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Production of Particle board Using Sawdust and Plastic Waste

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PRODUCTION OF PARTICLE BOARD USING SAWDUST AND PLASTIC WASTE

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DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The high demand for forest timber has led to high deforestation rate worldwide. This has caused negative impact on the environment. In Ghana, in the processing of these forest timbers for export and domestic purposes enormous quantities of wood residues including sawdust are produced annually and these residues are usually not put into commercial use. Moreover, Ghana and most countries in the world are engulfed with plastic waste emanating from drinking water manufacturers, plastic product manufacturers as well as packages of materials. Studies are being conducted on the search for the possible effective ways of utilisation of sawdust as well as possible ways of recycling these plastics. This study focuses on the use of sawdust in the production of particleboard using low density polyethylene as an adhesive. In the production, the sawdust was collected and separated whiles the polyethylene was collected, washed, dried and shredded. The two materials were mixed using plastic-sawdust combination (1:1.75, 1:2 and 1: 1.3). The mixture was pressed at a pressure of 6.5kgcm^{-2} in 1 hour and at two different temperatures (145^{o}C and 200^{o}C). The moisture content and densities as well as bending and compression properties of the boards were examined. Results show that the bending stress of the boards ranges from 0.7 to 3.07Nmm^{-2} whiles that of the compression stress ranges from 0.399 to 3.242Nmm^{-2}. The density of the boards also ranges from 316kgm^{-3} to 383kgm^{-3} at 3.0% - 4.7% moisture content. However, the highest bending stress of 3.07Nmm^{-2} and compression stress of 3.242Nmm^{-2} was obtained from the board with 1:1.3kg plastic-sawdust combination and temperature of 200^{o}C. Generally, the results of the physical and mechanical properties of the sawdust and low density polyethylene particleboard were comparable to medium density particleboards available.

However, high temperature in the production was noticed to have resulted in boards with low moisture content, whiles the reduction of polyethylene in the plastic-sawdust combination of particleboards produced resulted in increased bending and compression stresses of the boards.

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CHAPTER ONE

1.0 INTRODUCTION

The International Tropical Timber Organization (ITTO) (1992) described sustainable forest management as the process of managing the forest to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment. ITTO (1992) indicated that sustainable forest management involves planning for the production of wood for commercial purposes as well as providing for the other forest product needs of local citizens. Meanwhile, it is identified that over 90% of Ghana's high forest has been logged since the late 1940s. The rate of deforestation is 5% in off-reserves and 2% in on-reserves. The off-reserves have been seriously degraded and fragmented to less than 5% of the forested area of 83,489km^2. The deforestation rate is about 22,000 ha per annum (Tamakloe, 2000).

Ghana, therefore, may face future export deficits and there is the likelihood that the country's forestry sector will get depleted as only 20% of the forest reserve remains (Wagner *et al.*, 2008). The exploitation of the forest has not been for domestic use only but also for export. For instance in the December, 2009 report of Timber Industry Development Division (TIDD) on export of wood indicated that Ghana realised €9,844,948 from the export of 33,817 m^3 of wood. The corresponding figures for the same period in 2008 were €12,196,197 and 31,768m^{3}showing a decrease of 19.28% in value and an increase of 6.45 %in volume respectively.

However, in the processing of timber for export and for domestic purposes, Tamakloe (2000) outlined that enormous quantities of sawdust are produced annually by the sawmills. The sawdust produced in sawing a thousand 30cm board of 2.5cm hardwood lumber with a saw cutting of 0.625cm kerf is at least 63m³ of wood. Machining of lumber also lead to further residues. Hardkin (1969) stated that planer mill produced about 272kg of dry residue per thousand 30cm board. Thus, the total amount of air-dry wood fines originating in U.S industries alone exceeds 15 million tons a year enough to make a pile 1524cm high, 3048cm wide, and over 241km long. It is explained further by Ofori *et al.* (1993) that in the production of school chairs by Fuga Complex Ltd, only 38.3% of the wood obtained was used for the product, while 21.5%, 5.5% and 31.1% of the wood was turned into sawdust, shavings and solid residues/firewood respectively. However, there is no market for sawdust even though there are some uses such as making fake snow, getting a grip, soaking up spills, feeding plants, making a fire starter, filling wood holes and defects, packing a path, chasing away weeds, lightening up cement, and cleaning a floor (Powers, 2008). Another important use of sawdust is particleboard production (Hoadley, 2000).

Drinking water sold in sachets or fast food packed in takeaway bags may be a practical option for the consumer in Ghana but the enormous problem caused by discarded plastic has for a long time outweighed its convenience. Plastic waste not only creates an eyesore in the streets but chokes drains, harbours disease causing organisms. Every year, the perennial problem of flooding plagues towns and cities in Ghana during the rains. War has been declared on plastic waste by Metropolitan/ Municipal/ District Chief Executives and the battle has been going on for some years now. Levies have been put on plastic producers but inappropriately discarded plastic is still estimated to cause about 22,000 tonnes of rubbish annually (Tamakloe, 2000).

In particleboard production, adhesives play vital role in bonding the particles together. One material that can be used as an adhesive is polyethylene, which is in abundance in every corner of the Ghanaian society (Olatunji-Osei, 2010). Hoadley (2000) indicated that particleboard is produced by spraying wood particles like sawdust with adhesive, forming them into a mat and compressing the mat to desired thickness between heated platens to cure the adhesive. There are two types of adhesives usually used for the production of particleboard; formaldehyde based resins and no added urea-formaldehyde (NAUF) resins. Mostly, formaldehyde based adhesives are used for the manufacture of particleboard. According to Anon. (2006), despite the excellent strength, durability and cost effectiveness of these formaldehyde based adhesives, it has only not been classified by the World Health Organisation (WHO) as a known carcinogen but also in high levels above 0.1 parts per million of air can cause watery eyes, burning sensations in the eyes, nose and throat, nausea, coughing, chest tightness, wheezing, skin rashes, and allergic reactions. Some persons have developed allergic reactions, asthmatic reactions and skin rashes from skin contact with solutions of formaldehyde or durable-press clothing containing formaldehyde.

The other type of adhesive which does not contain any formaldehyde is the thermoplastics which include Low Density Polyethylene (Petrie, 2006). Thermoplastic is a plastic material that melts when heated and hardens when cooled (English *et al.*, 1997). Low density polyethylene, according to Cope (1960), begins to melt around 140ºC and Brumbaugh (1960) outlined that it is combined with waste paper into forms suitable for processing into composites. Therefore, it would be very useful for the development of particleboard from sawdust using polyethylene waste as an adhesive. The development was done using a constant pressure and time; and two pressing temperatures and three plastic- sawdust combination.

The success of this project will have a positive effect on the natural forest. Since the wood residue which would have been burnt to ashes and the plastic waste which would have been a nuisance to the environment would be put into judicious use such as particleboard production. As a result, the pressure on solid board will be reduced as the particle board will adequately substitute it in the making of furniture, door and other wood products. It will also create job for people in the production of particle board using these wastes, enhance knowledge in the utilization of sawdust and plastic waste for particleboard production and provide opportunity for further study into the use of sawdust and plastic waste for particleboard production. Finally, the success of this project will accelerate the achievement of the United Nations Millennium Development Goal (MDG) of achieving zero waste which is a subset of environmental sustainability and will lead to increased profits resulting from significant cost savings, improved environmental performance, and stronger local economies (Mwai *et al.*, 2008).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Particleboard

Haygreen and Bowyer (1996) defined particleboard as a panel product produced by compressing small particles of wood whiles simultaneously bonding them with an adhesive. Particleboard is a panel product manufactured by spraying wood particles with adhesive, forming them into a mat, and compressing the mat to desired thickness between heated Platens to cure the adhesive (Hoadley, 2000). Particleboard can also be said to be a three-layered board, with fine particles on the top and bottom surfaces, and larger wood flakes in the middle. Particleboard can be said to be a generic term for a composite panel primarily composed of cellulosic materials (usually wood), generally in the form of discrete pieces or particles, as distinguished from fiber, bonded together with a bonding system, and which may contain additives. The wood particles are pressed and bonded together with resin creating a tight compact panel that can be machined cleanly. The surfaces are sanded smooth at the mill, ready for use or finishing with a high-pressure laminate, decorative foil or timber veneer.

Particleboard is one of the two groups of particle composites which are commonly recognized based on size of wood components and the method of manufacture. Particleboards have chips, flakes, or wafers as the major constituent. The other group of particle composites is the fibreboard. It has its major constituents as fibre and fibre bundles (Bodig and Jayne, 1982). The strength of the product is determined by the adhesive used and not the fibre used, although the size and shape have influence on the strength (Kent and Riegel, 2007).

2.2 History and development of particleboard production

Modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940s there was not enough lumber around to manufacture plywood affordably. Particleboard was intended to be a replacement. German inventor of particle board was Max Himmelheber. The first commercial piece was produced during World War II at a factory in Bremen, Germany. It used waste materials such as planer shavings, offcuts or sawdust, hammer-milled into chips, and bound together with a phenolic resin. Hammer-milling involves smashing material into smaller and smaller pieces until they pass out through a screen. Most other early particleboard manufacturers used similar processes, though often with slightly different resins. It was found that better strength, appearance and resin economy could be achieved by using more uniform, manufactured chips. Manufacturers began processing solid birch, beech, alder, pine and spruce into consistent chips and flakes. These finer layers were then placed on the outsides of the board, with the central section composed of coarser, cheaper chips. This type of board is known as three-layer particleboard. More recently, graded-density particleboard has also evolved. It contains particles that gradually become smaller as they get closer to the surface (Anon., 2010).

Haygreen and Bowler (1996) agreed that the development of the particleboard industry was stimulated in Europe by lumber shortages and in the United States by large quantities of unused softwood mill residues. In the late 1940s, a number of particleboard plants were built in Europe and United States but the product was crude and the industry struggled to capture new markets (Cartyle *et al.,* 1956). By 1960 the industry had been established and growing rapidly as the world production increased from 0.02 million m^3/yr in 1950 to 3 million m^3/yr in 1960 to 20 million m^3/yr in 1990 (Anon., 2010).

As the world's need for sawn wood increased from 55 million tonnes from 1913 to 62 million tonnes in 1950 and then to 102 million tonnes in 1980, particleboard has no record at all in 1913 and 1950 until 1980 when there was a record of 24.1 million tonnes(Westoby, 1989).

2.3:Particleboard production line

Shanghai Jinnan Import and Export Co. Ltd stated that particleboard is made from small-diameter wood, branches, wood residues and non-wood agricultural residues via chip preparation, drying, spreading and hot press section. Finished boards can be used for furniture, building, packaging, vehicle and ship decoration and lamination (Anon., 2010).

The production line of particleboard is placed under the sections below.

1. Chip preparation section
2. Drying and sifting section
3. Glue regulating and applying section
4. Forming and hot-pressing section
5. Cooling and sizing section
6. Sanding section

Particleboard making starts with particles preparation in the laboratory where the trees are harvested and bucked into smaller segments before it is chipped by using a commercial chipper. The chips are then reduced into particles using laboratory type hammer mill. The air-dried particles are screened on a vibrator screen machine to obtain the sizes of particles of 0.5-1.0 and 1.0-2.0 mm. The accepted particles are dried in an oven with temperature of 60°C to achieve moisture content (mc) of 4-6%. A pre-weighted amount of particles comprised are blended initially without binder to enable it to mix thoroughly prior to spraying of the furnish that comprised of urea formaldehyde resin, wax emulsion and ammonium chloride (NH_4Cl). Urea-formaldehyde resin catalyst is applied at a resin content of 10% resin solids based on oven-dry weight of wood particles. The wax emulsion is applied at 1% based on the weight of the resin and ammonium chloride (NH_4Cl) catalyst act as hardener was applied at 1% based on the resin content(Loh *et al.*, 2010).

