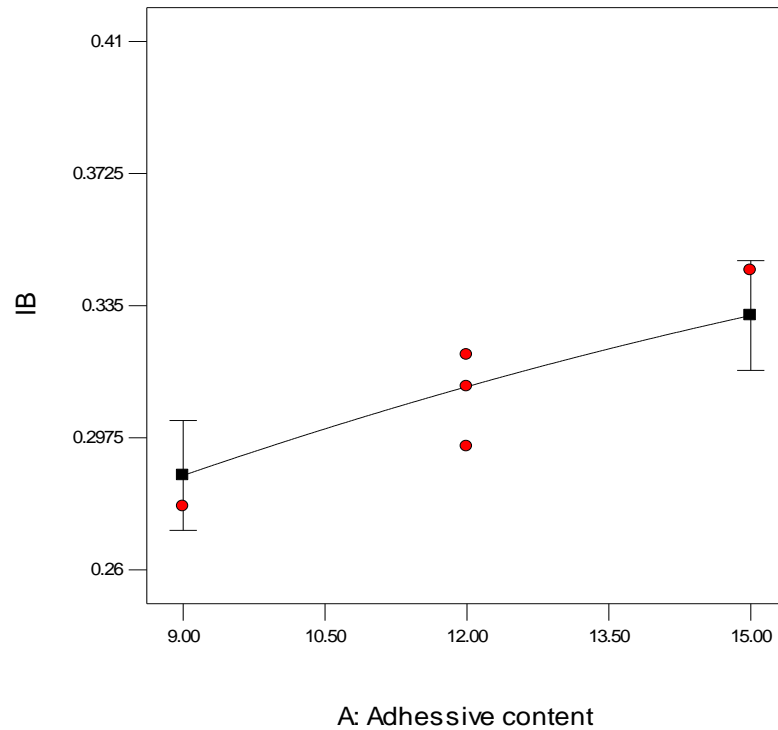


Figure 4. 4: Effect of adhesive content on internal bonding of particleboard

4.2.5 Effect of density on internal bonding (IB)

Figure 4.5 below shows the effect of density on internal bonding of the particleboard. It can be observed that as density increase the value of internal bonding also increasing linearly.

The normal vertical density gradient in flat-pressed particleboard adversely affects the IB. Highly densified surfaces increase the bending strength of particleboard, as shown by Geimer et al. (1975), but the resultant lower density core region normally reduces the IB (Strickler 1959;Plath and Schnitzler 1974) (U. F. Service & Report, 1977) (Wu, 1989).

Design-Expert® Software

IB

● Design Points

X1 = B: Density

Actual Factors

A: Adhesive content = 12.00

C: Pressure = 40.00

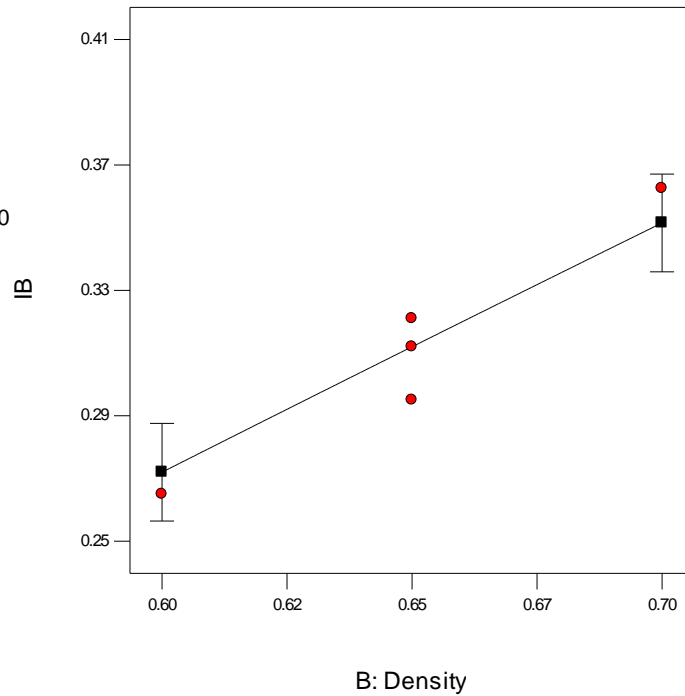


Figure 4. 5:- Effect of density on internal bonding

4.2.6 Effect of pressure on internal bonding of produced particle board

The effect of pressing pressure on internal bonding was shown in figure 4.6 below. From the graph it can be observed that the pressure start to increase from low coded (-1) to high coded (+1) or from 35bar to 45bar, internal bonding also increase. I.e., at high pressing pressure, porosity between particles decreased and it occurs high density.

Design-Expert® Software

IB

● Design Points

X1 = C: Pressure

Actual Factors

A: Adhesive content = 12.00

B: Density = 0.65

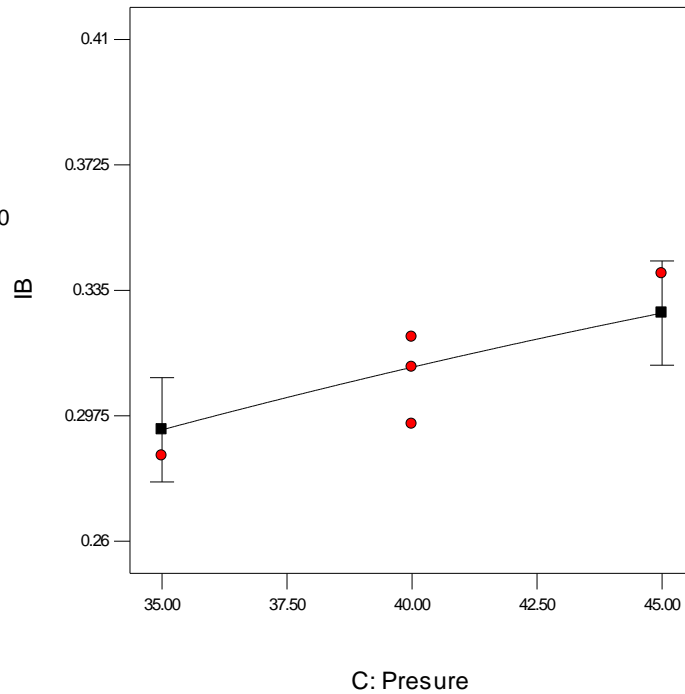


Figure 4. 6: Effect of pressure on internal bonding of particleboard

4.3 Effects of interactive factors between process variable on the response parameters

Figure 4.7 and 4.8 shows the effect of interaction and contour plot of UF resin content and density on MOR. Where the maximum value of MOR (14.5674 Mpa) were at resin content of 15% and density of 0.7g/cm^3 . Low resin content (9%) and low density (0.6 g/cm^3) showed the minimum modulus of rupture values (5.6637 Mpa). Board density and resin content in addition to wood species had a significant effect on the MOR of boards. The MOR increased with increasing board density and resin content. This agreed with the findings of Oyagade (1990), Geimer *et al.* (1993) and Fuwape (1995). And also maximum internal bonding (IB) (0.41 Mpa) occurs at the maximum processing variables (resin content 15% and density 0.7g/cm^3) (see figure 4.9 and 4.10). IB is minimum (0.25Mpa) at minimum resin content and minimum density (9% and 0.6 g/cm^3 respectively). That means the increment of resin content and density affects increasing of both modulus of rupture (MOR) and internal bonding (IB).

As predicted in figure 4.11 and 4.13 both modulus of rupture and internal bonding were increased as

increasing resin content and pressure. Similar to this figure 4.15 and 4.17 the processing variables, density and pressure increases with increasing of the response variables (MOR and IB).

Generally the board properties increased when the resin content and pressure increased (Panel, Nayeri, Tahir, Jawaid, & Harun, 2014).

