2022-01

Investigation On The Mechanical Properties And Process Parameters Optimization Of Composite Made By Maze Cob & Urea Formaldehyde Matrix For Celling Application

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http://ir.bdu.edu.et/handle/123456789/14603

BAHIR DAR UNIVERSITY
BAHIR DAR INSTITUTE OF TECHNOLOGY
FACULTY OF MECHANICAL & INDUSTRIALENGINEERING
GRADUATE PROGRAM

Investigation On The Mechanical Properties And Process Parameters Optimization Of Composite Made By Maze Cob & Urea Formaldehyde Matrix For Celling Application

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January, 2022
Addis Ababa, Ethiopia

DECLARATION

This is to certify that the thesis entitled “**Investigation on the mechanical properties and process parameters optimization of composite made by maze cob & urea formaldehyde for celling application**”, submitted in partial fulfilment of the requirements for the degree of Master of science in specialization of Manufacturing Engineering under faculty of mechanical and industrial engineering, Bahir Dar Institute of Technology is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

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This thesis has been submitted for examination with our approval as a university advisor.

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ACKNOWLEDGEMENT

First, I would like to thank Almighty God with his mother saint Mary for being there for me in my journey. I would also want to thank Bahir dar University department of Mechanical and industrial engineering Manufacturing stream and for arranging week end postgraduate program, I would like to express my heartfelt appreciation and thank to my Instructors and this Thesis Research advisor **Dr Assfa Asmare** for his sustainable and appreciable guidance, tireless advising, and sharing his knowledge, skill, experience. Additionally, I want to express my gratitude to Ethiopian chip wood and furniture share co staffs for their support to carry out experimental works. Finally, to everyone who have contributed directly or indirectly to the success of this Thesis work.

ABSTRACT

Environmentally friendly or green building materials are becoming more widely used as our society becomes aware of harmful consequences associated with the use of standard practices in industrial production. This leads to growing tendency of recycling of waste materials and using them production of particle boards. Particle Boards are produced from Municipal solid waste, agro-waste materials such as rice husk, jute sticks, waste wood, sugarcane waste, kitchen waste, maize cob etc. The mechanical properties such as high surface hardness and flexural strength plays a vital role in the efficient usage of them for domestic and industrial purposes. All these properties majorly depend on the kind of raw material used and these properties may be improved for the quality betterment of the products and also their applications can be extended. The present study deals about the optimization process parameters (Pressing Temperature, Pressing Time and Resin content) using grey rational methods for Maize Cob particle board production and their mechanical properties for improving flexural strength and Hardness.

Key words:- **Grey rational methods, Optimization**

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1.INTRODUCTION

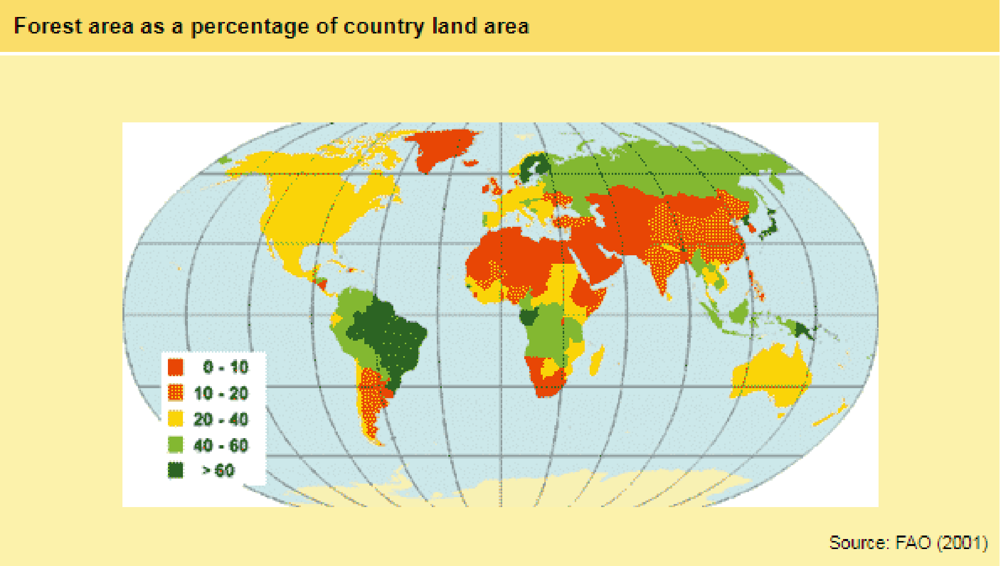
1.1Background of Study

Particleboards are a mixture of cellulose material and resin pressed together at certain pressure and temperature (“ANSI A208.2” 3). The pressure applied on the mixture helps informing the thickness required by reducing the voids. Particleboards can be classified into two types of panels, one being made with an adhesive that offers a bit water resistant and other being made with water proof resin. These panels are further divided into three types depending on the density as medium, low, and high classes.