After blending, the particles are spread evenly into 340mm x 340mm wooden box former using metal caul Plate as the base to produce a loose mat. Silicone release agent is sprayed onto the caul Plate to prevent the panel from sticking to the Plate during hot pressing. The mat formed is initially pre-pressed manually to consolidate the thickness. Distance bars are placed at both sides of the mat in order to get the targeted board thickness during hot pressing. The mat is then hot pressed (Frederick and Norman, 2004) in a thermal-oil heated hydraulic hot press at an elevated temperature of 145°C up to 200°C (Mirski *et al.*,2008) with a specific pressure of 18 kg cm^{-2} to achieve target thickness 12 mm. The mat is hot-pressed for 5 min based on the recommendation of the resin supplier. After hot-pressed, the boards are then conditioned in a conditioning room maintained at a relative humidity of 65±5% and 20±2°C for 7 to 10 days prior to properties evaluation (Loh *et al.*,2010).

2.3.1 Factors affecting the properties of particleboards

There are many factors affecting the properties of the particleboards and the most important are species of wood, fibre structure, density, hardness, compressibility, type and size of particles and method of particle drying (Eom *et al.,* 2005). Other factors include particle screening and separation, particle size distribution, type and amount of binding agents, method of mat formation, structure of particleboard, moistening of particles prior to pressing, final moisture content of board, conditioning, curing conditions, thickness of board (Moslemi, 1974).

2.4: Product of Particleboard Standards and Certification

The American National Standard for Particleboard (ANSI A208.1) (2009) is the North American industry voluntary standard, which classifies particleboard by physical, mechanical and dimensional characteristics as well as formaldehyde levels. The Standard was developed through the sponsorship of the Composite Panel Association (CPA) in conjunction with producers, users and general interest groups. The standard has a tiered system of emission levels allowing either a maximum of 0.18 ppm or 0.09 ppm for industrial grades or 0.20 parts per million (ppm) for manufactured home decking. To meet the needs of the market many particleboard manufacturers have voluntarily developed ultra low-emitting and no added urea-formaldehyde (NAUF) products, so there are a wide variety of products available today with reduced formaldehyde levels, as well as a growing number of non-formaldehyde alternatives (ANSI, 1993). ANSI A208.1 (2009) stated that formaldehyde shall not exceed 0.3 parts per million (ppm) under test conditions. Test conditions include an air exchange rate of 0.5/hour and test temperatures of 77^{o}. Board should meet or exceed this requirement when manufactured. ANSI (2009) also indicated that the moisture content of particleboard should not exceed 10%.

2.4.1: Safety of particleboard

Safety concerns are of two parts, one being fine dust released when particleboard is machined (e.g., sawing or routing), and occupational exposure limits exist in many countries recognizing the hazard of wood dusts. The other concern is with the release of formaldehyde which is classified by the WHO as a known human carcinogen (Anon., 2006). Particleboard is a reconstituted wood product containing wood, resin and wax. Machine tools should be fitted with dust extractors and the wearing of a dust mask and eye protection is recommended (Anon., 2011a).

2.4.2: Use of Formaldehyde adhesives in particleboard manufacturing

According to the U.S. Consumer Product Safety Commission formaldehyde is one of the most widespread chemicals in the world. It is a simple compound made of carbon, hydrogen and oxygen, and is a colorless, strong-smelling gas. It is one of the large family of chemical compounds called volatile organic compounds. The use of the word 'volatile' means that the compounds vaporize, that is, become a gas, at normal room temperatures. Formaldehyde is naturally produced in plants and animals. It is important in the human metabolic process. It is a by-product of combustion in burning wood, kerosene, natural gas, automobile engines and cigarettes. Formaldehyde can also off-gas from materials made with it (Anon., 2011a).Urea formaldehyde adhesives are used in most particleboard products worldwide. It enables the adhesive to bond the wood particles and fibres together. These adhesives are easy to work with, strong, durable and cost-effective. Changes in resin technology and improved manufacturing controls have dramatically reduced formaldehyde emissions in particleboard, as much as 80-90% since the early 1980's. Product standards (ANSI A208.1 for particleboard) contain formaldehyde emissions limits at levels lower than those common in the past.

2.4.3 Risk of formaldehyde emission to indoor air

The formaldehyde content of the resin and the emissions to indoor air has been a major problem for the fibreboard industry and is still a problem regarding products made from fibreboard (Kollmann *et al.,* 1975). Formaldehyde is normally present at levels less than 0.03 parts per million of air (ppm) in both outdoor and indoor air. Rural areas have lower concentrations than urban areas. Indoor levels can increase with the presence of products that may add formaldehyde to the air. Typical exposures to humans are much lower and the risk of causing cancer is believed to be small. Formaldehyde is just one of several gases present indoors that may cause illnesses. Many of these gases, as well as colds and flu, cause similar symptoms.

2.5 Common Uses of Particleboard

According to Davis and Dhingra (2001), today's particleboard gives industrial users the consistent quality and design flexibility needed for fast, efficient production lines and quality consumer products. Particleboard panels are manufactured in a variety of dimensions and physical properties providing maximum design flexibility for specifiers and end users. Some of the common uses of particleboard are countertops, door core, floor underlaying, manufacture of home decking, office and residential furniture, shelving, store fixtures, stair treads and kitchen cabinets.

2.6 Environmental impact of Particleboard

Tamakloe (2000) reported that over 90% of Ghana's high forest have been logged since the late 1940s. The rate of deforestation is 5% in off-reserves and 2% in on-reserves. The off-reserves have been seriously degraded and fragmented to less than 5 percent of the forested area 83,489km^2. The current deforestation rate is about 22,000 hectares (ha) per annum. Ghana, therefore, may face future export deficits and there is the likelihood that the country's forestry sector will die out. Wagner *et al.* (2008) also added that only 20% of Ghana's forest reserve remains. Grainger (1993) agreed that deforestation and logging have environmental effects which include the treat to biological diversity. The tropical rain forest is one of the world's 12 major types of ecosystem. It contains between two and five million species of plant species. Deforestation and logging also have effect on the soil. Rainfall in humid tropics is not only high and continuous throughout the year but also very erosive, arriving in brief, heavy showers. Fortunately, rain is slowed down by the dense vegetation cover of litter and herbaceous vegetation protects soil from the impact of raindrops and, together with the dense network of shallow tree roots, from being washed away by surface water. Other effects of deforestation and logging are changes in climate which eventually lead to changes in water flows.

FAO (1950) also put the usefulness of the forest in the field of protective influence on the climate, soil and water resources, productive uses such as supply of wood and other forest products and accessory benefits such as recreation, amazing improvement in the conditions of health and comfort of the people and in the local economy in general resulting from the afforestation.

Also, enormous quantities of sawdust are produced annually by sawmills. The sawdust produced in cutting a thousand 30cm board of 2.5cm hardwood lumber with a saw cutting a 0.625cm kerf is at least 63 m³ of solid wood (Tamakloe, 2000). Economical disposal of sawdust and shavings is a problem of growing concern to the wood industries as in most cases there is no market for the sawdust produced (Ofori, *et al.*, 1993). In addition, Hardkin (1969) reported that planing and machining of lumber and other manufacture from wood leads to further residues. A planer mill produces about 272kg of dry residue per thousand 30cm board. Thus, the total amount of air-dry wood fines originating in U.S industries alone exceeds 15 million tons a year enough to make a (triangular cross section) pile 1524cm high, 3048cm wide, and over 241km long. However, technology is evolving for using waste or low grade wood blended with plastics to make an array of high-performance reinforcement composite products. This technology provides a strategy for producing advanced materials that take advantage of the enhance properties of both wood and plastic (Youngquist, *et al.*, 1993).

2.7 Export of wood products in Ghana

Annual gross wood production from the forest totals 1.2 million cubic metres of logs, which represents the annual allowable cut. In the early 1990s about 700,000 cubic metres of this supported products and 500,000 cubic metres fed domestic demands (Pleydell, 1994). According to the Timber Industry Development Division report on export of wood products, December 2009, Ghana realised Euro 9,844,948 from the export of 33,817 cubic metres of wood products in December 2009.The corresponding figures for the same period in 2008 were Euro 12,196,197 and 31,768 cubic metres showing a decrease of 19.28 % in value and an increase of 6.45 %in volume respectively. Figures for January - December 2009 were Euro 128,226,984 and 426,221 cubic metres compared to Euro 186,611,447and 545,915 cubic metres in January - December 2008, representing decreases of 31.29 %in value and21.93 %in volume over the same period previous year.

The decline was due largely to a drastic global economic downturn which has generally affected the cash flow of most buyers of wood products. Of the total value of Euro 128,226,984 for January - December 2009, Primary products (Poles and Billet) accounted for Euro 12,613,306 as compared to Euro 20,578,875 from the total value of Euro 186,611,447 in January - December 2008. Tertiary products registered Euro 8,126,147 in January - December 2009 and Euro 14,175,651 in January - December 2008. Secondary Products fetched a total of Euro 107,487,531 in January - December 2009 and Euro 160,858,924 in January - December 2008 respectively. On Direction of Trade, Africa recorded Euro 52,679,026 and 200,440 cubic metres (41.08% and 47.03%) in value and volume of total wood exports for January - December 2009.Europe accounted for Euro 37,746,260 and 83,420 cubic metres (29.44% and 19.57%) in value and volume respectively of total wood exports for January - December 2009. Key markets included Italy, France, Germany, The United Kingdom, Belgium, Spain, Ireland and Holland.

The emerging markets in Asia/Far East: India, Malaysia, Taiwan, China, Singapore and Thailand together contributed Euro 23,097,150 (18.01%) to the total of wood export value in January - December 2009. India continues to be the leading importer of teak Poles, Billet and Teak Lumber. The US accounted for 6.00 % and 4.19% of the total export value and volume respectively of Ghana's wood. Export for January - December 2009 as compared to 11.45% and 8.40% in January - December 2008. That market has recorded revenue declines in terms of wood imports from Ghana. The ECOWAS market (mainly Nigeria, Senegal, Niger, Gambia, Mali, Benin, Burkina Faso and Togo) absorbed Euro 45,619,879 (86.60%) of Africa's Euro 52,679,026 wood imports from Ghana in January - December 2009. Plywood and Air dried Lumber (Ofram / Ceiba Species) continue to interest the Nigeria and Niger markets. The Middle East countries, notably

Saudi Arabia, Lebanon, United Arab Emirate and Israel together contributed Euro 6,435,118 (4.79%) to the total export value for January - December 2009 (TIDD 2009)

2.8 Wawa (*Triplochitonscleroxylon*)

The Nigerian name obeche and the Ghana name wawa have been adopted as alternative British Standard names for the timber of this species; obeche is the usual trade name in Britain (Anon., 2011b). It is widely distributed in Africa (Grimshaw, 1976). The wood is creamy-white to pale-straw in colour with no clear distinction between sapwood and heartwood, though the wide sapwood is more susceptible to discoloration and insect attack. It is the lightest low-cost utility hardwood in general use (Anon., 2011), the density being 375kg/m^3 at 12-15% moisture content (Pleydell, 1994). The grain is slightly interlocked; the texture open. When cut on the quarter and stained it has some resemblance to African mahogany. Large logs commonly contain brittle heart. It is fairly elastic and resilient, considering its weight, but should not be used for purposes where strength is critical. Wood from the centre of large logs is inclined to be brittle (brittleheart) (brittle heart). On the basis of laboratory tests it is classed as moderately good for steam bending. Obeche is not resistant to decay or staining fungi. Freshly felled logs are extremely prone to attack by pinhole borer beetles, and seasoned timber is often infested by powder-post beetles. In regions where termites are present obeche is very liable to be damaged. The heartwood resists preservative treatment. Although it cannot be described as hard, the wood is firm under the tool, and even in texture. It works very easily with hand and machine tools, and does not blunt cutting edges of tools very quickly. In end-grain working, the timber may show a tendency to crumble, unless the tools are kept sharp, and edges are not allowed to become thick. It can be turned but is rather soft for this type of use as centres are apt to sink in. For jointed work, gluing is preferable to nailing or screwing, except for very light work. It stains and polishes well (the grain needs to be filled). The wood takes paint well with normal primers. Obeche is readily obtainable in large sizes, clear of defects, and at a fairly low price and is ideal for mass-production work. It is used in the manufacture of lower-priced domestic cabinet work and kitchen furniture, and for interior joinery and similar purposes where American whitewood or joinery-grade softwood were formerly specified; also for boxes and packing cases where a good appearance is required, since less wastage occurs in conversion. Obeche should never be used without preservative treatment in exposed or damp situations (Anon., 2011b).