Design-Expert® Software

MOR

14.5674

5.6637

X1 = A: Adhesive content

X2 = B: Density

Actual Factor

C: Pressure = 40.00

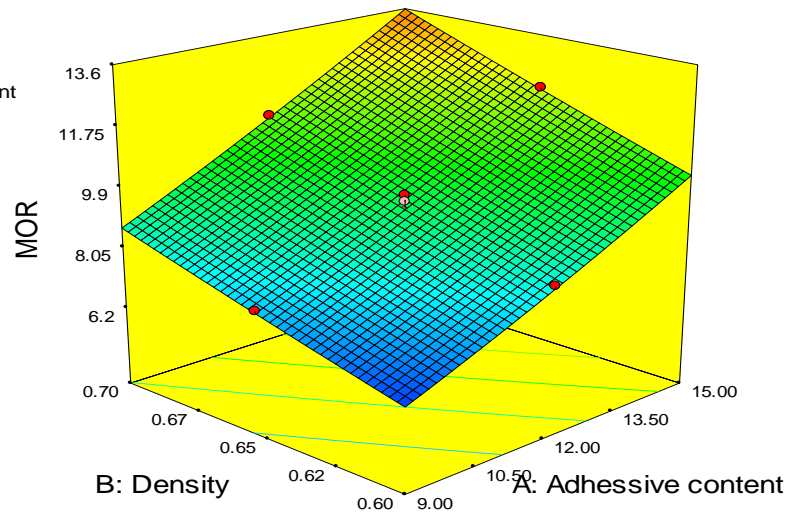


Figure 4. 7: Effects of adhesive content and density interaction on modulus of rapture

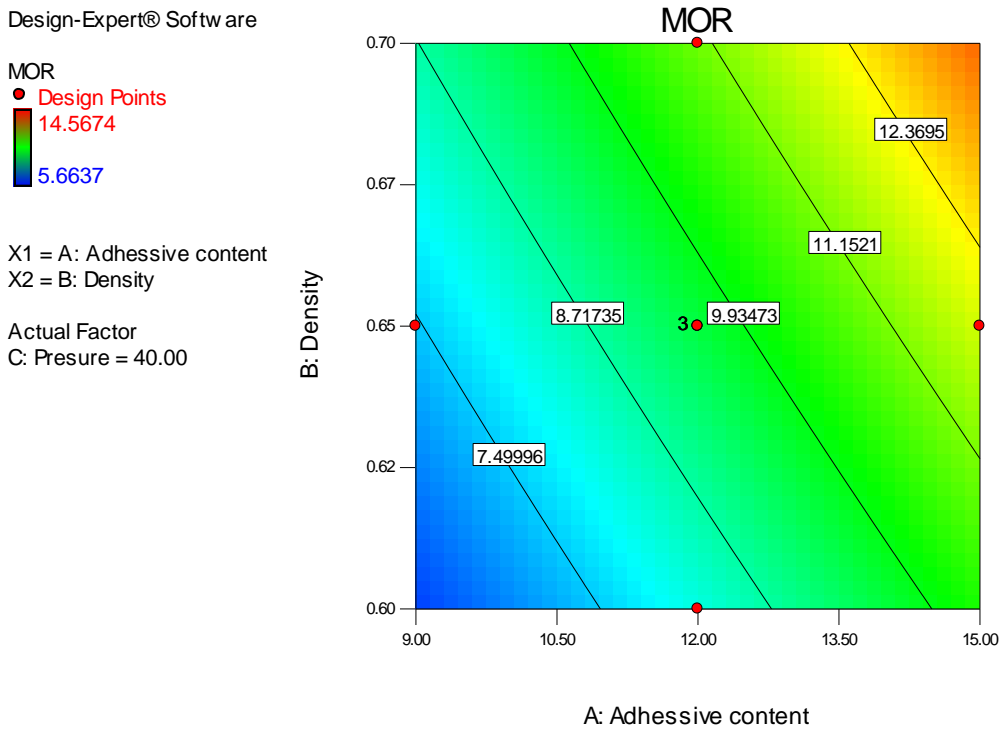


Figure 4. 8: Effects of adhesive content and density on modulus of rapture contour plot particleboard

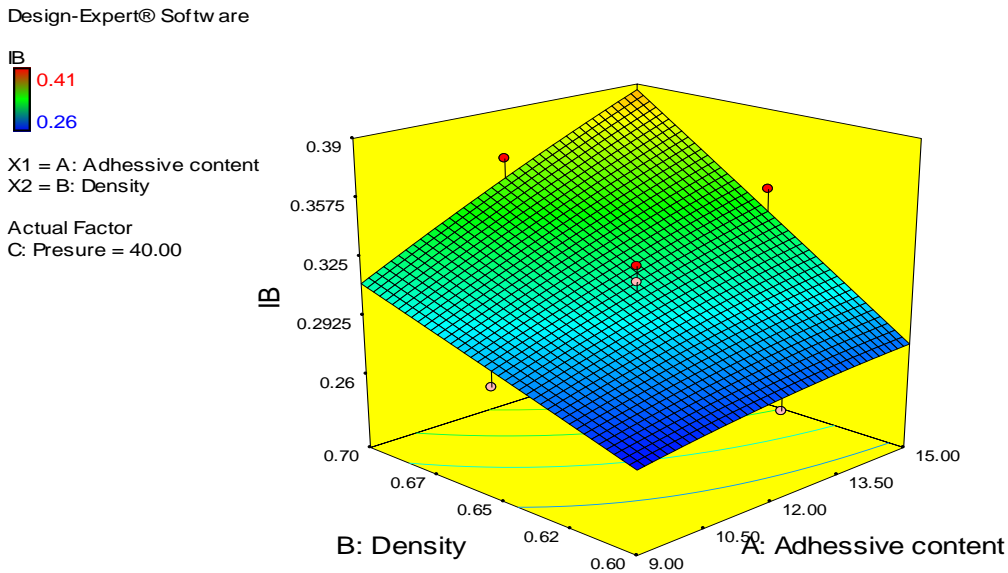


Figure 4. 9: Effects of adhesive content and density interaction on internal bonding