Particleboards are used in interior signs, table tennis and pool tables, furniture, kitchen counter tops, construction, and many other applications depending on the type of resin and coatings applied. A permanent increase in the demand for wooden raw material is asking for an increase in the production of primary raw material. If no alternative way of providing the required raw material can be found challenges due to limitations in production area and climatic conditions. Forestry will try to increase the production of a single species on the available land and decrease the time of the rotation cycle to meet the increasing demand. But an increasing demand for one type of raw material leads to greater competition and higher prices for the raw material, as it is a limited source.

In developing countries, the construction industry is considered as an important part of the economy. This sector is heavily dependent on forest resources for the purpose of roofing, ceiling construction, paneling, furniture manufacture and other fabrication works that require the use of wood. In particular, the panel/board industry in Ethiopia or other developing countries has experienced continuous growth in recent years. This has placed a lot of strain on forest resources leading to deforestation and its attendant adverse effect on the environment as well as increase in the price of wood.

For the particleboard producing industry it might be necessary to concentrate on alternative raw material sources such as lignocellulose raw materials from monocotyledons (non-wood plants). The demand for wood and other biomass-based particleboard materials have considerably increased due to the rate of population growth in the world, Moreover, the world population currently consumes over 5.46 billion tons of green wood annually, which corresponds to about 0.7tons per person. If the consumption rate of wood fiber and the rate of population growth stay constant, demands for wood fiber will increase by over 60 million tons each year (Kadja, et. al.2018). Therefore, a huge imbalance between supply and demand will be inevitable. Efficient conversion technologies and new products will play an important role in the wood fiber supply demand (Kadja, et.al 2018).


Forest area as a percentage of country land area

Source: FAO (2001)

Figure 1.1 Forest area as percentage of country land area

If the particleboard-producing industry succeeds in using lignocellulose raw material from non-wood plants as a direct substitute for wooden raw material it would have great advantages (Linnaeus University Dissertations., 2016). Lignocellulose material can be used as raw material for particleboard manufacturing. Besides wood, industries can use residues from agribusiness such as, cereal straw, bagasse of sugar cane, cornstalks, corn cobs, cotton stalks, barley husks, rice husks, sunflower stalks and hulls. Cotton stalk, corn cob, barley husk, and rice husk are the raw materials found in large amount at any level can decrease the final cost of the product (Milo, et.al, 2014).

Maize Cob was a waste by-product of Maize farming and a problem to dispose of as it tends to harbor parasites such as pink bollworm.

Particle boards are mainly made from wood and other materials. The increase in demand for wood panel material in Ethiopia will result in exhaustion of the existing forest resources. The regeneration of forest takes considerable time and therefore it is unlikely that timber alone can serve as the raw material required by the wood product industries. Removal of forests also has a direct impact on the GHG (Greenhouse Gas) concentration in the atmosphere. Use of agricultural residue and non- wood plants as a substitute for wood in particle board industry like Maize Cob residue will provide three bold benefits. The first one is partially reducing the increasing demand for wood there by saving forests. Second providing effective utilization of the Maize Cob, presently treated as waste and disposed of in the field, the third one it serves as alternative raw material for particle board production. Ethiopia is rich in non-wood fiber materials. Residues of both agricultural and industrial process by products, naturally occurring uncultivated crops and on purpose or dedicated crops are found in different regions of the country with a significant amount. Therefore, utilizing these materials for the purpose as a raw material for particle board production is recommended in many ways.

A number of studies on the utilization of the wastes of agricultural crops in the production of the wood- and plastic-based particleboard materials have been conducted, and the outcome of these studies showed that it will be beneficial to use the agro-fiber wastes in the production of particleboard material in terms of the environmental and socio-economic aspects. It has also the chances to produce wood based panels with the combination of wood chips. It is possible to produce particle boards from the wastes of agricultural crops like cotton, bamboo, palms, maize cob, tea leaves and peanut shells having physical and mechanical properties required in related standards (Suleiman et al., 2013) (china et. Al. 2015).

Generally, in Ethiopia Maize cob is highly available without any benefit for industrial uses, So investigating this raw material for different use may be help full for the future. Almost all categories of non-wood fiber are found in the country. According to this work particle board was produced from agricultural residues of maize cob and tested its quality like the mechanical and physical property of the products, weather it meets to the standard or not**.** And if this study works, there will other reason for the production and development of maize in Ethiopia for different uses, in additions to animal food, textile, and edible oil and particle board production as well as for other uses like production of cellulose, adhesive, and other research studies.