2.9 Plastic waste in Ghana

According to Olatunji-Osei (2010) drinking water sold in sachets or fast food packed in takeaway bags may be a practical option for the consumer in Ghana but the enormous problems caused by discarded plastic has for a long time outweighed its convenience. Plastic waste not only creates an eyesore in the streets but also chokes drains, harbours disease and threatens wildlife. Every year, the perennial problem of flooding plagues towns and cities in Ghana during the rainy seasons. We then raise our hands in exasperation at the choked state of gutters but despite expressed resolve, the problem persists. War has been declared on plastic waste and the battle has been going on for some years now. Levies have been put on plastic producers but inappropriately discarded plastic is still estimated to cause about 22,000 tonnes of rubbish annually (Olatunji-Osei, 2010).

Ghana is not the only country fighting the scourge of plastic waste, indeed the problem is a global one. Many European countries for example, have introduced levies on shopping bags from the supermarket. However, there are many differences between Europe and Ghana with regard to the plastic waste issue. Of major importance is the fact that Europe has a much more effective waste management system than Ghana. Every household in Britain can expect their rubbish to be collected at least weekly, paid for by council taxes. In Ghana, unless you can afford such a service privately, rubbish disposal is an individual problem. In Europe, the use of plastic packaging has been prolific since the 1960's, yet you are unlikely to see discarded bags strewn all over the streets, clinging to bushes and clogging up drains. It is true they have many more public bins and street cleaners but there is also a greater awareness among consumers who are less likely to drop rubbish indiscriminately.

Conversely, it is still within recent memory when every shopper in Ghana would go to the market with his or her own basket or bowl and would cover purchased groceries in them with a tea towel. Drinking water was once dispensed to consumers from a vessel on the seller's heads in re-usable cups. We used to carry our own bottles to the cooking oil sellers for refill. Yet, in as little as 10 years, plastic waste has hit our streets in a manner that has never been seen in most European countries. With 'modernization' things may get worse. It is interesting to note that the drinks industry is moving away from recycled bottles in the name of 'progress.' Club Muscatella, for example, is no longer available in redeemable glass and can only be purchased in throwaway plastic bottles or cans. This is not to say that the rubbish situation has not improved in Ghana. There is a visible difference in areas where Zoomlion have sprung into action and their efforts are to be commended. However, a trip into areas where Zoomlion have yet to reach, including some villages that should be rural idylls, the picture is a messy one. Plastic waste has pervaded every nook and cranny of the country but it may take some time for the street cleaners and rubbish collectors to follow.

There exist schemes and proposals to tackle the problem of plastic waste in Ghana. Recycling is the new buzz word in the country. Trashy Bags is an NGO whose mission is to convert waste plastic into reusable shopping bags, wallets and other accessories. It has also been suggested that a levy be placed on water sachets such that the consumer inevitably pays for the right to litter. By charging an extra 20 pesewa on every sachet that is redeemable once returned to a recycling point such as Trashy Bags, sellers and consumers will have extra incentive to dispose of empty sachets appropriately. The only dilemma is that consumers are yet to purchase these recycled items in enough quantity to even make a dent in the waste problem. New proposals have recently been announced by the Mayor of Accra to convert waste into energy which, if implemented, may have a significant effect on the issue (Olatunji-Osei, 2010).

The ultimate answer must be in public education. If it was not a problem to shop with our own baskets and bottles in the recent past then surely the consumer can be convinced to return to similar practices today. Environmental awareness might encourage consumers in Ghana to purchase the products from organisations like trashy bags instead of collecting an endless stream of free plastic that they cannot dispose of properly.

2.10 Low-density polyethylene (LDPE)

Thermoplastic is any material that softens when heated and hardens when cooled. Thermoplastics selected for use with lignocellulosics must melt at or below the degradation point of the lignocellulosic component, normally 200-220°C. This group includes polypropylene, polystyrene, vinyls, both low- and high-density polyethylenes (English *et al.*, 1997).

Polyethylene is the widely used plastic, with an annual production of approximately 80 million metric tons. It is a thermoplastic polymer which softens at around 140ºC. It absorbs no water, resist acids, inorganic chemical and alkalis. No solvent can attack it at ordinary temperature unless around 140ºC (Cope, 1960). Polyethylene varies in types namely Low-density polyethylene, Medium density polyethylene and High-density polyethylene.

Low-density polyethylene (LDPE) is a thermoplastic made from petroleum. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process via free radical polymerization. Its manufacture employs the same method today. LDPE is commonly recycled and has the number "4" as its recycling symbol. Despite competition from more modern polymers, LDPE continues to be an important plastic grade. In 2009 the worldwide LDPE market reached a value of 22.2 billion US-Dollars (Anon., 2009)

2.11 Application of LDPE

LDPE is widely used for manufacturing various containers, dispensing bottles, wash bottles, tubing, plastic bags for computer components, and various moulded laboratory equipment. Its most common use is in plastic bags. Other products made from it include:

1. Trays and general purpose containers
2. Food storage and laboratory containers

3. Corrosion-resistant work surfaces
4. Parts that need to be weldable and machinable
5. Parts that require flexibility, for which it serves very well
6. Very soft and pliable parts
7. Six pack rings
8. Juice and milk cartons, whose "cardboard" is actually liquid packaging board, a laminate of paperboard and LDPE (as the water-proof inner and outer layer), and often with of a layer of aluminium foil (thus becoming aseptic packaging).
9. Parts of computer hardware, such as hard disk drives, screen cards, and optical disc drives
10. Playground slides
11. Plastic wraps

Research has been conducted into combining waste paper and waste plastics such as polyethylene and polypropylene into forms suitable for processing into composites (Brumbaugh, 1960).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the study were wawa (*Triplochitonscleroxylon)* sawdust and low density plastic (polyethylene) waste. The sawdust was produced by the band saws and chain saws from Lumber and Logs Limited (LLL), whiles the polyethylene was collected from food vendors.

3.2 Methodology

3.2.1 Collection and Preparation of Sawdust

The sawdust was collected from Lumber and Logs Limited (LLL), a Timber Company located in Asokwa, a suburb of Kumasi in the Ashanti Region of Ghana. The sawdust was then transported to Forestry Research Institute of Ghana (FORIG), Kumasi where the research was to be conducted. The sawdust was air-dried to a moisture content range of between 2% to 8% in order to aid the adhesion of the polyethylene to sawdust particles together. The-air dried sawdust was separated using a sieve of mesh numbered 25 and of aperture 0.600mm. The sawdust particles retained on the sieve were used for the development of the particleboard.

3.2.2 Collection and preparation of Low Density Polyethylene

Low Density Polyethylene was collected from food vendors who use it for wrapping food items for customers. Since most of the polyethylene wastes contained oils, they were washed with warm water with *'omo'* detergent and dried very well in the sun. The washing was done to remove the oils as well as any other food item or materials they might be harbouring. After drying of the polyethylene, it was shredded using pair of scissors. The shredding was done to an average size of 2-3mm by 3-5mm. These sizes were to aid the rate of the melting of the polyethylene.

3.2.3 Preparation of mould for making sample particleboard

Mild steel was used to make mould (formwork) with inner dimension of 300mm x 300mm and depth 20mm, as seen in Plate 1.

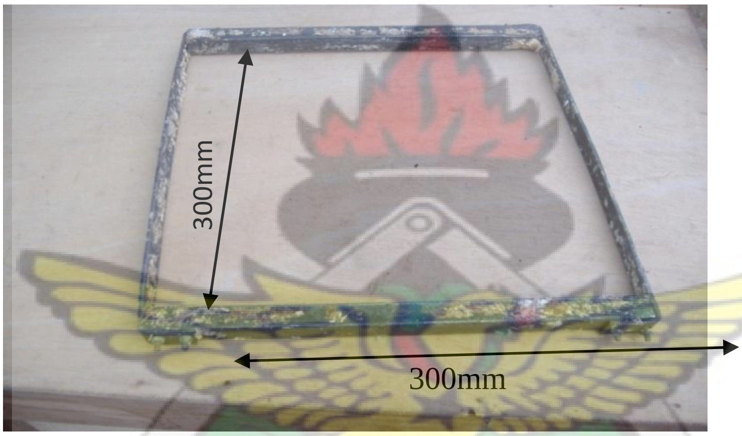

Plate 1. Mould for forming particleboard sample

3.2.4 The experiment for the development of particleboard from sawdust and low density polyethylene

The particleboard samples were all produced at a constant pressing pressure of $6.5kg/cm^2$ and in a constant time of one (1) hour. Two temperatures of 145^oC and 200^oC; and weight ratios of polyethylene to sawdust (1:7.5, 1:3, 1:2, and1:1.3) were used. The Solms Nebelung's Hydraulic hot press machine; Plate 2 was used to consolidate the materials into board. It uses electricity to heat up the two Plates that lie horizontally parallel to each other. When the Plates reached the required temperature, the mixture was loaded into the mould placed on the bottom Plate. The material was then pressed together for the specified time. When the pressing time was reached, the particleboard produced was removed and allowed to cool.

Heating and Pressing plate

Plate 2: Hydraulic pressing machine

3.2.5 Preparation and Property testing of Boards

All the boards were conditioned to 74% humidity and a temperature of 24^{o}C for at least two weeks prior to testing. From each board, four (4) bending test pieces measuring 20 mm x 20 mm x 300 mm and four (4) compression test pieces measuring 20mm x 20 mm x 60 mm were cut using the circular saw. In accordance to ANSI A208.1-2009, an American Standards of Testing and Methods (ASTM) standards of testing; the pieces in an air-dried condition were randomly selected and tested for the bending and compression properties. The testing was done using the Instron machine. Plate 3 and Plate 4 show test samples under test.

Plate 3: Particleboard sample under static bending test on the Instron machine

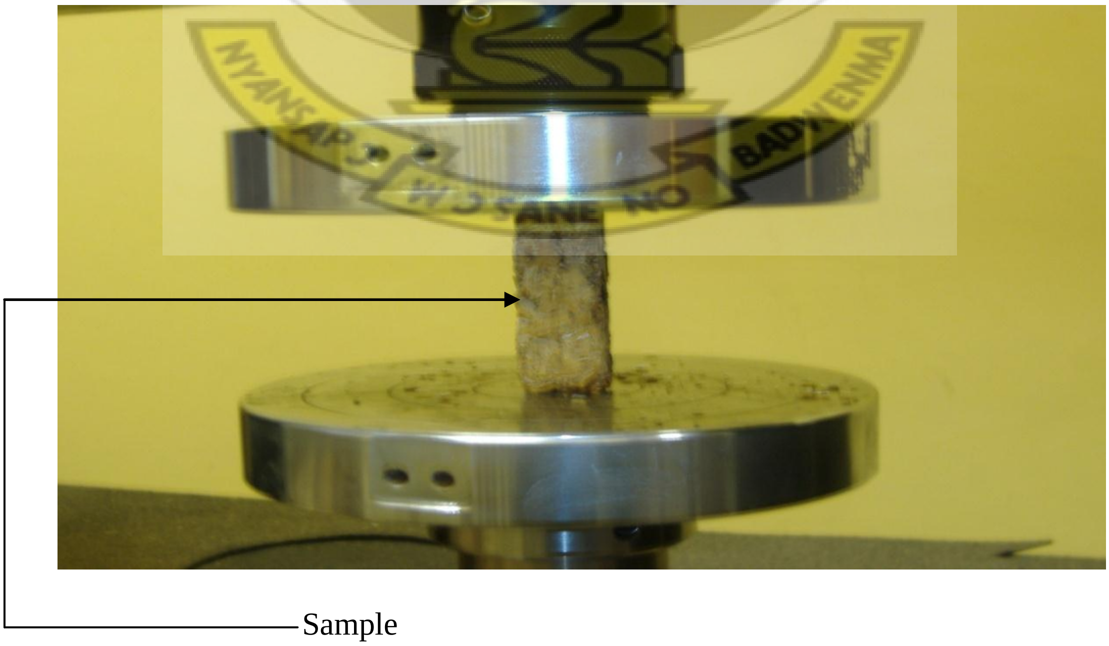

Plate 4: Particleboard sample under compression test on the Instron machine

3.3 Analysis of test results

The experimental test was conducted to ascertain the bending and compression strengths of particleboard produced from wawa sawdust and plastic waste using three plastic-sawdust combination 1: 1.75, 1:1.2 and 1:3; and two temperature range 145ºC and 200ºC.The effect of the plastic- sawdust combination and temperature range as well as their interaction on the stress, strain and modulus of elasticity, density and moisture content of particleboards in respect to bending and compression strengths were examined using a two-way factorial analysis with the descriptive statistics mainly used to summarise the moisture content, density, stresses, strains and modulus of elasticity of the boards being the mean. The T- test (Least Significant Difference) (ANOVA) was further used to determine significant differences among different specimen.