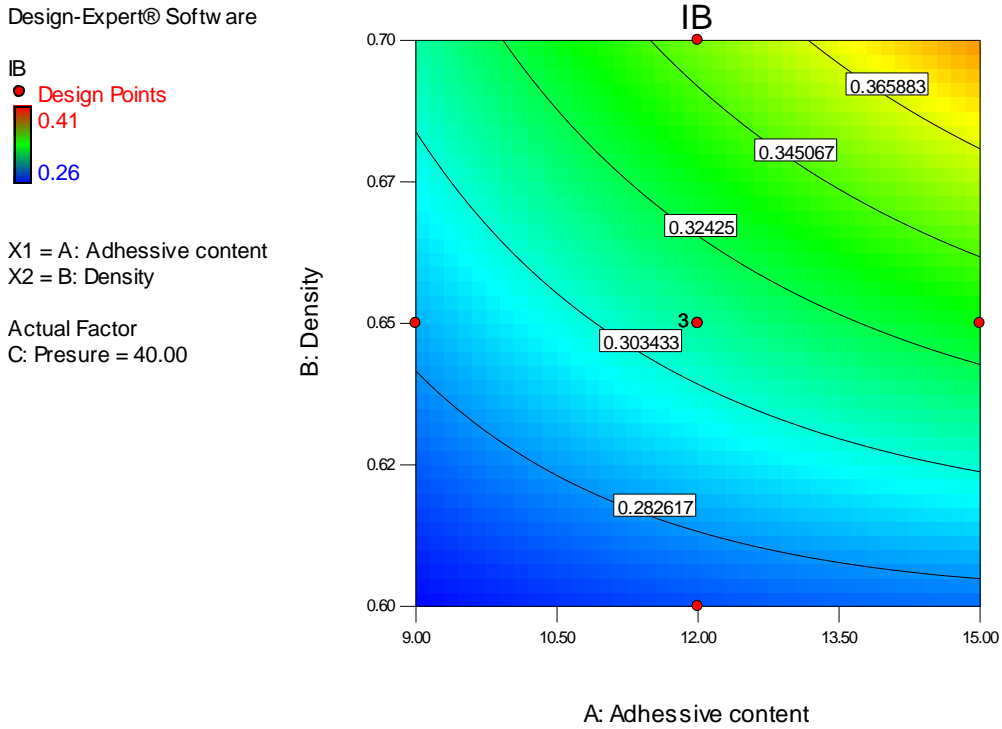


Figure 4. 10: contour effects of resin content and density on internal bonding

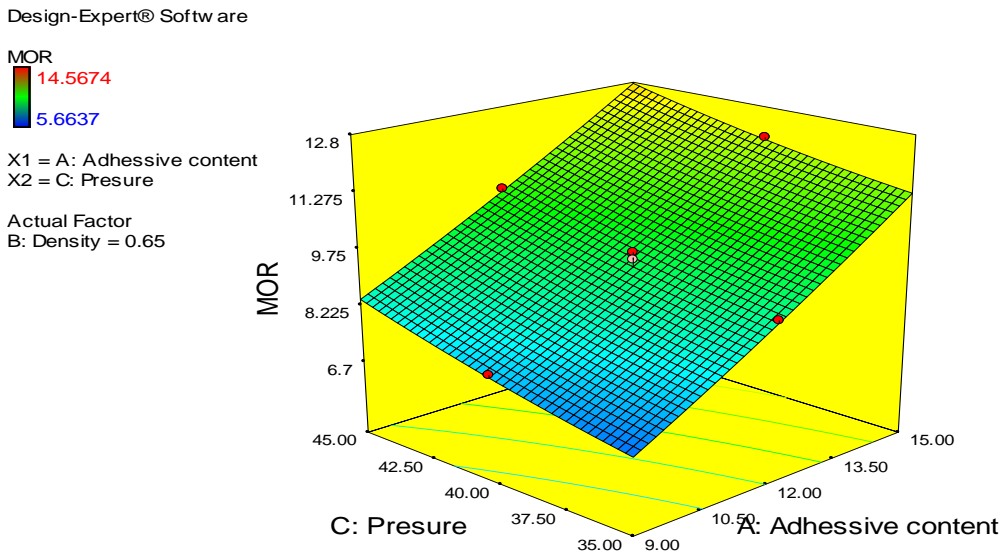


Figure 4. 11: interactive effects of resin content and pressure on MOR

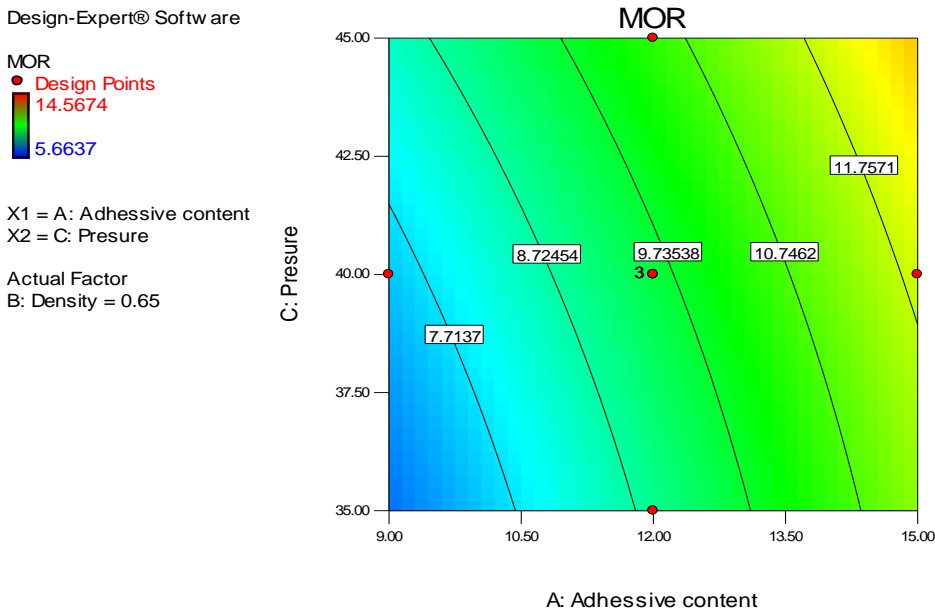


Figure 4. 12: contour effect of resin content and pressure on MOR

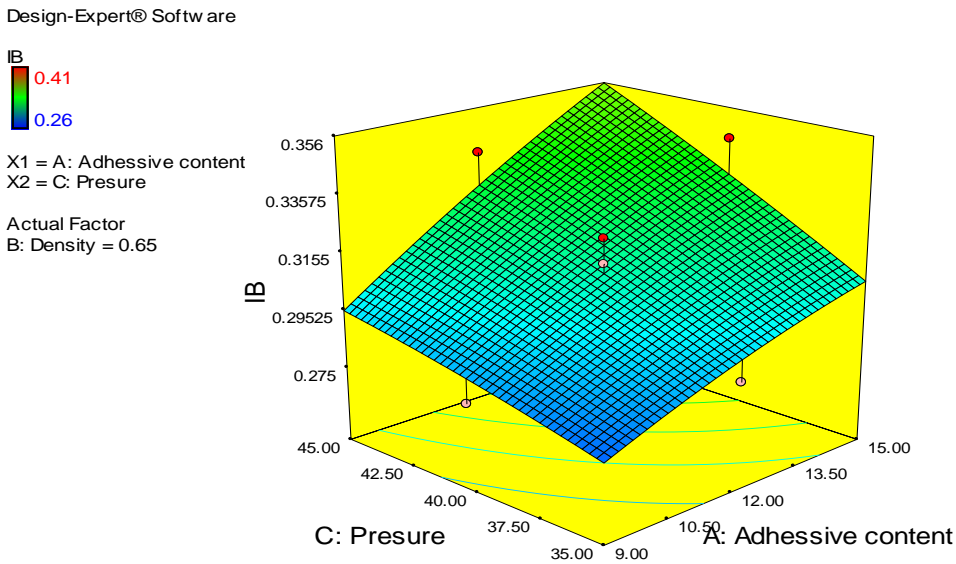


Figure 4. 13: interaction effects of resin content and pressure on internal bonding

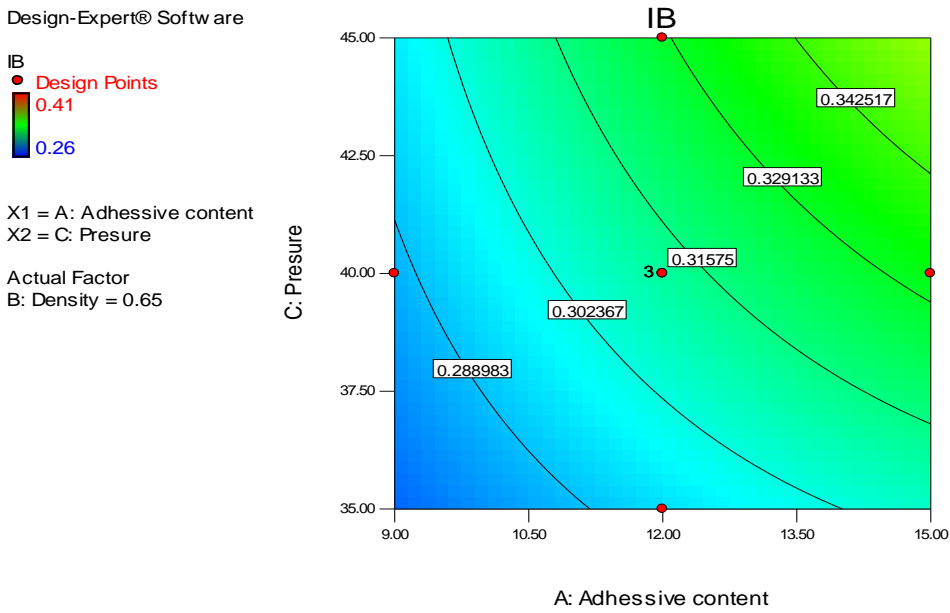


Figure 4. 14: contour effects of resin (adhesive) content and pressure on internal bond (IB)