3.4Limitations

The pressing machine used for the melting and pressing of the particle board was handicapped in a lot of areas some of which were the inability to heat above 200^{o}C, inability press above 6.5kgcm^{-2}and the frequent breakdown of the machine. For these reasons the study could not include other plastics which melts above 200^{o}C, the inability to produce a lot of samples of the particle boards and the inability to press above 6.5kgcm^{-2}.

CHAPTER FOUR

4.0 RESULTS

4.1 Particleboard produced with their parameter combinations and test results

This Chapter presents the result of the experiment conducted on the bending and compression strengths of particleboard produced from wawa sawdust and plastic waste. Table 1 is the parameter combinations used for each particleboard produced with their test results. Particleboard A (Plate 5), produced with a plastic-sawdust combination of 1:1.75 at 145^{o}C and with a pressing pressure of 6.5kg/cm^2 for 1 hour, had a mean density of 350kg/m^3 at a mean mc of 3.9%. The mean bending stress, strain and modulus of elasticity were 1.65N/mm^2, 0.0121 and 235.33N/mm^2 respectively, whiles the compression stress, strain and modulus of elasticity of the board were 0.399N/mm^2, 0.0207 and 75.687N/mm^2 respectively. Particleboard B (Plate 5) with a plastic-sawdust combination of 1:1.75 at a 200^{o}C and pressure of 6.5kg/cm^2 in 1 hour recorded the mean density of 383kg/m^3 at mean mc of 3.0%. Its mean bending stress, strain and modulus of elasticity were 1.44N/mm^2, 0.0079 and 296.55/mm^2 respectively whiles the compression stress, strain and modulus of elasticity the board were 0.416/mm^2, 0.0186 and 81.768/mm^2 respectively. The board looked charred.

Particleboard C (Plate 5) with a plastic-sawdust combination of 1:2 at 145^{o}C and pressure of 6.5kg/cm^2 for 1 hour had a mean density of 316kg/m^3 at mean mc of 4.5%. Its mean bending stress, strain and modulus of elasticity were 0.7N/mm^2, 0.0065 and 248.93N/mm^2 respectively whiles the compression stress, strain and modulus of elasticity of the board were 0.604N/mm^2, 0.0255 and 75.008N/mm^2 respectively. Particleboard D (Plate 5) produced with a plastic-sawdust combination of 1:2 at 200^{o}C and pressure of 6.5kg/cm^2 for 1 hour had a mean density of 363kg/m^3 at mean mc of

3.8%. Its mean bending stress, strain and modulus were 1.3N/mm^2, 0.0092 and 357.75N/mm^2 respectively whiles the compression stress, strain and modulus of elasticity were 0.513N/mm^2, 0.0154 and 62.288/mm^2 respectively. The board also looked charred. Particleboard E (Plate 5) produced with a plastic-sawdust combination of 1:1.3 at 145^{o}C and pressure of 6.5kg/cm^2 for 1 hour had a mean density of 352kg/m^3 at a mean mc of 4.7%. Its mean bending stress, strain and modulus of elasticity were 2.18/mm^2, 0.0116 and 408.65N/mm^2 respectively whiles the compression stress, strain and modulus of elasticity were 2.513N/mm^2, 0.0255 and 183.625N/mm^2 respectively.

Particleboard F (Plate 5) produced with a plastic-sawdust combination of 1:1.3 at 200^{o}C and pressure of 6.5kg/cm^2 for 1 hour had a mean density of 350kg/m^3 at a mean mc of 3.8%. Its mean bending stress, strain and modulus of elasticity were 3.07N/mm^2, 0.0076 and 559.18N/mm^2 respectively whiles the compression stress, strain and modulus of elasticity were 3.242/mm^2, 0.0214 and 294.325N/mm^2 respectively. This board too looked charred.

Table 1: Summary of parameter combinations and test results of particleboards produced

No. of boards	Plastic-sawdust combi-nation (g)	Tempe-rature (^oC)	Time (Hr)	Pre-ssure ($Kgcm^{-2}$)	Mean mc (%)	Mean Density (Kgm^{-3})	Mean Ben-ding stress (Nmm^{-2})	Mean Bending strain	Mean MOE (Nmm^{-2})	Mean Compre-ssion stress (Nmm^{-2})	Mean Compression Strain	Mean Compre-ssion MOE (Nmm^{-2})
A	1:1.75	145	1	6.5	3.9	350	1.65	0.0121	235.33	0.399	0.0207	75.687
B	1:1.75	200	1	6.5	3.0	383	1.44	0.0079	296.55	0.416	0.0186	81.768
C	1:2	145	1	6.5	4.5	316	0.7	0.0065	248.93	0.604	0.0176	75.008
D	1:2	200	1	6.5	3.8	363	1.3	0.0092	357.75	0.513	0.0154	65.288
E	1:1.3	145	1	6.5	4.7	352	2.18	0.0116	408.65	2.513	0.0255	183.625
F	1:1.3	200	1	6.5	3.8	350	3.07	0.0076	559.18	3.242	0.0214	294.325

Plate 5 is a display of the pictures of the produced particleboards A, B, C, D, E and F; and their various parameter combinations used in producing them.Particleboard A was produced with a plastic-sawdust combination 1:1.75 at a temperature of 145 ^oC while particleboard B with a plastic-sawdust combination 1:1.75 and a temperature of 200^oC.Particleboard C was produced with a plastic-sawdust combination of 1:2 at a temperature of 145 ^oC, particleboardD with a plastic-sawdust combination of 1:2 at 200 ^oC. Particleboard E with plastic-sawdust combination of 1:1.3 at a temperature of 145 ^oC and particleboard F with plastic-sawdust combination of 1:1.3 at 200 ^oC

Particle board A

Particle board B

Particle board C

Particle board D

Particle board E

Particle board F

Plate 5: Various particleboards (A-F) produced from wawa sawdust and low density polyethylene

4.2: Moisture Content of particleboards

Table 2 shows the results of the test conducted to find out the moisture content (mc) of the six specimens. The highest mean moisture content of 4.7% was recorded for particleboard E with plastic-sawdust combination of 1:1.3 at145ºC followed by 4.5% for particleboard C (plastic-sawdust combination of 1:2 at 145ºC). Particleboard B (plastic-sawdust combination of 1:1.75 at 200ºC) recorded the least mean mc of 3.0%.

Table 2: Summary of Moisture content of the particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No.of samples per board	Mean Moisture Content (%)	Standard Deviation
A	1:1.75	145	4	3.9	0.163
B	1:1.75	200	4	3.0	0.082
C	1:2	145	4	4.5	0.0
D	1:2	200	4	3.8	0.08
E	1:1.3	145	4	4.7	0.163
F	1:1.3	200	4	3.8	0.141

Table 3 shows a significant difference between the plastic- sawdust combination as well as temperature on the moisture content of the particleboard produced. There was however no significant difference among the interaction between the plastic- sawdust combination and temperatures at 5 % level of probability (<0.05).

Table 3: ANOVA of Plastic- sawdust combination, Temperatures and their interaction on the moisture content of the specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	0.023	0.0078	0.49	0.6925
Plastic-sawdust combination	2	3.04	1.5200	96.34	0.0001*
Temperature	1	4.167	4.1667	264.08	0.0001*
P-S combination/ Temperature	2	0.053	0.0267	1.69	0.2178
Total	8	7.283	5.9615	362.6	0.9105

Table 4 shows that the differences in the plastic- sawdust combination have effect on the moisture content of the particleboard produced. The significant differences occurred between plastic-sawdust combination 1:1.75 and 1:2 as well as 1:1.75 and 1:1.3. There was no significant difference between the ratios 1:2 and 1:1.3 at 5 % level of probability (<0.05).

Table 4: T-Test (LSD) of moisture content of the boards for Plastic- sawdust combination

Plastic-sawdust combination	Mean
1:1.75	3.45_b
1:2	4.15_a
1:1.3	4.25_a

Means with the same letter are not significantly different at 5% level of probability

Table 5 shows that the differences in the temperatures have effect on the moisture content of the particleboard produced. The temperature 145ºC is significantly different from 200ºC at 5 % level of probability (<0.05) with the data at 200ºC having lower moisture content compared with those at 145ºC for all the combinations tried.

Table 5: T-Test (LSD) of moisture content between Temperatures of particleboards

Temperatures (ºC)	Mean
145ºC	4.3667_a
200ºC	3.5333_b

Means with the same letter are not significantly different at 5% level of probability

4.3: Density of particleboards

From Table 6, the highest mean density of 383 Kg/m^3 was recorded for particleboard B with plastic-sawdust combination 1:1.75 at 200ºC followed by particleboard D (plastic-sawdust combination of 1:2 at 200ºC) with mean density of 363 Kg/m^3. Particleboard C of plastic-sawdust combination 1:2 at 145ºC recorded the least mean density of 316 Kg/m^3.

Table 6: Summary of Density of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean Density (Kg/m^3)	Standard deviation
A	1:1.75	145	4	350	3.559
B	1:1.75	200	4	383	2.449
C	1:2	145	4	316	2.828
D	1:2	200	4	363	0.816
E	1:1.3	145	4	352	2.160
F	1:1.3	200	4	350	1.633

From Table 7, it is evident that there is a significant difference among the plastic- sawdust combination, temperatures as well as their interactions on the density of the particleboards produced at 5 % level of probability (<0.05).

Table 7: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the density specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	10.333	3.44	0.55	0.6548
Plastic-sawdust combination	2	2937.33	1468.67	235.2	<.0001*
Temperature	1	4056.00	4056.00	649.54	<.0001*
Plastic-sawdust combination/ Temperature	2	2548.00	1274.00	204.02	<.0001*
Total	8	9551.663	6804.11	1089.39	0.6548

Table 8 shows that the three plastic- sawdust combinations are significantly different from each other at 5 % level of probability (<0.05).

Table 8: T-Test (LSD) of density between Plastic- sawdust combination

Plastic-sawdust combination	Mean
1:1.75	366.5_a
1:2	339.5_c
1:1.3	351.0_b

Means with the same letter are not significantly different at 5% level of probability

Table 9 shows that the differences in the temperatures have effect on the density of the bending and compression strengths of particleboard produced. Each temperature is significantly different from each other at 5 % level of probability (<0.05).

Table 9: T-Test (LSD) of density between Temperatures

Temperatures (ºC)	Mean
145ºC	339.33_b
200ºC	365.33_a

Means with the same letter are not significantly different at 5% level of probability

4.4: Bending stress of particleboards

From Table 10, the highest mean bending stress of 3.07N/mm^2 was recorded for particleboard F with plastic- sawdust combination of 1:1.3 at 200ºC followed by particleboard E (plastic-sawdust combination 1:1.3 at 145ºC) with mean bending stress of 2.18 N/mm^2. Particleboard C of plastic-sawdust combination 1:2 at 145ºC recorded the least mean bending stress of 0.70N/mm^2.

Table 10: Summary of bending stress of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean stress (N/mm^2)	Standard deviation
A	1:1.75	145	4	1.65	0.58
B	1:1.75	200	4	1.44	0.4
C	1:1.2	145	4	0.7	0.3
D	1:1.2	200	4	1.3	0.73
E	1:1.3	145	4	2.18	0.59
F	1:1.3	200	4	3.07	0.18

Table 11 shows that there were significant differences among the plastic- sawdust combination on the bending stress of the particleboard produced. There was however no significant difference among the temperatures as well as the interaction between the plastic- sawdust combination and temperatures at 5 % level of probability (<0.05).

Table 11: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the bending stresses of the specimens

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	0.486	0.162	0.6	0.6238
Plastic-sawdust combination	2	10.88	5.440	20.19	0.0001*
Temperature	1	1.073	1.073	3.98	0.0645
Plastic-sawdust combination/ Temperature	2	1.267	0.643	2.39	0.1258
Total	8	13.706	7.318	27.17	0.8142

Table 12 shows that the differences in the plastic- sawdust combination have effect on the bending stress of particleboard produced. The significant differences occurred between plastic-sawdust combination 1:1.3 and 1:1.75 as well as 1:1.3 and 1:2. There was no significant difference between the plastic-sawdust combinations 1:2 and 1:1.75 at 5 % level of probability (<0.05).

Table 12: T-Test (LSD) of bending stress between Plastic- sawdust combinations

Plastic-sawdust combination	Mean strain
1:1.75	1.550_b
1:2	1.0043_b
1:1.3	2.6251_a

Means with the same letter are not significantly different at 5% level of probability

4.5: Bending Strain of particleboards

From Table 13, the highest mean bending strain of 0.0121 $N/mm^2$was recorded for particleboard A with plastic-sawdust combination 1:1.75 at 145ºC followed by particleboard E (plastic-sawdust combination 1:1.3 at 145ºC) with a mean bending strain of 0.0117 N/mm^2. Specimen C (plastic-sawdust combination 1:2 at 145ºC) recorded the least mean bending strain of 0.0065 N/mm^2.

Table 13: Summary of bending strains of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean strain	Standard deviation
A	1:1.75	145	4	0.0121	0.0026
B	1:1.75	200	4	0.0079	0.0015
C	1:1.2	145	4	0.0065	0.0008
D	1:1.2	200	4	0.0092	0.0011
E	1:1.3	145	4	0.0116	0.0017
F	1:1.3	200	4	0.0076	0.0013

From Table 14, it is evident that there are significant differences among the plastic-sawdust combination on the bending strain of the particleboard produced. The same applied to the temperatures. There was however significant difference among the interactions between the plastic- sawdust combination and temperatures at 5 % level of probability (<0.05).

Table 14: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the bending strains of the specimens

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	0.00000436	0.00000145	0.50	0.6869
Plastic-sawdust combination	2	0.00002127	0.00001064	3.67	0.0504*
Temperature	1	0.00002128	0.00002128	7.34	0.0161*
Plastic-sawdust combination/ Temperature	2	0.00006237	0.00003118	10.76	0.0013*
Total	8	0.00010928	0.00006455	22.27	0.7547

Table 15 shows that the significant differences occurred between plastic-sawdust combination 1:1.3 and temperature 200ºC interaction and the other interactions. Also, there was significant difference between the plastic-sawdust combination 1:1.3 and temperature 145ºC interaction and the other interactions. There was no significant difference between the plastic-sawdust combinations 1:2 and 1:1.3 and temperature 200ºC interactions as well as 1:1.75 and 1:2 plastic- sawdust combination and temperature 145ºC interactions at 5 % level of probability (<0.05).

Table 15: T-Test (LSD) of bending strain between Plastic- sawdust combination and Temperature interactions

Plastic-sawdust combination	Mean	Temperature (ºC)	Mean
1:1.75	0.0099750_{a}	145	0.0100667_{a}
1:2	0.0095875_{ab}	200	0.0081833_{b}
1:1.3	0.0078125_{b}		

Means with the same letter are not significantly different at 5% level of probability

4.6: Bending Modulus of elasticity of particleboards

From Table 16, the highest mean modulus of elasticity of 559.18 N/mm^2 was recorded for particleboard F with plastic-sawdust combination 1:1.3 at 200ºC followed by particleboard E (plastic-sawdust combination 1:1.3 and temperature 145ºC) with mean modulus of elasticity of 408.65N/mm^2. Particleboard C of plastic-sawdust combination 1:2 at 145ºC recorded the least mean modulus of 248.93 N/mm^2.

Table 16: Summary of bending modulus of elasticity of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean MOE (N/mm^2)	Standard Deviation
A	1:1.75	145	4	235.33	58.48
B	1:1.75	200	4	296.55	79.37
C	1:1.2	145	4	248.93	115.72
D	1:1.2	200	4	357.75	47.46
E	1:1.3	145	4	408.65	292.45
F	1:1.3	200	4	559.18	49.83

From Table 17, it is evident that there is a significant difference among the plastic- sawdust combination on the bending modulus of the particleboard produced. There was however no significant difference among the temperatures as well as the interaction between the plastic-sawdust combination and temperatures at 5 % level of probability (<0.05).

Table 17: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the modulus of the specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	70196.7	23398.9	1.30	0.3108
Plastic-sawdust combination	2	204297.8	102148.9	5.68	0.0146*
Temperature	1	59431.6	59431.4	3.30	0.0892
Plastic-sawdust combination/ Temperature	2	12647.2	6323.6	0.35	0.7093
Total	8	346573.3	137812.8	10.63	1.1239

Table 18 shows that the differences in the plastic- sawdust combination have effect on the bending modulus of particleboard produced. The significant differences occurred between plastic-sawdust combination 1:1.75 and 1:2 as well as 1:1.75 and 1:1.3. There was no significant difference between the plastic-sawdust combinations 1:2 and 1:1.3 at 5 % level of probability (<0.05).

Table 18: T-Test (LSD) of bending modulus between Plastic- sawdust combinations

Plastic-sawdust combination	Mean
1:1.75	483.91_a
1:2	303.34_b
1:1.3	275.94_b

Means with the same letter are not significantly different at 5% level of probability

4.7: Compression stress of particleboards

Table 19 indicated that the highest mean compression stress of 3.242 N/mm^2 was recorded for particleboard F with plastic-sawdust combination 1:1.3 at 200ºC followed by specimen E (plastic-sawdust combination 1:1.3 at 145ºC) with a compression stress of 2.513N/mm^2. Particleboard A of plastic-sawdust combination 1:1.75 at 145ºC recorded the least mean compression stress of 0.399 N/mm^2.

Table 19: Summary of compression stress of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean stress (N/mm^2)	Standard deviation
A	1:1.75	145	4	0.399	0.263
B	1:1.75	200	4	0.416	0.211
C	1:2	145	4	0.604	0.130
D	1:2	200	4	0.513	0.325
E	1:1.3	145	4	2.513	0.297
F	1:1.3	200	4	3.242	0.649

From Table 20, it is evident that there is significant difference among the plastic- sawdust combination as well as the interaction between the plastic-sawdust combination and temperature on the compression stress of the particleboard produced.

Table 20: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the compression stresses of the specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	0.787	0.262	2.71	0.0820
Plastic-sawdust combination	2	30.66	15.330	158.42	<.0001*
Temperature	1	0.286	0.285	2.95	0.1063
Plastic-sawdust combination/ Temperature	2	0.794	0.397	4.10	0.0379*
Total	8	32.527	16.274	168.18	0.2262

Table 21 shows that the differences in the plastic- sawdust combination have effect on the compression stress of particleboard produced. The significant differences occurred between plastic-sawdust combination 1:1.3 and 1:1.75 as well as 1:1.3 and 1:2. There was no significant difference between the ratios 1:2 and 1:1.75 at 5 % level of probability (<0.05). Apart from 1:1.3 plastic-sawdust combination and the temperatures 145ºC and 200ºC interactions differences were significant in all the other interactions at 5 % level of probability.

Table 21: T-Test (LSD) of compression stress between Plastic- sawdust combination and the interactions

Plastic-sawdust combination	Mean	Temperature	Mean
1:1.75	0.4076_b	145ºC	1.3903_a
1:2	0.5586_b	200ºC	1.1720_a
1:1.3	2.8773_a		

Means with the same letter are not significantly different at 5% level of probability

4.8: Compression strain of particleboards

From Table 22, the highest mean compression strain of 0.0255 N/mm^2 was recorded for particleboard E with plastic-sawdust combination 1:1.3 at 145ºC followed by particleboard F (plastic-sawdust combination 1:1.3 and temperature 200ºC) with mean compression strain of 0.0214 N/mm^2. Particleboard D of plastic-sawdust combination 1:2 at 200ºC recorded the least mean compression strain of 0.0154 N/mm^2.

Table 22: Summary of Compression Strain of Particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	No. of samples per board	Mean strain	Standard deviation
A	1:1.75	145	4	0.0207	0.0048
B	1:1.75	200	4	0.0186	0.0098
C	1:1.2	145	4	0.0176	0.0053
D	1:1.2	200	4	0.0154	0.0053
E	1:1.3	145	4	0.0255	0.0037
F	1:1.3	200	4	0.0214	0.0025

Table 23 indicated that there were significant differences among the plastic- sawdust combination on the compression strain of the particleboard produced. There was however no significant difference among the temperatures as well as the interactions between the plastic-sawdust combination and temperatures. The T-test (LSD) was further conducted to identify the plastic-sawdust combination that produced the differences in the strain of the particleboard.

Table 23: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the compression strains of the specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	0.000194	0.000065	2.47	0.1021
plastic- sawdust combination	2	0.000192	0.000096	3.66	0.0508*
Temperature	1	0.000046	0.000046	1.75	0.2052
p- s combination/ Temperature	2	0.000005	0.000003	0.10	0.9071
Total	8	0.000437	0.000210	7.98	1.2652

Table 24 shows that the significant differences occurred only between plastic- sawdust combination 1:1.3 and 1:2 at 5 % level of probability (<0.05).

Table 24: T-Test (LSD) of compression strain between Plastic- sawdust combinations

Plastic-sawdust combination	Mean
1:1.75	0.019663_{ab}
1:2	0.016500_{b}
1:1.3	0.023413_{a}

Means with the same letter are not significantly different at 5% level of probability

4.9: Compression Modulus of elasticity of particleboards

From Table 25, the combination with the highest mean compression modulus of 294.325 N/mm^2 was specimen F with ratio 1:1.3 and temperature 200ºC followed by specimen E of mean compression modulus of 183.625 N/mm^2 and of plastic-sawdust combination 1:1.3 and temperature 145ºC. Specimen D of plastic-sawdust combination 1:2 and temperature 200ºC recorded the least mean compression modulus of 65.288 N/mm^2.

Table 25: Summary of compression modulus of elasticity of particleboards

Specimen	Plastic-sawdust combination (g)	Temperature (ºC)	Number of sample per board (N/mm^2)	Mean	Standard Deviation
A	1:1.75	145	4	75.687	41.200
B	1:1.75	200	4	81.768	51.404
C	1:2	145	4	75.008	47.233
D	1:2	200	4	65.288	37.482
E	1:1.3	145	4	183.625	40.109
F	1:1.3	200	4	294.325	88.304

Table 26 showed a significant difference among the plastic- sawdust combination on the compression modulus of the particleboard produced. There was however no significant difference among the temperatures as well as the interaction between the plastic- sawdust combination and temperatures. The T-test (LSD) was further conducted to ascertain the ratio that produced the differences in the modulus of the particleboard.

Table 26: ANOVA of Plastic- sawdust combination, Temperatures and the interaction between them on the compression modulus of the specimen

Source	DF	Sum of Square	Mean Square	F value	Pr>F
Replicate	3	9304.345	3101.45	1.09	0.3852
Plastic-sawdust combination	2	144681.6	72340.8	25.33	<.0001*
Temperature	1	7641.229	7641.23	2.68	0.1227
Plastic-sawdust combination/ Temperature	2	17130.64	8565.32	3.00	0.0802
Total	8	178737.919	91648.8	32.1	0.5881

Table 27 shows that the differences in the plastic- sawdust combination have effect on the compression modulus of particleboard produced. The significant differences occurred between plastic-sawdust combination 1:1.3 and 1:1.75 as well as 1:1.3 and 1:2. There was no significant difference between the plastic- sawdust combination 1:2 and 1:1.75 at 5 % level of probability (<0.05).