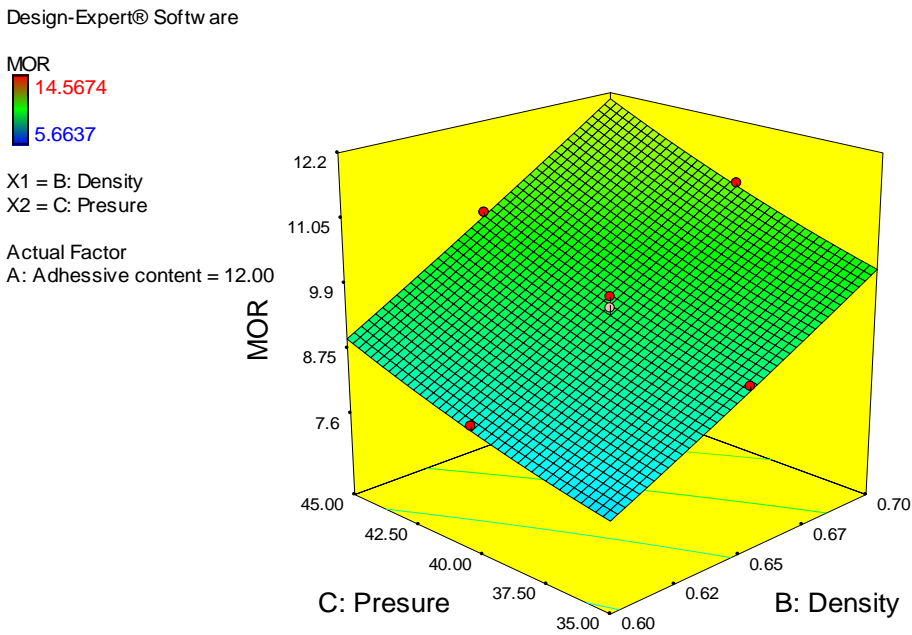


Figure 4. 15: interaction effects of density and pressure on MOR

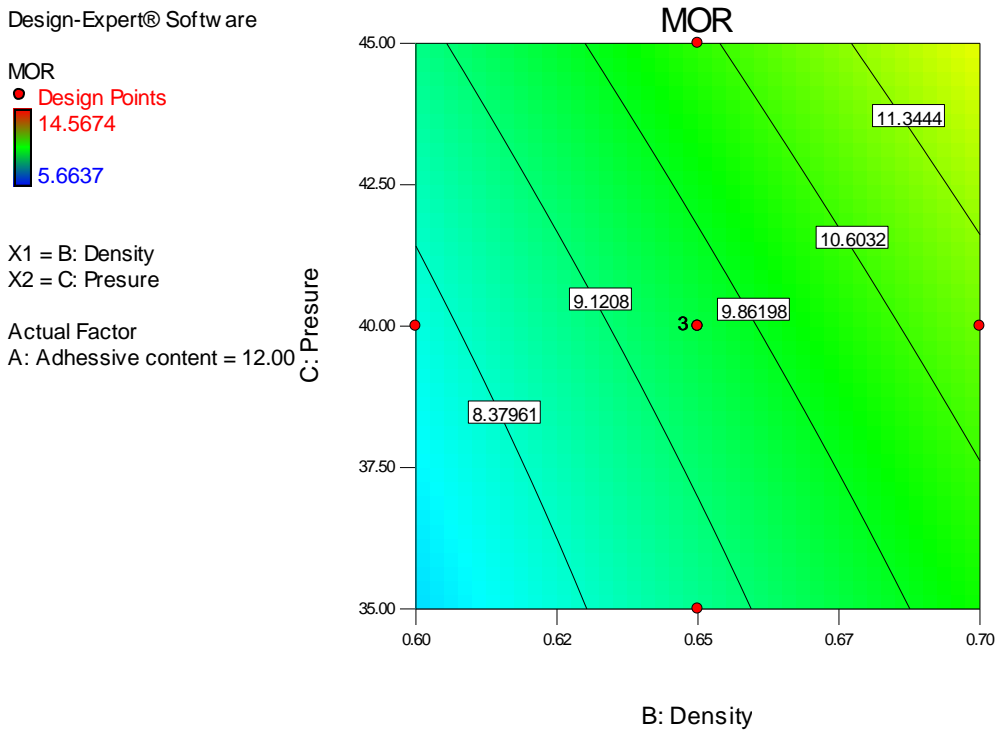


Figure 4. 16: contour effect of density and pressure on MOR

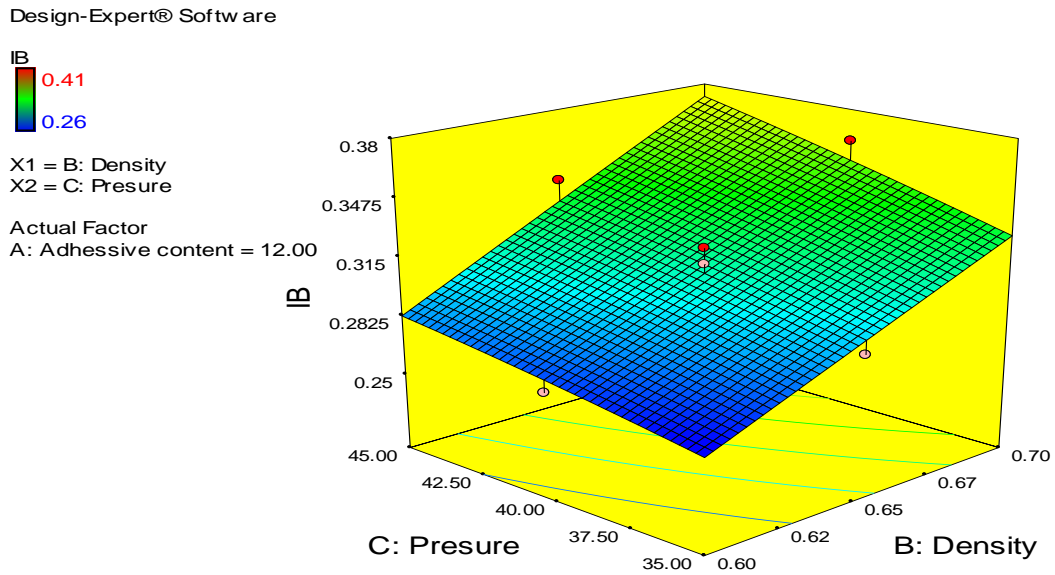


Figure 4. 17: interaction effects of density and pressure on IB

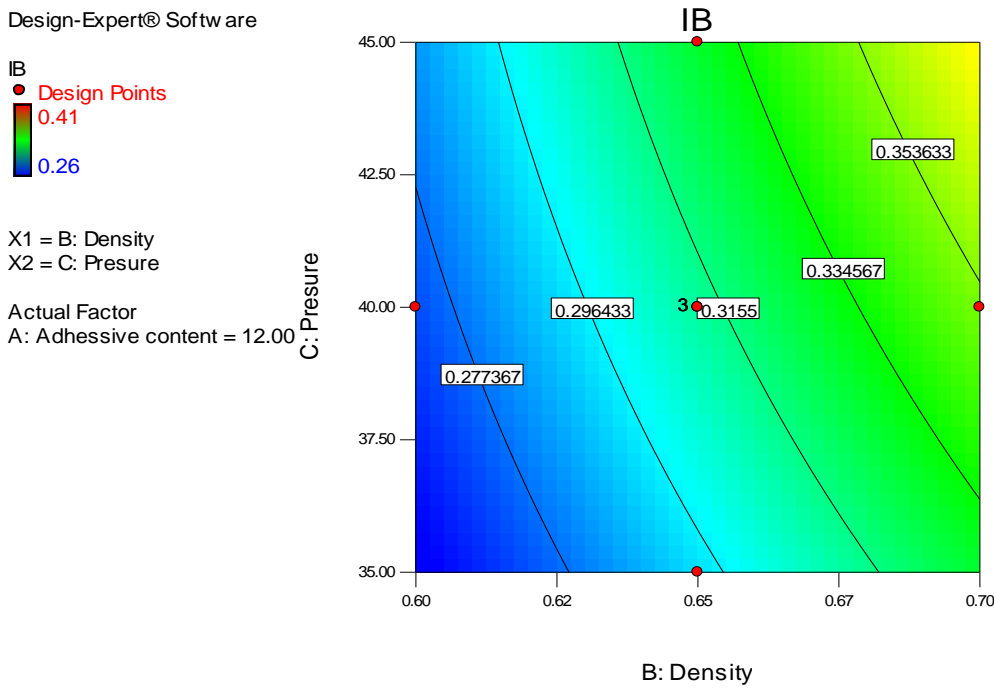


Figure 4. 18: contour effects of density and pressure on IB

4.4 optimization of process factors

The board optimization objective is the maximization of quality and minimizing of adhesive (resin) cost. RSM (response surface methodology) is a collection of statistical and mathematical techniques used for developing improving, and optimizing processes in which a response of interest is influenced by several variables and the objective is to optimize the response (Li, 2011). RSM has important application in the design, development and formulation of new products, as well as in the improvement of existing product design. It defines the effect of independent variables, alone or in combination, on the process. In addition to analyzing the effects of independent variables, this experimental methodology generates a mathematical model which describes the physical or biochemical process (Bradley, 2007). It consists of a group of mathematical and statistical techniques that can be used to define the relationship between the response and the independent variables. In addition to analyzing the effects of independent variables, this experimental methodology also generates a mathematical model. The graphical perspective of the mathematical model has led to the term response surface methodology (Gunst, 1996). Optimization studies using RSM could be separated in to three stages. The first stage is the preliminary work in which the

determination of the independent parameters and their levels are carried out. The second stage is the selection of the experimental design and the prediction and verification of the model equation. The last one is obtaining the response surface plot and contour plot of the response as a function of the independent parameters and determination of optimum points (Bradley, 2007). Optimization analysis were conducted on the data from the central composite design (CCD) to relate resin content, density and pressure to modulus of rapture and internal bonding of developed specimen. The numerical optimization was generated by design expert 7.0.0 software and elucidated in table 4.3 below as a function of three factors resin content, density and pressure. An optimal processing conditions of particleboard developed from sugarcane bagasse was selected for further characterization based resin content, density and pressure setting in the range and as well as maximizing the modulus of rapture and internal bonding of the sample (see table 4.3 below). Therefore considering these parameters the value obtained from optimum experimental resin content (15%), density (0.7g/cm³), pressure (45 bar), MOR (14.5674) and IB (0.405154) were obtained with desirability of 0.985