Table 27: T-Test (LSD) of compression modulus between Plastic- sawdust combinations

Plastic-sawdust combination	Mean
1:1.75	78.73_b
1:2	70.15_b
1:1.3	283.98_a

Means with the same letter are not significantly different at 5% level of probability

CHAPTER FIVE

5.0 DISCUSSION

5.1 Moisture content of particleboard

The moisture content (mc) of the particle boards produced ranged between 3.0% and 4.7% with lower temperature of 145ºC giving the higher mc values than higher temperature of 200ºC. The highest mc of 4.7% obtained, was in line with particle boards produced from rubberwood and mahang particle board that were dried at 60% to achieve mc of 4-6% (Loh *et al.*, 2010). The mc of the boards produced also conformed to the ANSI standard of mc not exceeding 10% (ANSI, 2009). Lower plastic-sawdust combinations used for the production of the boards resulted in high mc of at all temperatures than those of higher plastic-sawdust combinations.

Plastics are usually moisture resistant and since low plastic-sawdust combinations of 1:1.3 had more plastic in its mixture, there was the possibility of resistance to inflow of moisture into the particle board coupled with high temperature of the plates (145ºC and 200ºC) causing the moisture in the board to evaporate rapidly and easily. These factors resulted in the boards produced with low plastic-sawdust combination at higher temperature yielding low mc than boards produced at low temperature (Dexin and Ostman, 1983). To produce boards with low mc; it is advised that low plastic-sawdust combination of 1:1.3 and higher temperature of 200ºC be used.

5.2 Density of particleboard

The density of the particle boards produced ranged between 316kg/m^3 and 383kg/m^3. Low temperature of 145ºC seems to have resulted in low densities of 350kg/m^3, 316kg/m^3 and 352kg/m^3 than the high temperature of 200ºC whose densities were 383kg/m^3, 363kg/m^3 and 350kg/m^3. Boards with plastic-sawdust combination of 1:1.75 too resulted in higher density. These results showed that average amount of plastic in the mixture resulted in high density. The densities of the particle board produced (316kg/m^3 to 383kg/m^3) were lower than those produced by Loh *et al.* (2010) whose density varied from 394 to 511kg/m^3; and that of Han *et al.*(1998) that ranged between 55kg/m^3 and 900 kg/m^3 but met the ANSI(2009) standard of less than 640kg/m^3 for low density particle boards.

The average plastic-saw dust combination of 1:1.75 resulted in high densities of 350kg/m^3 and 383kg/m^3 because less plastic in the mixture was not adequate enough to bond the sawdust particles together. This agrees with Moslemi (1974) that the increase in the amount of adhesive in the particleboard led to the availability of more bonding sites between the materials being bonded and thereby increased the density of the particleboard. However, too much of low density plastic in the mixture will eventually not result in high density. In temperature wise, it was noticed that high temperature of 200ºC resulted in bonds with high density because high temperatures melt plastics better than low temperatures thereby resulting in better adhesion of sawdust particles (Nemu, 2002) and resulting in high density (Unsal *et al.*, 2009). Meanwhile, the densities of the particle boards produced could have been increased if the core density of the sawdust was slightly reduced (Wong *et at.*, 1998), and a traditional or better adhesive were used (Han, *et al.*, 1998). Moreover, increasing the pressure of the press to consolidate the particle mat and eliminate more voids in the mat to compact the wood structures could have increased the density of the boards (Kelly, 1977). From the results it is advised that the production of particle boards with high density could be done from an average plastic-sawdust combination of 1:1.75 at high temperature of 200ºC.

5.3 Bending stress of particleboard

The mean bending stress of the particle boards produced ranged between 0.7N/mm^2 and 3.07N/mm^2. The highest mean bending stress was obtained from boards produced with low plastic-sawdust combination of 1:1.3 as well as high temperature of 200ºC. The bending stress obtained (0.7N/mm^2 to 3.07N/mm^2) were less than those produced by Bekhta *et al.*, (2013) whose bending stress was 5.58 N/mm^2. It could also not meet the ASTM D1037 standard of 3590N/mm^2 for medium density fibreboard. The increased adhesive in the mat coupled with higher production density influenced the bending stress of the particleboard produced (Moslemi, 1974). This could be due to the fact that high temperature increased the volume of plastics more and thereby had more bonding sites and penetration into the sawdust particles to form a stronger unit (Nadir and Songklod, 2010 and Bekhta *et al.*, 2003). Meanwhile, the highest bending stress obtained (3.07N/mm^2) from the particle board produced was less than the standard minimum bending stress of 11.5N/mm^2 (Bekhta *et al.*, 2003). The bending stresses were eventually low because increased densities of particle boards have corresponding increase in bending stress (Han *et al.*, 1998). Low particle boards could therefore only be suitable for products such as insulations and vertical applications like book shelves and stair thread. However, the stress could be increased by 91% for adequate strength by coating them with laminated plastics (Bekhta and Marutzky, 2007).

5.4 Bending strain of particleboard

Mean bending strain of the particle board produced was 6.5 x 10^{-4} to 1.21 x 10^{-2}. The plastic-sawdust combination that contained an average amount of plastic in the mixture resulted in the highest bending strain. Temperature wise, it was noticed that out of the three plastic-sawdust combination, the highest results were recorded for boards produced at lower temperature of 145ºC. This result agrees with DeXin and Ostman, (1983) and Nemu, (2002) that lower temperatures increase in bending strain of the particleboard. This is because high temperature increases the crystallisation of the plastics after it cools down and thereby making them more fragile. The effect of this is low bending strain. Moreover, less adhesive in the mat could not permit proper bonding between the sawdust particles hence resulting in low bending strain but too much of plastic in the mat increased the brittleness of the boards after the plastic crystallised when it cooled down. This made the boards brittle (DeXin and Ostman, 1983).

However, the bending strain could have been improved if the density of the boards were higher because mechanical properties of particle boards are improved if the density of the boards were higher (Han *et al.*, 1998). To produce particle boards with higher bending strain, adequate plastic-sawdust combination at high temperature could be the appropriate parameter combinations.

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5.5 Bending modulus of elasticity of particleboard

The modulus of elasticity (MOE) is an important property in particle board production since it is the measure of stiffness or resistance to bending when the board is stressed (McNatt, 1973). The particle board produced at high temperature of 200ºC had their MOE higher than their counterparts produced at lower temperature of 145ºC. Lower plastic-sawdust combination which had more plastic in the mat had the highest MOE of 559.18N/mm^2. The intermediate plastic-sawdust combination had the least values whiles the combination with more plastic had the highest value. It implied that the more the plastic in the mixture the higher the bending MOE.

The particle board produced could not meet the ASTM D 1037 standard for medium density particleboard but had its value of 559.89Nmm^2 higher than 550N/mm^2, the least bending MOE grade value for low density particle board (ANSI, 2009). The result could have met the standard for medium density particle board if there was an improvement on the density of the boards produced (Han *et al.,* 1998). In this wise, the boards produced fall under low density particle board so would be suitable for applications where load bearing is minimal as in book shelves, threads of stairs and insulations. However, the bending MOE of the boards produced can be improved to 50% up to 60% when coated with laminated plastics than untreated panels (Bekhta and Marutzky, 2007).

5.6 Compression stress of particleboard

The mean compression stress of the particle boards produced ranged from 0.399 N/mm^2 to 3.242N/mm^2. The highest compression stress was recorded from boards produced at higher temperature of 200ºC. This agrees with Nadir and Songklod (2010) that high temperature results in high compression stress because when the temperature is increased, the polyethylene adhesive was able to melt better and produce better cohesion between the particles of sawdust (Nemu, 2002). The increase in the amount of plastic in the mixture also resulted in increase in the compression stress of the boards produced. This agrees with Moslemi (1974) that increase in adhesive (polyethylene in the plastic-sawdust combination) in particleboards increases the compression stress of the boards. The production of boards with more plastic at higher temperature had a tremendous improvement in the compression stress. However, the highest stress of 3.242N/mm^2 was below the minimum compression stress ASTM D 1037 standard of 9.1N/mm^2 (ANSI, 2009). The low compression stress recorded for the boards could be attributed to the low densities recorded for the boards as a result of the less pressing pressure that was used during the production (Han *et al.*, 1998). Another factor that reduced the compression stress perhaps was that the plastic-sawdust combination was still high since the increase in plastic in the mat was always seen to have resulted in the increase in the compression stress. Notwithstanding, the compression stress could be improved by 91% by coating them with laminated plastics (Bekhta and Marutzky, 2007). From the result, it is advised that for particle boards that need adequate compression strength, a low plastic-sawdust combination at a higher temperature would be the best parameters that should be used.

5.7 Compression strain of particleboard

Compression strain of the particle boards produced ranged from 0.0154 to 0.0255. The results showed increase in plastic-sawdust combination correspondingly increases the compression strain. The outcome is in line with Nemu (2003) that when the amount of adhesive in particle board increases its compressive strain. However, when the adhesive in the mat is above 30% the compressive strain begins to decrease (Mamza and Kambai 2008). Also, as in agreement with DeXin and Ostman (1983), lower temperature was noticed to have resulted in higher compression strain. This outcome of result was due to the fact that at high temperature, the plastic crystallises when it cools down and thereby making it less pliable. The compression strain obtained from the results was not up to the ASTM D 1037 standard of 0.329 (ANSI, 2009) but could have been improved by increasing the pressing pressure so that there would be more particle to particle contact to remove the voids in the boards which would have eventually led to higher density (Kelly, 1977). However, it is advised that for particle board with high compressive strain, plastic-sawdust combination such as 1:1.3 that had more plastic in the mixture should be used at higher melting temperature of 200ºC.

5.8 Compression modulus of elasticity of particleboard

The particle board produced had their compression MOE from 65.288N/mm^2 to 294.325N/mm^2. The highest value recorded by the particle board (294.325N/mm^2) was from plastic-sawdust combination with the highest amount of plastic content in the mixture such as 1:1.3 as well as higher temperature of 200ºC. It was likely that higher amount of plastic in the mix resulted in better bonding between the sawdust particles (Nemu, 2002, and Bekhta *et al.*, 2003). Another factor was that when higher temperature was used, the plastics were able to melt better and have better penetration into the sawdust and therefore caused the particle to have direct particle to particle contact with each other. This improved the stiffness of the boards (Kelly, 1977).

However, the results recorded (65.288N/mm^2 to 294.325N/mm^2) were less than the values obtained from particle boards produced by Ramponi *et al.*, (2009) that recorded a value of 779.1N/mm^2. The result could not also meet the ASTM D 1037 standard too. Meanwhile, it is advised that the plastic-sawdust combination (1:1.3) with more plastic content could be used for the production of particle boards at higher temperature of 200ºC.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study examined the viability of utilizing wawa sawdust and low density polyethylene, as an adhesive in particleboard production. It is concluded that particleboard can be produced from sawdust using low density polyethylene as an adhesive with a Plastic-sawdust combination F of 1:1.3 at 200°C and a pressure of 6.5kgcm^{-2} in 1 hour. Six (6) particleboards (A, B, C, D, E and F) were produced with densities ranging between 316kg/m^3 to 383kg/m^3 which are comparable to densities of particleboards produced from sawdust and formaldehyde resin adhesives. The highest bending stress of 3.07N/mm^2 was obtained from board F with 1:1.3 plastic-sawdust combinations at 200°C, and the highest compression stress of 3.242N/mm^2 at 200°C. Increase in polyethylene in the plastic-sawdust combination of the particleboards inversely affected their bending and compression stresses. Low density polyethylene is therefore suitable as adhesive in particleboard production.

6.2 Recommendations

The following recommendations are made from the study:

1. Particleboard F of plastic-sawdust combination 1:1.3 at 200ºC could withstand both the bending and compression loads. It is therefore advised for general applications where the product must withstand both bending and compression loads.

2. Particle boards made from sawdust and plastic waste can suitably be used for making furniture, door and other wood products so as to reduce the pressure on solid board and the natural forest.

3. Polyethylene waste can be appropriately used as an adhesive alternative for formaldehyde based resins in particle board manufacturing so as to eliminate the health effects formaldehyde-based resins cause to humans.