Table 4. 3: optimization constraint for developed particleboard

Constrains Name	Goal	Lower Limit	Upper Limit	Lower weight	Upper weight	Importance
Resin content(RC)	Is the range	9	15	1	1	3
Density	Is in range	0.6	0.7	1	1	3
Pressure	Is in range	35	45	1	1	3
MOR	Maximize	5.6637	14.5674	1	1	3
IB	Maximize	0.26	0.41	1	1	3

5 ECONOMIC ANALYSIS OF BAGASSE PARTICLEBOARD

Bagasse is the residue from sugarcane milling after the juice has been expressed from the crushed cane stalk (Briones et al., 2010)(Wales, Valley, Vue, Engineers, & Don, 1870). When milling the cane by heavy milling rollers and rotating knives to extract the juice the left overs of the crushed cane stalks become the by-product bagasse. The amount of bagasse being produced per cane stalk is about 30% (Bilba and Arséne, 2008). For every 10 tons of sugar canes being processed in the mills, approximately 3 tons of wet bagasse is being produced (Wirawan et al. 2011). Currently sugar cane bagasse is mainly used as a fuel in sugar mill boilers (Onoszko & Hallersbo, 2015). It consists of water, fibers and relatively small quantities of soluble solids (Joel, 2016). Its composition varies according to the variety of cane, its maturity, the method of harvesting, and the efficiency of the milling plant (Semret, 2014) (Shrivastav & Hussain, 2013). Bagasse is powdery by its nature and is hard to handle and manage especially when produced in excess and when no storage place is available. For convenience, Pellet mill is used to compress the powdery material in to firm and uniformly shaped granules called Pellets. Pellets are dust free thus reducing dust explosion potential and minimizing particle emission during combustion. In addition it Reduces cost for shipping, storage and handling, densities waste materials, Converts combustible energy resources into more efficiently consumed, cleaner burning pelleted fuel (Arthur & Hofe, n.d.).

Bagasse depithing and Drying

To obtain bagasse fibers suitable for bagasse board manufacture, it is necessary to separate the true fibers from the pith. The pith is objectionable in particle board because it is highly absorptive and thus increases the amount of binding resin which must be used. At the same time, pith does not contribute to the strength of the board; indeed, pith will seriously impair the strength of the particle board if it is present in levels exceeding 5-7% by weight. Pith separation from the fiber is essential to upgrade the quality of the raw material Bagasse. Pith constitutes nearly 30-35% of bagasse, the rest being useful fiber (60-65%) & soluble (5%). The chemical properties of fiber and pith are more or less similar, but they differ vastly in physical and morphological properties. Pith contains a lot of soft, thin walled, irregularly shaped parenchymatous cells, with higher quantity of inorganic ash and high absorbency. Therefore it is necessary to remove this pith as effectively as possible. There are three common methods used for of depithing bagasse. The same are discussed hereunder

1. Dry Depithing Processes: Dry depithing is carried out on stored bagasse having a moisture content of less than 35%. Hammer and shredders, are used in the separation of pith from bagasse. This

method has several disadvantages like heavy wear and tear of the process equipment, loss of valuable fiber along with the pith and production of lots of dust etc. The depithing efficiency of the process is also quite low and not more than 40% i.e. the depithed bagasse obtained by this process still contains 20% residual pith as against the original pith content of 30-35% in the original bagasse.

2. Moist Depithing: This type of depithing is generally done at the sugar mill when the wet bagasse has about 50% moisture. Several types of depithers such as Horkel, Rieth, Gunne, Peadcco & others are commercially used for moist depithing. These depithers are designed to break open the fiber bundles and to dislodge the pith by mechanical rubbing and mild disintegrating action. The unit consists of a rotor with sewing or rigid hammers attached to it. The hammers are enclosed fully or partially by perforated screen plates through which the pith fraction is discharged. The bagasse feeding to depithers is along either the horizontal or vertical axis of the unit depending upon the construction. The depithed fiber is discharge at the end of the rotating axis. Up to 50% of the original pith content in bagasse is removed by this method.

3 Wet depithing: The process is suitable for either baled bagasse or bagasse delivered from bulk storage. This method is more applicable at the pulp mill for the final cleaning and depithing just before bagasse enters the digester. The bagasse is fed to the hydropulper where it is thoroughly wetted and broken up at a consistency of around 2 to 2.5%, which maintained by continuous recirculation of process water. The slurry is pumped to the depither where defibrating operation is completed. The pith passes through the perforated screen. The depithed bagasse is delivered at about 20% consistency to the pulping unit and the pith is separated and thickened by dewatering press before disposal. In all the above depithing process residual pith content is not less than 14-15%. Maximum depithing efficiency achieved is around 70%. It is therefore very difficult to produce a bagasse chemical pulp having high alpha cellulose content from bagasse obtained by employing the above processes (Bs et al., 2013).

Mixing

Depithed bagasse fibers are brought from the storage area or from the depithing station to the mixing station, passing through dryers which ensure a uniform moisture level of 12-16% by weight. Fibers which have depithed must be returned to a free, loose condition by appropriate mechanical processes. The flow of bagasse fibers into the mixing station must be carefully controlled for uniformity and continuity. Special intermediate storage bins are installed to fill in any gaps in the supply of fibers from the depithing station or storage area. The flow of fibers is metered by weight,

and the addition of resin binders and other additives is accurately controlled (U. F. Service & Report, 1977).

Pressing

The pressing operation is obviously an extremely critical step in particleboard production. It is during this step that many of the physical properties are determined, especially those properties influenced by the vertical density gradient. Mat moisture content, press closing speed, and press time and temperature are the most significant pressing conditions affecting the properties of particleboard (U. F. Service & Report, 1977).

Finishing

As boards leave the pressing station, they are transferred manually or by machine to a finishing station. This station provides for the sanding of the surface of the board to a prescribed smoothness and thickness.

5.1 Machinery and Equipment

Machinery and equipment required for the production of particleboard are presented in Table below.

The total cost of plant machinery and equipment is estimated at about birr million.

Table 5. 1: Cost estimation and equipment prices with 15 years of service life

Type of equipment	Quantity	Price of each \$	ETB
Hummer mill (depithing machine)	1	10000	270,000
dryer	1	\$20,000 (Semret, 2014)	540,000
Mixer	1	20000	540,000
Pressing machine	1	20000	540,000

www.allibaba.com

Once the total equipment cost has been determined in the year of interest, we can add several other direct and indirect costs to determine the total capital investment (TCI). Project contingency and construction activities, and other costs related to construction are computed relative to the total direct cost (TDC) and give the fixed capital investment (FCI) when summed. The sum of FCI and the working capital for the project is the total capital investment (TCI).

Table 5. 2:- Estimation costs: direct, indirect and total capital

investment Direct cost (DC)	Factor	Cost (ETB)
Purchased equipment	1	2046697.13
Purchased equipment installation	0.47	961947.65
Instrumentation and control	0.18	368405.48
Piping (installed)	0.66	1350820.12
Electrical(installed)	0.11	225136.68
Building	0.18	368405.48
yard improvement	0.1	204669.71
Service facilities	0.3	614009.14
Land	0.06	122801.83
Total plant direct cost (TPDC) =ΣDC		6262893.22
Indirect cost (IDC)	Factors	Cost (ETB)
Engineering and supervision	0.33	675410.05
Construction and expense	0.41	839145.82
Indirect cost (IDC) = ΣID		1514555.87
Total indirect and direct cost (TIDC) = TPDC + IDC		7777449.09
Contractors fee (CF)	0.21	429806.4
Contingency (C)	0.40	818678.85
Fixed capital investment (FCI) = TIDC + CF + C		9025934.34
Working capital (WC)	0.86	1760159.53
Total capital investment (TCI) = FCI + WC		10786093.87

Source (Onoszko & Hallersbo, 2015)

Table 5. 3:- Man power requirement and annually labor cost

No	Description	Number	monthly salary per unit(birr)	monthly salary(birr)	annual salary(birr)
1	General manager	1	11000	11000	132,000
2	Quality manager	1	4000	4000	48,000
3	Production manager	1	4000	4000	48,000
4	Operation manager	4	3000	12000	144,000
5	Secretary	2	1500	3000	36,000
6	Chemist	2	3000	6000	72,000
7	Mechanical Engineer	1	4000	4000	48,000
8	Electrical Engineer	1	4000	4000	48,000
9	Chemical Engineer	2	4000	8000	96,000
10	Civil engineer	1	3500	3500	42,000
11	Accountant	2	2000	4000	48,000
12	Sale person	2	3500	7000	84,000
13	Operators	15	1500	22,500	270,000
14	Cleaner	4	700	2800	33,600
15	Medical purpose	2	4000	8000	96,000
16	Guards	9	700	6300	108,000
Total(OL)		52	53,400	114,100	1,401,600

Operating Labor (OL) is 10% of total product cost (TPC)

$$TPC = OL / 0.1$$

$$= 1,401,600 / 0.1 \text{ year}$$

$$= 14,016,000 / \text{yr}$$

Variable Operating Costs

Variable operating costs, which include raw materials, waste handling charges, and by-product credits, are incurred only when the process is operating.