4. Since sawdust and plastic wastes are nuisance to the environment, they can be appropriately used in the formation of particle boards so as to help accelerate the realisation of the United Nations Millennium Development Goal (MDG) of achieving zero waste.

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APPENDIX A

BENDING DATA OF PARTICLEBOARDS PRODUCED AND THEIR ANALYSIS

Obs	PS comb	Tempt	Rep	Displacement	Load	Stress	Strain	Modulus	Moisture	Density
1	1	1	1	7.21	0.0295	1.5500	0.0110	258.3	3.9	350
2	1	1	2	8.84	0.0456	2.3960	0.0135	313.0	3.7	355
3	1	1	3	9.76	0.0322	1.6920	0.0149	278.6	3.9	348
4	1	1	4	5.85	0.0188	0.9870	0.0090	175.4	4.1	347
5	1	2	1	4.39	0.0215	1.1280	0.0067	291.1	3.0	383
6	1	2	2	5.93	0.0215	1.1280	0.0091	236.9	3.0	380
7	1	2	3	4.20	0.0295	1.5500	0.0064	409.1	3.1	386
8	1	2	4	6.04	0.0376	1.9730	0.0092	245.1	2.9	383
9	2	1	1	4.50	0.0161	0.8458	0.0069	399.4	4.5	316
10	2	1	2	3.62	0.0054	0.2819	0.0055	279.6	4.5	320
11	2	1	3	3.98	0.0134	0.7051	0.0061	167.9	4.5	314
12	2	1	4	4.82	0.0188	0.9870	0.0074	148.8	4.5	314
13	2	2	1	6.82	0.0349	1.8320	0.0104	389.8	3.9	363
14	2	2	2	5.85	0.0349	1.8320	0.0090	346.2	3.8	363
15	2	2	3	6.28	0.0242	1.2690	0.0096	295.6	3.7	362
16	2	2	4	4.98	0.0054	0.2819	0.0076	399.4	3.8	364
17	3	1	1	8.64	0.0564	2.9600	0.0132	836.7	4.7	352
18	3	1	2	8.55	0.0430	2.2550	0.0131	264.8	4.9	350
19	3	1	3	6.69	0.0295	1.5500	0.0102	188.2	4.5	351
20	3	1	4	6.52	0.0376	1.9730	0.0100	344.9	4.7	355
21	3	2	1	4.46	0.0618	3.2420	0.0068	502.0	3.8	350
22	3	2	2	4.47	0.5370	2.8190	0.0067	588.9	4.0	352
23	3	2	3	6.17	0.0591	3.1010	0.0094	611.1	3.7	348
24	3	2	4	4.75	0.0591	3.1010	0.0073	534.7	3.7	350

The ANOVA Procedure for Bending Data of Particle boards produced

Class Level Information

Class	Levels	Values
Rep	4	1 2 3 4
PScombination	3	1 2 3
Tempt	2	1 2

Number of observations 24

1. **Dependent Variable: Load**

The ANOVA Procedure for Load

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	0.10860606	0.01357576	1.44	0.2597
Error	15	0.14180153	0.00945344		
Corrected Total	23	0.25040759			

R-Square	CoeffVar	Root MSE	Load Mean
0.433717	183.3352	0.097229	0.053033

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.03045726	0.01015242	1.07	0.3898
PS Combination	2	0.03997446	0.01998723	2.11	0.1553
Tempt	1	0.01402634	0.01402634	1.48	0.2420
PScom*Tempt	2	0.02414801	0.01207400	1.28	0.3075

t Tests (LSD) for Load

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.009453
Critical Value of t	2.13145
Least Significant Difference	0.1036

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	0.11044	8	3
A	0.02953	8	1
A	0.01914	8	2

t Tests (LSD) for Load

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.009453
Critical Value of t	2.13145
Least Significant Difference	0.0846

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	0.07721	12	2
A	0.02886	12	1

Level of PS Comb.	Level of Tempt	N	-------------Load------------ Mean	Std Dev
1	1	4	0.03152500	0.01102403
1	2	4	0.02752500	0.00770298
2	1	4	0.01342500	0.00578641
2	2	4	0.02485000	0.01391318
3	1	4	0.04162500	0.01130498
3	2	4	0.17925000	0.23850340

2. Dependent Variable: Stress

The ANOVA Procedure for Stress

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	13.72639747	1.71579968	6.37	0.0011
Error	15	4.04195573	0.26946372		
Corrected Total	23	17.76835320			

R-Square	CoeffVar	Root MSE	Stress Mean
0.772519	30.06386	0.519099	1.726654

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.48649487	0.16216496	0.60	0.6238
PS Combintation	2	10.88017197	5.44008598	20.19	<.0001
Tempt	1	1.07277045	1.07277045	3.98	0.0645
PS comb*Tempt	2	1.28696018	0.64348009	2.39	0.1258

t Tests (LSD) for Stress

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.269464
Critical Value of t	2.13145
Least Significant Difference	0.5532

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	2.6251	8	3
B	1.5505	8	1
B	1.0043	8	2

t Tests (LSD) for Stress

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.269464
Critical Value of t	2.13145
Least Significant Difference	0.4517

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	1.9381	12	2
A	1.5152	12	1

Level of PS Comb	Level of Tempt	N	------------Stress----------- Mean	Std Dev
1	1	4	1.65625000	0.57956672
1	2	4	1.44475000	0.40446951
2	1	4	0.70495000	0.30461027
2	2	4	1.30372500	0.73109076
3	1	4	2.18450000	0.59264745
3	2	4	3.06575000	0.17742111

3. **Dependent Variable: Strain**

The ANOVA Procedure for Strain

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	0.00010928	0.00001366	4.71	0.0048
Error	15	0.00004348	0.00000290		
Corrected Total	23	0.00015276			

R-Square	CoeffVar	Root MSE	Strain Mean
0.715358	18.65877	0.001703	0.009125

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.00000436	0.00000145	0.50	0.6869
PS Combination	2	0.00002127	0.00001064	3.67	0.0504
Tempt	1	0.00002128	0.00002128	7.34	0.0161
PS Com*Tempt	2	0.00006237	0.00003118	10.76	0.0013

t Tests (LSD) for Strain

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	2.899E-6
Critical Value of t	2.13145
Least Significant Difference	0.0018

Means with the same letter are not significantly different.

t Grouping		Mean	N	PS Combination
	A	0.0099750	8	1
B	A	0.0095875	8	3
B		0.0078125	8	2

t Tests (LSD) for Strain

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	2.899E-6
Critical Value of t	2.13145
Least Significant Difference	0.0015

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	0.0100667	12	1
B	0.0081833	12	2

Level of PS combination	Level of Tempt	N	------------Strain----------- Mean	Std Dev
1	1	4	0.01210000	0.00262170
1	2	4	0.00785000	0.00150665
2	1	4	0.00647500	0.00084212
2	2	4	0.00915000	0.00118181
3	1	4	0.01162500	0.00176328
3	2	4	0.00755000	0.00126095

4. **Dependent Variable: Modulus**

The ANOVA Procedure for Modulus

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	346573.0617	43321.6327	2.41	0.0678
Error	15	269924.0879	17994.9392		
Corrected Total	23	616497.1496			

R-Square	CoeffVar	Root MSE	Modulus Mean
0.562165	37.85180	134.1452	354.3958

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	70196.7046	23398.9015	1.30	0.3108
PS Combination	2	204297.8433	102148.9217	5.68	0.0146
Tempt	1	59431.3538	59431.3538	3.30	0.0892
PS Com*Tempt	2	12647.1600	6323.5800	0.35	0.7093

t Tests (LSD) for Modulus

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	17994.94
Critical Value of t	2.13145
Least Significant Difference	142.96

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	483.91	8	3
B	303.34	8	2
B	275.94	8	1

t Tests (LSD) for Modulus

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	17994.94
Critical Value of t	2.13145
Least Significant Difference	116.73

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	404.16	12	2
A	304.63	12	1

Level of PS Com.	Level of Tempt	N	-----------Modulus----------- Mean	Std Dev
1	1	4	256.325000	58.483580
1	2	4	295.550000	79.369243
2	1	4	248.925000	115.720565
2	2	4	357.750000	47.462090
3	1	4	408.650000	292.450503
3	2	4	559.175000	49.825654

5. **Dependent Variable: Moisture Content**

The ANOVA Procedure for Moisture Content

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	7.28333333	0.91041667	57.70	<.0001
Error	15	0.23666667	0.01577778		
Corrected Total	23	7.52000000			

R-Square	CoeffVar	Root MSE	Moisture Mean
0.968528	3.179990	0.125610	3.950000

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.02333333	0.00777778	0.49	0.6925
PS Combination	2	3.04000000	1.52000000	96.34	<.0001
Tempt	1	4.16666667	4.16666667	264.08	<.0001
PS Com *Tempt	2	0.05333333	0.02666667	1.69	0.2178

t Tests (LSD) for Moisture

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.015778
Critical Value of t	2.13145
Least Significant Difference	0.1339

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	4.25000	8	3
A	4.15000	8	2
B	3.45000	8	1

t Tests (LSD) for Moisture

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.015778
Critical Value of t	2.13145
Least Significant Difference	0.1093

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	4.36667	12	1
B	3.53333	12	2

Level of PS Com.	Level of Tempt	N	-----------Moisture---------- Mean	Std Dev
1	1	4	3.90000000	0.16329932
1	2	4	3.00000000	0.08164966
2	1	4	4.50000000	0.00000000
2	2	4	3.80000000	0.08164966
3	1	4	4.70000000	0.16329932
3	2	4	3.80000000	0.14142136

6. Dependent Variable: Density

The ANOVA Procedure for Density

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	9551.666667	1193.958333	191.20	<.0001
Error	15	93.666667	6.244444		
Corrected Total	23	9645.333333			

R-Square	CoeffVar	Root MSE	Density Mean
0.990289	0.709240	2.498889	352.3333

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	10.333333	3.444444	0.55	0.6548
PS Combination	2	2937.333333	1468.666667	235.20	<.0001
Tempt	1	4056.000000	4056.000000	649.54	<.0001
PS Com*Tempt	2	2548.000000	1274.000000	204.02	<.0001

t Tests (LSD) for Density

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	6.244444
Critical Value of t	2.13145
Least Significant Difference	2.6631

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	366.500	8	1
B	351.000	8	3
C	339.500	8	2

t Tests (LSD) for Density

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	6.244444
Critical Value of t	2.13145
Least Significant Difference	2.1744

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	365.333	12	2
B	339.333	12	1

Level of PS Combination	Level of Tempt	N	Density Mean	Density Std Dev
1	1	4	350.000000	3.55902608
1	2	4	383.000000	2.44948974
2	1	4	316.000000	2.82842712
2	2	4	363.000000	0.81649658
3	1	4	352.000000	2.16024690
3	2	4	350.000000	1.63299316

7. Dependent Variable: Displacement

The ANOVA Procedure for Displacement

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	46.66655000	5.83331875	4.71	0.0048
Error	15	18.56598333	1.23773222		
Corrected Total	23	65.23253333			

R-Square	CoeffVar	Root MSE	Displacement Mean
0.715388	18.63021	1.112534	5.971667

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	1.98006667	0.66002222	0.53	0.6665
PS Combination	2	9.22990833	4.61495417	3.73	0.0485
Tempt	1	8.93040000	8.93040000	7.22	0.0169
PS Com*Tempt	2	26.52617500	13.26308750	10.72	0.0013

t Tests (LSD) for Displacement

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	1.237732
Critical Value of t	2.13145
Least Significant Difference	1.1857

Means with the same letter are not significantly different.

t Grouping		Mean	N	PS Combination
	A	6.5275	8	1
B	A	6.2813	8	3
B		5.1063	8	2

t Tests (LSD) for Displacement

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	1.237732
Critical Value of t	2.13145
Least Significant Difference	0.9681

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	6.5817	12	1
B	5.3617	12	2

Level of PS Combination	Level of Tempt	N	----------Displacement--------- Mean	Std Dev
1	1	4	7.91500000	1.73406074
1	2	4	5.14000000	0.97982992
2	1	4	4.23000000	0.53404120
2	2	4	5.98250000	0.77727623
3	1	4	7.60000000	1.15160757
3	2	4	4.96250000	0.81614439