Production and economic analysis of particleboard from sugarcane bagasse

Table 5. 4:- Direct production cost (variable cost)

Item		Cost (ETH Birr)	
Raw materials	0.11 TPC		1,541,760
1	Operating labor(L)	10% TPC	1,401,600
2	Direct supervisors and clerical labor	0.12 OL	168,192
3	Utilities(electric & water cost)	0.13 TPC	1,822,080
4	Maintenance and repair	0.06FCI	541556.06
5	Operating supplies	0.01FCI	90259.34
6	Patent and royalty	0.02 TPC	280320
7	Laboratory charge	0.11 OL	154176
Total direct production cost = 5,999,943			

Fixed Operating Costs

Fixed operating costs are generally incurred in full whether or not the plant is producing at full capacity. These costs include labor and various overhead items. The number of employees was estimated by considering the likely degree of automation for each area and adding a reasonable number of management and support employees. Salaries were estimated by using commercially available salary. A 90% labor burden is applied to the salary total and covers items such as safety, general engineering, general plant maintenance, payroll overhead (including benefits), plant security, janitorial and similar services, phone, light, heat, and plant communications.

S. No	Items	Cost (ETH Birr)	
1	Depreciation	0.1FCI	902593.43
2	Local taxes	0.02FCI	180518.69
3	Insurance	0.005FCI	45129.67
4	Rent	0.08(land + building)	39296.58
Total fixed charges		1167538.4	

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Plant overhead costs

S. No	Item	Cost (ETH Birr)	
1	Plant overhead cost	60% OL	840960

Manufacturing cost = direct production cost (variable) + fixed operating cost + plant overhead cost =
 $5,999,943 + 1167538.4 + 840960 = 8,008,441.4$

S. No	Item	Cost(ETH Birr)	
1	Administrative cost	0.04TPC	560640
2	Distribution and sell cost	0.08TPC	1,121,280
3	Research and development	0.05TPC	700,800
Total general expense		2,382,720	

Sell cost for one particleboard = 197.5 birr and its mass is an average of 16.7kg

Assume the factory produces 300 boards per day (5010 kg)

Annual sells income = $11.83 \text{ birr/kg} \times 5010 \text{ kg/day} \times 365 \text{ days/yr}$

$$= 21,632,930 \text{ birr/year}$$

Gross profit = total income – total product cost

$$\text{GP} = 21,632,930 \text{ birr/yr} - 14,016,000$$

$$= 7,616,929.5 \text{ birr/yr}$$

Annual tax = 35% total annual income

$$= 0.35 \times 7,616,929.5 \text{ /yr} = 2,665,925 \text{ birr/yr}$$

Net profit = Gross profit - Annual tax

$$= 7,616,929.5 \text{ /yr} - 2,665,925.3 \text{ /yr}$$

$$= 4,951,004 \text{ birr/yr}$$

Rate of return on investment (ROI)

Assume minimum acceptable rate of return (mar) = 15% and assuming a 15 years' service life,

Net profit average = 9,419,674/yr

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$$\begin{aligned}\text{ROI} &= (\text{net profit average} / \text{total capital investment}) * 100 \\ &= (4,951,004/\text{yr.} / 10786093.87/\text{yr.}) * 100 \\ &= 45.9\%\end{aligned}$$

Payback period

$$\begin{aligned}\text{Payback period} &= \text{FCI} / (\text{net profit}/\text{yr.} + \text{Depreciation}/\text{yr.}) \\ &= 9025934.34 / (4,951,004 + 902593.43/\text{yr})\end{aligned}$$

$$\text{Payback period} = 2 \text{ years}$$

Since the payback period is less than 5 years the project is and acceptable

6. CONCLUSION AND RECOMMENDATION

6.1 conclusions

Commercial by-product utilization is a very interesting alternative; much care should be taken to diminish risks when investing. New technologies are a good opportunity, as by-products can achieve very high values, allowing the mills to increase sales and revenues. Sugar cane bagasse represents a sizeable and readily accessible source of natural fibers. In many regions of the world, many developing countries, in particular, have significant natural resources in the bagasse fibers produced annually by their sugar industries. The development of byproduct uses for sugar cane bagasse should therefore be of considerable interest to both the sugar-producing developing countries and their domestic sugar industries. The diversification of their operations, moreover, is often desired by sugar industries seeking to counteract the fluctuations in their income resulting from changing prices for sugar in the open world markets.

Sugarcane bagasse, an agro industrial waste produced, is a promising material for the manufacture of particleboard. This study presents a new alternative for particleboard production in the laboratory from sugarcane bagasse particles using urea form aldehyde based adhesive.

Resin content, density and pressure of pressing in particleboard manufacturing were important factors to determine the quality of product. Based on mechanical properties evaluation in particleboard, sugarcane bagasse had potential value to be developed as raw material in particleboard manufacturing. Three levels of resin used in this experiment were compatible to sugarcane bagasse for particleboard manufacturing. Urea form aldehyde was the best resin for resulting superior quality of particleboard made from sugarcane bagasse. According to the results, mechanical properties of sugarcane bagasse particle boards were strongly depended on resin percentage and density and slightly affect by pressing pressure. The higher resin contents, density and pressing pressure, the better mechanical properties.

Based on the analysis of experimental results, it is found that the three process variables exhibited significant interaction effect on the responses. This shows that the capability of the design of experimental analysis in successfully capturing these effects. A resin content of 15%, density of 0.7g/cm^3 and pressure 45bar, the response variables MOR and IB results an optimal value of 14.5674 and 0.41Mpa respectively. Which is similar work done Widyorini et al (2005) assessed the quality of particleboard panels produced with sugarcane bagasse with resin content of 8%-10% and

obtained maximum MOR value 11 MPa for static bending and Mendes et al (2007), he is found average values of internal bond of 0.2 MPa for panels made from sugarcane bagasse.

From our preliminary cost analysis, particleboard processing plant is designed with a capacity of 5010kg per day. The project is found to be financially viable and earns a net profit of about Birr 4,951,004birr within the project life. Such result induces the project promoters to reinvest the profit. A payback period of 2 years is an indication of a promising and feasible plant. In the project life under consideration, the region will collect about Birr 2,665,925 million from corporate tax payment alone (i.e. excluding income tax, sales tax and VAT). Such result creates additional fund for the regional government that will be used in expanding social and other basic services in the region.

6.2 Recommendation

Based on the current investigation the following recommendations are forwarded:

First specific and detailed information of production equipment performances and costs is needed. Such information, if incorporated into the investment analysis framework elaborated in this thesis, would provide a better understanding of the general appropriateness of the possible modes of production under various conditions and at various levels of production.

Second, another area of needed research is a more comprehensive comparison of bagasse particle board with other building materials under diverse economic, geographic, climatic, and other conditions. Such research would hopefully go beyond the simple criterion of the profitability of production used in the investment analysis of this thesis, and would include an evaluation of the proper role of bagasse particle board production in the national development priorities of developing and other countries. Such a study must investigate the macro-economic benefits and other effects of bagasse particle board production.

- More work should be undertaken to optimize the production of particleboard using sugarcane bagasse at an appropriate time and temperature.
- Further investigation should be done to analyze the potential of particleboard production from sugarcane bagasse using hydrogen per oxide as bleaching agent and calcium carbonate as filler.
- An economic feasibility analysis of the overall conversion process from sugarcane bagasse to particleboard should be necessary for the purpose of commercialization.