APPENDIX B

COMPRESSION DATA AND THEIR ANALYSIS OF PARTICLEBOARDS PRODUCED

Obs	PS Com	Tempt	Rep	Displacement	Load	Stress	Strain	Modulus	Moisture	Density
1	1	1	1	0.1235	1.6390	0.4273	0.0272	32.37	3.9	350
2	1	1	2	0.2094	1.3190	0.7246	0.0212	48.58	3.7	355
3	1	1	3	0.0242	1.5540	0.0836	0.0162	110.10	3.9	348
4	1	1	4	0.1047	1.2190	0.3623	0.0182	111.70	4.1	347
5	1	2	1	0.1772	1.9390	0.6131	0.0303	51.63	3.0	383
6	1	2	2	0.1450	1.4340	0.5017	0.0232	26.54	3.0	380
7	1	2	3	0.0349	1.1590	0.1208	0.0110	111.70	3.1	386
8	1	2	4	0.1235	0.6934	0.4273	0.0100	137.20	2.9	383
9	2	1	1	0.1262	1.0430	0.4367	0.0155	51.07	4.5	316
10	2	1	2	0.2175	1.4060	0.7526	0.0233	53.89	4.5	320
11	2	1	3	0.1745	1.2040	0.6038	0.0202	49.27	4.5	314
12	2	1	4	0.1799	0.7191	0.6225	0.0113	145.80	4.5	314
13	2	2	1	0.2416	1.0420	0.8360	0.0167	85.35	3.9	363
14	2	2	2	0.1262	0.5991	0.0929	0.0078	17.54	3.7	362
16	2	2	4	0.1987	1.2760	0.6875	0.0202	55.16	3.8	364
17	3	1	1	0.6094	1.7460	2.1090	0.0285	158.70	4.7	352
18	3	1	2	0.8161	1.3020	2.8240	0.0210	241.60	4.9	350
19	3	1	3	0.7463	1.5460	2.5820	0.0238	179.30	4.5	351
20	3	1	4	0.7325	1.7140	2.5360	0.0285	154.90	4.7	355
21	3	2	1	0.7758	1.4240	2.6840	0.0230	196.50	3.8	350
22	3	2	2	1.2080	1.4690	4.1800	0.0230	328.60	4.0	352
23	3	2	3	0.8752	1.0580	3.0280	0.0178	399.00	3.7	348
24	3	2	4	0.8886	1.2990	3.0750	0.0217	253.20	3.7	350

The ANOVA Procedure for Compression Data on the Particle boards produced

Class Level Information

Class	Levels	Values
Rep	4	1 2 3 4
PS Combination	3	1 2 3
Temperature	2	1 2
Number of observations	24	

1. **Dependent Variable: Load**

The ANOVA Procedure for Load

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	1.32559119	0.16569890	1.97	0.1235
Error	15	1.26466131	0.08431075		
Corrected Total	23	2.59025250			

R-Square	CoeffVar	Root MSE	Load Mean
0.511761	22.61058	0.290363	1.284192

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.38141603	0.12713868	1.51	0.2530
PS Combination	2	0.74832024	0.37416012	4.44	0.0306
Tempt	1	0.16693344	0.16693344	1.98	0.1798
PS Com*Tempt	2	0.02892148	0.01446074	0.17	0.8440

t Tests (LSD) for Load

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.084311
Critical Value of t	2.13145
Least Significant Difference	0.3094

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	1.4448	8	3
A	1.3696	8	1
B	1.0383	8	2

t Tests (LSD) for Load

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.084311
Critical Value of t	2.13145
Least Significant Difference	0.2527

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	1.3676	12	1
A	1.2008	12	2

Level of PS Combination	Level of Tempt	N	-------------Load------------ Mean	Std Dev
1	1	4	1.43275000	0.19652714
1	2	4	1.30635000	0.52088395
2	1	4	1.09302500	0.29016731
2	2	4	0.98352500	0.28158131
3	1	4	1.57700000	0.20323714
3	2	4	1.31250000	0.18427968

2. **Dependent Variable: Stress**

The ANOVA Procedure for Stress

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	32.52889082	4.06611135	42.02	<.0001
Error	15	1.45161292	0.09677419		
Corrected Total	23	33.98050374			

R-Square	CoeffVar	Root MSE	Stress Mean
0.957281	24.28190	0.311086	1.281142

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.78710754	0.26236918	2.71	0.0820
PS Combination	2	30.66194574	15.33097287	158.42	<.0001
Tempt	1	0.28571108	0.28571108	2.95	0.1063
PS Com*Tempt	2	0.79412645	0.39706323	4.10	0.0379

t Tests (LSD) for Stress

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.096774
Critical Value of t	2.13145
Least Significant Difference	0.3315

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	2.8773	8	3
B	0.5586	8	2
B	0.4076	8	1

t Tests (LSD) for Stress

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.096774
Critical Value of t	2.13145
Least Significant Difference	0.2707

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	1.3903	12	2
A	1.172	12	1

Level of PS Combination	Level of Tempt	N	------------Stress----------- Mean	Std Dev
1	1	4	0.39945000	0.26308395
1	2	4	0.41572500	0.21092126
2	1	4	0.60390000	0.12963217
2	2	4	0.51327500	0.32510749
3	1	4	2.51275000	0.29733637
3	2	4	3.24175000	0.64933113

3. **Dependent Variable: Strain**

The ANOVA Procedure for Strain

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	0.00043641	0.00005455	2.08	0.1049
Error	15	0.00039271	0.00002618		
Corrected Total	23	0.00082912			

R-Square	CoeffVar	Root MSE	Strain Mean
0.526350	25.76609	0.005117	0.019858

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.00019375	0.00006458	2.47	0.1021
PS Combination	2	0.00019159	0.00009580	3.66	0.0508
Tempt	1	0.00004593	0.00004593	1.75	0.2052
PS Com*Tempt	2	0.00000514	0.00000257	0.10	0.9071

t Tests (LSD) for Strain

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.000026
Critical Value of t	2.13145
Least Significant Difference	0.0055

Means with the same letter are not significantly different.

t Grouping		Mean	N	PS Combination
	A	0.023413	8	3
B	A	0.019663	8	1
B		0.016500	8	2

t Tests (LSD) for Strain

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.000026
Critical Value of t	2.13145
Least Significant Difference	0.0045

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	0.021242	12	1
A	0.018475	12	2

Level of PS Com	Level of Tempt	N	Strain Mean	Strain Std Dev
1	1	4	0.02070000	0.00479583
1	2	4	0.01862500	0.00982798
2	1	4	0.01757500	0.00527091
2	2	4	0.01542500	0.00532439
3	1	4	0.02545000	0.00370270
3	2	4	0.02137500	0.00246086

4. Dependent Variable: Modulus

The ANOVA Procedure for Compression Modulus

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	178757.8211	22344.7276	7.82	0.0004
Error	15	42841.5037	2856.1002		
Corrected Total	23	221599.3247			

R-Square	CoeffVar	Root MSE	Modulus Mean
0.806671	41.33750	53.44249	129.2833

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	9304.3450	3101.4483	1.09	0.3852
PS Combination	2	144681.6064	72340.8032	25.33	<.0001
Tempt	1	7641.2291	7641.2291	2.68	0.1227
PS Com*Tempt	2	17130.6405	8565.3203	3.00	0.0802

t Tests (LSD) for Modulus

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	2856.1
Critical Value of t	2.13145
Least Significant Difference	56.955

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	238.98	8	3
B	78.73	8	1
B	0.15	8	2

t Tests (LSD) for Modulus

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	2856.1
Critical Value of t	2.13145
Least Significant Difference	46.504

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	147.13	12	2
A	111.44	12	1

Level of	Level of		-----------Modulus-----------	
PS Com	Tempt	N	Mean	Std Dev
1	1	4	75.687500	41.2000917
1	2	4	81.767500	51.4038334
2	1	4	75.007500	47.2332851
2	2	4	65.287500	37.4819026
3	1	4	183.625000	40.1089662
3	2	4	294.325000	88.3036947

5. Dependent Variable: Moisture

The ANOVA Procedure for Moisture

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	7.28333333	0.91041667	57.70	<.0001
Error	15	0.23666667	0.01577778		
Corrected Total	23	7.52000000			

R-Square	CoeffVar	Root MSE	Moisture Mean
0.968528	3.179990	0.125610	3.950000

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.02333333	0.00777778	0.49	0.6925
PS Combination	2	3.04000000	1.52000000	96.34	<.0001
Tempt	1	4.16666667	4.16666667	264.08	<.0001
PS Com *Tempt	2	0.05333333	0.02666667	1.69	0.2178

t Tests (LSD) for Moisture

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.015778
Critical Value of t	2.13145
Least Significant Difference	0.1339

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	4.25000	8	3
A	4.15000	8	2
B	3.45000	8	1

t Tests (LSD) for Moisture

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.015778
Critical Value of t	2.13145
Least Significant Difference	0.1093

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	4.36667	12	1
B	3.53333	12	2

Level of PS Com	Level of Tempt	N	-----------Moisture---------- Mean	Std Dev
1	1	4	3.90000000	0.16329932
1	2	4	3.00000000	0.08164966
2	1	4	4.50000000	0.00000000
2	2	4	3.80000000	0.08164966
3	1	4	4.70000000	0.16329932
3	2	4	3.80000000	0.14142136

6. Dependent Variable: Density

The ANOVA Procedure for Density

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	9551.666667	1193.958333	191.20	<.0001
Error	15	93.666667	6.244444		
Corrected Total	23	9645.333333			

R-Square	CoeffVar	Root MSE	Density Mean
0.990289	0.709240	2.498889	352.3333

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	10.333333	3.444444	0.55	0.6548
PS Combination	2	2937.333333	1468.666667	235.20	<.0001
Tempt	1	4056.000000	4056.000000	649.54	<.0001
PS Com*Tempt	2	2548.000000	1274.000000	204.02	<.0001

t Tests (LSD) for Density

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	6.244444
Critical Value of t	2.13145
Least Significant Difference	2.6631

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	366.500	8	1
B	351.000	8	3
C	339.500	8	2

t Tests (LSD) for Density

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	6.244444
Critical Value of t	2.13145
Least Significant Difference	2.1744

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	365.333	12	2
B	339.333	12	1

PS Com	Level of Tempt	N	Level of Mean	-----------Density----------- Std Dev
1	1	4	350.000000	3.55902608
1	2	4	383.000000	2.44948974
2	1	4	316.000000	2.82842712
2	2	4	363.000000	0.81649658
3	1	4	352.000000	2.16024690
3	2	4	350.000000	1.63299316

7. Dependent Variable: Displacement

The ANOVA Procedure Displacement

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	8	2.71659144	0.33957393	42.02	<.0001
Error	15	0.12123000	0.00808200		
Corrected Total	23	2.83782144			

R-Square	CoeffVar	Root MSE	Displacement Mean
0.957281	24.28142	0.089900	0.370242

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Rep	3	0.06569309	0.02189770	2.71	0.0822
PS Combination	2	2.56058955	1.28029478	158.41	<.0001
Tempt	1	0.02390228	0.02390228	2.96	0.1060
PS Com*Tempt	2	0.06640652	0.03320326	4.11	0.0378

t Tests (LSD) for Displacement

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.008082
Critical Value of t	2.13145
Least Significant Difference	0.0958

Means with the same letter are not significantly different.

t Grouping	Mean	N	PS Combination
A	0.83149	8	3
B	0.16144	8	2
B	0.11780	8	1

t Tests (LSD) for Displacement

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	15
Error Mean Square	0.008082
Critical Value of t	2.13145
Least Significant Difference	0.0782

Means with the same letter are not significantly different.

t Grouping	Mean	N	Tempt
A	0.40180	12	2
A	0.33868	12	1

PS Com	Level of Tempt	Level of N	----------Displacement--------- Mean	Std Dev
1	1	4	0.11545000	0.07601213
1	2	4	0.12015000	0.06096723
2	1	4	0.17452500	0.03746575
2	2	4	0.14835000	0.09393510
3	1	4	0.72607500	0.08596101
3	2	4	0.93690000	0.18760615