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APPENDICES

Appendix A: vital pictures during the research work

I. Photograph of the experimental delignification

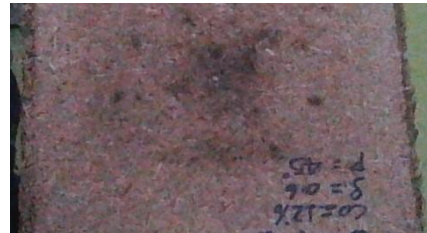


Fresh bagasse of sugar cane



sun drying bagasse

II. Photo graph of produced particleboard from sugarcane bagasse



Bagasse particlebord



Sample preparation for test

III. Equipment used during experimental process



Mechanical size reduction



sieving analysis



Hydraulic press machine



molding material



Universal testing machine



Appendix B

ANOVA for the two responses

Response 1 MOR

ANOVA for Response Surface Quadratic Model Analysis of variance table [Partial sum of squares Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	77.16	9	8.57	316.45	< 0.0001	significant
A-Adhesive content	49.75	1	49.75	1836.39	< 0.0001	
B-Density	20.21	1	20.21	745.92	< 0.0001	
C-Pressure	6.43	1	6.43	237.38	< 0.0001	
AB	0.37	1	0.37	13.61	0.0078	
AC	0.028	1	0.028	1.03	0.3448	
BC	0.16	1	0.16	5.95	0.0448	
A ²	0.035	1	0.035	1.31	0.2907	
B ²	4.419E-003	1	4.419E-003	0.16	0.6984	
C ²	0.035	1	0.035	1.31	0.2907	
Residual	0.19	7	0.027			
Lack of Fit	0.058	5	0.012	0.17	0.9492	not significant
Pure Error	0.13	2	0.066			
Cor Total	77.35	16				

The Model F-value of 316.45 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

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The "Lack of Fit F-value" of 0.17 implies the Lack of Fit is not significant relative to the pure error. There is a 94.92% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Std. Dev.	0.16	R-Squared	0.9975
Mean	9.72	Adj R-Squared	0.9944
C.V. %	1.69	Pred R-Squared	0.9943
PRESS	0.44	Adeq Precision	70.564

The "Pred R-Squared" of 0.9943 is in reasonable agreement with the "Adj R-Squared" of 0.9944.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 70.564 indicates an adequate signal. This model can be used to navigate the design space.

	Coefficient		standard	95% CI	95%CI Factor	
	Estimate	df	Error	Low	High	VIF
Intercept	9.56	1	0.070	9.40	9.73	
A-Adhesive content	2.23	1	0.052	2.11	2.35	1.00
B-Density	1.42	1	0.052	1.30	1.54	1.00
C-Pressure	0.80	1	0.052	0.68	0.93	1.00
AB	0.21	1	0.058	0.077	0.35	1.00
AC	-0.059	1	0.058	-0.20	0.079	1.00
BC	0.14	1	0.058	4.341E-003	0.28	1.00
A ²	0.11	1	0.10	-0.12	0.35	1.54
B ²	0.041	1	0.10	-0.20	0.28	1.54
C ²	0.11	1	0.10	-0.12	0.35	1.54

Response 2: Internal bonding

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.026	9	2.944E-003	17.46	0.0005 significant
A-Adhesive content	5.153E-003	1	5.153E-003	30.56	0.0009
B-Density	0.016	1	0.016	93.72	< 0.0001
C-Pressure	3.045E-003	1	3.045E-003	18.06	0.0038
AB	1.800E-003	1	1.800E-003	10.68	0.0137
AC	4.500E-004	1	4.500E-004	2.67	0.1463
BC	2.000E-004	1	2.000E-004	1.19	0.3122
A ²	1.675E-005	1	1.675E-005	0.099	0.7618
B ²	1.675E-007	1	1.675E-007	9.932E-004	0.9757
C ²	4.186E-006	1	4.186E-006	0.025	0.8792
Residual	1.180E-003	7	1.686E-004		
Lack of Fit	8.315E-004	5	1.663E-004	0.95	0.5833 not significant
Pure Error	3.487E-004	2	1.743E-004		
Cor Total	0.028	16			

The Model F-value of 17.46 implies the model is significant. There is only

a 0.05% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Production and economic analysis of particleboard from sugarcane bagasse

The "Lack of Fit F-value" of 0.5833 implies the Lack of Fit is not significant relative to the pure error. There is a 58.33% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Std. Dev.	0.013	R-Squared	0.9574
Mean	0.31	Adj R-Squared	0.9025
C.V. %	4.19	Pred R-Squared	0.7154
PRESS	7.877E-003	Adeq Precision	16.046

The "Pred R-Squared" of 0.7154 is in reasonable agreement with the "Adj R-Squared" of 0.9025. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 16.046 indicates an adequate signal. This model can be used to navigate the design space.

Factor	Coefficient		Standard Error	95% CI		VIF
	Estimate	df		Low	High	
Intercept	0.31	1	5.556E-003	0.30	0.33	
A-Adhesive content	0.023	1	4.106E-003	0.013	0.032	1.00
B-Density	0.040	1	4.106E-003	0.030	0.049	1.00
C-Pressure	0.017	1	4.106E-003	7.741E-003	0.027	1.00
AB	0.015	1	4.591E-003	4.145E-003	0.026	1.00
AC	7.500E-003	1	4.591E-003	-3.355E-003	0.018	1.00
BC	5.000E-003	1	4.591E-003	-5.855E-003	0.016	1.00
A ²	-2.500E-003	1	7.933E-003	-0.021	0.016	1.54
B ²	-2.500E-004	1	7.933E-003	-0.019	0.019	1.54
C ²	-1.250E-003	1	7.933E-003	-0.020	0.018	1.54

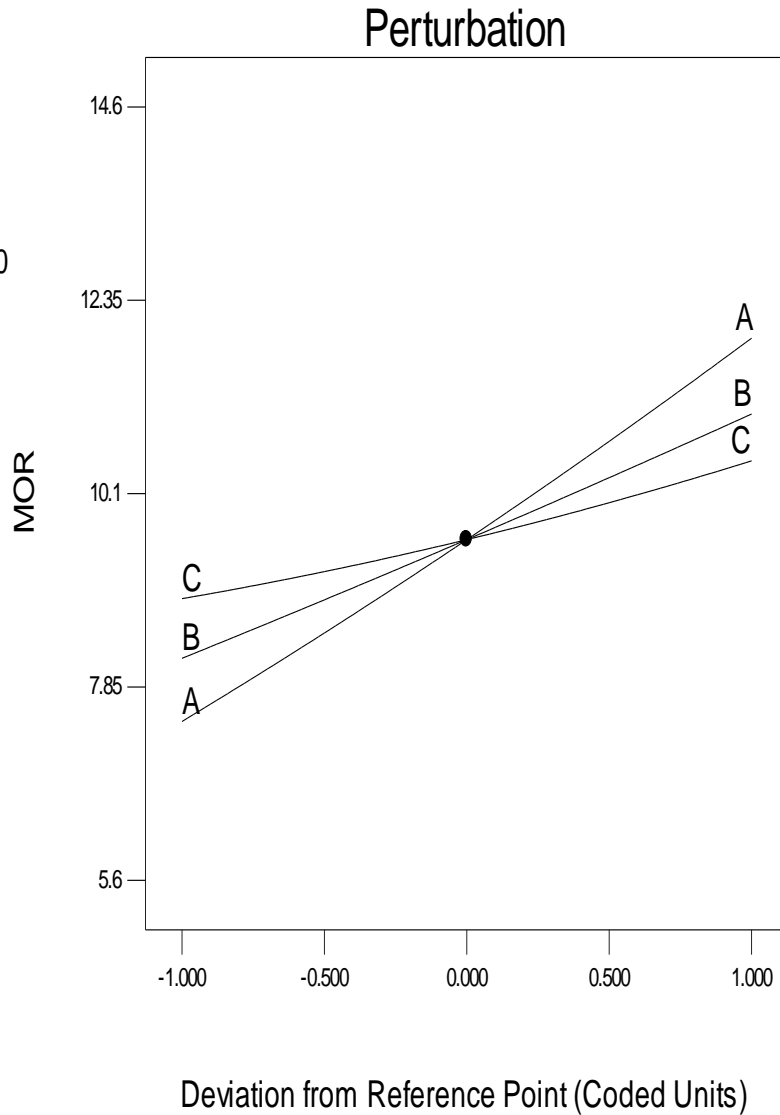
Appendix C: Perturbation plot for the two responses

I. perturbation graphs showing the interaction factor

Design-Expert® Software

MOR
● MOR

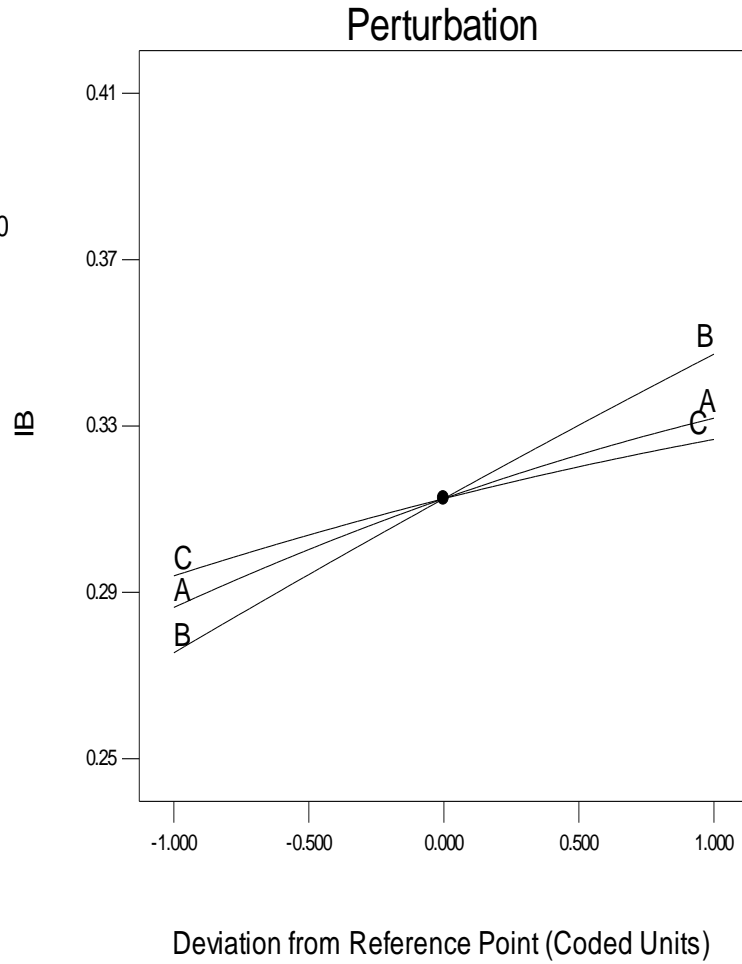
Actual Factors
A: Adhesive content = 12.00
B: Density = 0.65
C: Pressure = 40.00



Design-Expert® Software

IB
● IB

Actual Factors
A: Adhesive content = 12.00
B: Density = 0.65
C: Pressure = 40.00



Appendix D: calculations of the mixing process

Volume is the same at all experiments, because the thickness of board is taken by assuming 0.8cm for all experiments.

Experiment 1

RC=9%

Density=0.6g/cm³

Pressure=35bar

Volume= height*width*thickness

=20cm*20cm*0.8cm

=320 cm³

Total mixing mass (mt) = density * volume

=0.6g.cm³*320cm³

= 192g

Assume at 5% moisture content

MT =192g- 192g*0.05

= 182.4g

Let 60% of mass of total resin content is UF

Mass of total resin content (m.t.r.c) = (0.09/0.6)*mt

= (0.09/0.60)*182.4g

=27.4g

At 5% moisture content

m.t.r.c =27.4g+27.4g*0.05

= 28.8g

Muf =60% m.t.r.c

= 17.3g

mH₂O= 40% m.t.r.c

=11.5g

MSalt=0.5%mt=m wax

= 1g

Mass of bagasse (mb) =mt-(muf+msalt+mwx)

=163.1g

Experiment 2

RC=15%

Density=0.6g/cm

Pressure=35bar

Volume= height*width*thickness

=20cm*20cm*0.8cm

=320 cm³

Total mixing mass (mt) = density * volume

=0.6g.cm³*320cm³

= 192g

Assume at 5% moisture content

MT =192g- 192g*0.05

= 182.4g

Let 60% of mass of total resin content is UF

m.t.r.c =(0.15/0.6)*mt

= (0.15/0.60)*182.4g

=45.6g

At 5% moisture content

m.t.r.c =45.6g+45.6g*0.05

= 47.9g

Muf =60% m.t.r.c

= 29g

mH₂O= 40% m.t.r.c

=19.2g

MSalt=0.5%mt=m wax

= 1g

mb = mt-(muf+msalt+mwx)

=151.4g

Continue

Experiment 1

$$\begin{aligned} \text{Mcoarse} &= 70\% \text{ mb, mass of fine} = 30\% \text{ mb} \\ &= 114.2\text{g} \qquad \qquad = 48.9\text{g} \end{aligned}$$

Experiment 3

$$\text{RC} = 9\%$$

$$\text{Density} = 0.7\text{g/cm}^3$$

$$\text{Pressure} = 35\text{bar}$$

$$\text{Volume} = 320 \text{ cm}^3$$

$$\begin{aligned} \text{Total mixing mass (mt)} &= \text{density} * \text{volume} \\ &= 0.7\text{g.cm}^3 * 320\text{cm}^3 \\ &= 224\text{g} \end{aligned}$$

Assume at 5% moisture content

$$\begin{aligned} \text{Mt} &= 224\text{g} - 224\text{g} * 0.05 \\ &= 212.8\text{g} \end{aligned}$$

Let 60% of mass of total resin content is UF

$$\begin{aligned} \text{Mass of total resin content (m.t.r.c)} &= (0.09/0.6) * \text{mt} \\ &= (0.09/0.60) * 212.8\text{g} \\ &= 31.9\text{g} \end{aligned}$$

At 5% moisture content

$$\begin{aligned} \text{m.t.r.c} &= 31.9\text{g} + 31.9\text{g} * 0.05 \\ &= 33.5\text{g} \end{aligned}$$

$$\text{Muf} = 60\% \text{ m.t.r.c}$$

$$= 20.1\text{g}$$

$$\text{mH}_2\text{O} = 40\% \text{ m.t.r.c}$$

$$= 13.4\text{g}$$

$$\text{MSalt} = 0.5\% \text{ mt} = \text{m wax}$$

$$= 1.1\text{g}$$

Experiment 2

$$\begin{aligned} \text{Mcoarse} &= 70\% \text{ mb, mass of fine} = 30\% \text{ mb} \\ &= 106\text{g} \qquad \qquad = 45.4\text{g} \end{aligned}$$

Experiment 4

$$\text{RC} = 15\%$$

$$\text{Density} = 0.7\text{g/cm}^3$$

$$\text{Pressure} = 35\text{bar}$$

$$\text{Volume} = 320 \text{ cm}^3$$

$$\begin{aligned} \text{Total mixing mass (mt)} &= \text{density} * \text{volume} \\ &= 0.7\text{g.cm}^3 * 320\text{cm}^3 \\ &= 224\text{g} \end{aligned}$$

Assume at 5% moisture content

$$\begin{aligned} \text{Mt} &= 224\text{g} - 224\text{g} * 0.05 \\ &= 212.8\text{g} \end{aligned}$$

Let 60% of mass of total resin content is UF

$$\begin{aligned} \text{m.t.r.c} &= (0.15/0.6) * \text{mt} \\ &= (0.15/0.60) * 212.8\text{g} \\ &= 53.2\text{g} \end{aligned}$$

At 5% moisture content

$$\begin{aligned} \text{m.t.r.c} &= 53.2\text{g} + 53.2\text{g} * 0.05 \\ &= 55.9\text{g} \end{aligned}$$

$$\text{Muf} = 60\% \text{ m.t.r.c}$$

$$= 33.5\text{g}$$

$$\text{mH}_2\text{O} = 40\% \text{ m.t.r.c}$$

$$= 22.4\text{g}$$

$$\text{MSalt} = 0.5\% \text{ mt} = \text{m wax}$$

$$= 1.1\text{g}$$

Continue

Experiment 3

$$\begin{aligned} \text{Mass of bagasse (mb)} &= \text{mt} - (\text{muf} + \text{msalt} + \text{mwax}) \\ &= 190.5\text{g} \end{aligned}$$

$$\begin{aligned} \text{Mcoarse} &= 70\% \text{ mb}, & \text{mass of fine} &= 30\% \text{ mb} \\ &= 133.4\text{g} & &= 57.2\text{g} \end{aligned}$$

Experiment 4

$$\begin{aligned} \text{mb} &= \text{mt} - (\text{muf} + \text{msalt} + \text{mwax}) \\ &= 177.1\text{g} \end{aligned}$$

$$\begin{aligned} \text{Mcoarse} &= 70\% \text{ mb}, & \text{mass of fine} &= 30\% \text{ mb} \\ &= 124\text{g} & &= 53.1\text{g} \end{aligned}$$

It has the same procedure with the other rest experiments

Where:

RC = resin content

Mb= mass of bagasse

Mt= total mixing mass

m.t.r.c= mass of total resin content

Muf = mass of urea formaldehyde

M_{H2O} = mass of water

Msalt = mass of salt

Mwax= mass of liquid paraffin wax