This thesis work briefly reviews the optimization of process parameters (pressing temperature, pressing pressure and resin content) using grey rational methods in order to get better flexural strength and hardness. Hard fiberboard can be used **as** wall slab, door board, floor, furniture and other decorations instead of wood. And the soft fiberboard whose apparent density is low(< 400 kg/m^3) and porosity is high, often used as heatproof or acoustical materials and for ceiling purpose.

1.2 Statement of the Problem

The increase in the deforestation of our woodlands has led to the development of low-cost, renewable and biodegradable materials such as particleboards made from different materials. Since solid wood leads to deforestation it should be replaced by particleboards.

In our country Ethiopia industrialization and urbanization have ever been increasing. Indeveloping countries, the construction industry is growing at a rapidly while using wood and wooden products. This has caused great havoc to our environment. Agricultural residues are materials generated in large quantities in the world and can accumulate to such extent as to cause environmental problems. When forestlands are depleted, the agrochemical circles are negatively affected especially the carbon cycle, since nature depends on plants to reduce the amount of carbon dioxide in the atmosphere and when they are not in the environment as a result of man’s activities and this demand for wood, carbon dioxide in the atmosphere tends to increase, thereby resulting in the rising temperature of the biosphere.

Maize cobs are a by-product of the maize crop, The development of maize processing in the 20th century resulted in an increase in the volumes of this by-product (Lenz,1948). About 180 kg of cobs are obtained from each ton of maize shelled (Evers et al.,1994). In the USA, it was estimated that about 50 million ton of cobs were produced annually in the 2000s, most of them being left on the field (Jansen,2012), and maize cobs are a major by-product in many maize producing countries. According to the end uses of wood wastes and their possible reuse products, particleboard has found typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops and it seems that the manufacture of particleboard from biomass wastes is the most common way to reuse such waste materials.

Although most agricultural panels are environmentally friendly, in some cases the panels present poor mechanical, which limits their commercialization. For this reason, the mechanical properties of maize cob particle board should be analyzed by process parameter optimization .

1.3 Objectives of the Study

1.3.1 General Objective

- ✓ Investigating mechanical properties of particle board.
- ✓ To know the optimum operating variables and effects of control parameters on the product by varying modified Resin ratio, pressing pressure and Temperature.
- ✓ Determining significant parameters and their contribution.

1.4 Scope of the Study

The scope of this research work covers characterization of their contents, preparation of particleboard mechanical property testing, determining the operating parameters. In this study the suitability of raw material solid Maize Cob and modified starch adhesive according to the standard was studied for the preparation of particleboard.

1.5 Significance of the Study

The significance of this thesis is mainly focus on transforming maize cob into the valuable products a so called maize cob particleboard. The use of maize cob is used to create and increase awareness of the beneficial of effects of the use of solid organic wastes for particle board as environmental friendly, renewable and biodegradable, to make the use of Ethiopian renewable wastes or natural resources for its sustainable development and to determine the optimum process conditions for producing particle board from maize cob and modified starch adhesive.

CHAPTER TWO
LITERATURE REVIEW

2.1 Definition of particle board

Particle board is manufactured out of dry wood particles (chips) or fibers, which are coated with a synthetic resin binder and wax and formed into flat sheets under pressure. Heat is applied with the pressure, to cure the resin binder. The resin binders used are urea formaldehyde (UF) for interior applications and phenol formaldehyde for exterior products. Bitumen is also used for certain specific end use. Particle board may have a uniform structure throughout its thickness or it could be a sandwiched matrix with coarser grains at the center and finer ones on both sides. It is manufactured in different thicknesses and forms, such as plain, single or both sides veneered, with plywood lamination (Shaikh et al., 2009)(Gur jar, et.al., 2007) in this study the particle board can be produced from Maize corn with the standard adhesives other chemicals that can be used to see the property of the board.

2.1.1. Lignocellulosic materials

The use of natural fibers of vegetable origin to produce a composite material was old. It dates back to the use of straw and reeds to reinforce brickwork (Ashraf 1991). A wide range of wood and non-wood lignocellulosic materials can be used for particleboard production. The wood sources which can be utilized for particleboard manufacture can be in the form of round wood, slabs, edgings and off-cuts or from residues of furniture industries or other particulate wood from sawmills and other processes. The shortages of wood together with a need for the utilization of waste wood and availability of an annual abundance of plant residues inspired the production of boards from some non-wood lignocellulosic materials such as flax, jute, maize cob, bagasse and cotton stalks (Kozlowski et al. 1994). The fluctuating situation in annual plants production resulted in periodical lack of raw materials for plants operating on plant residues such as flax. The situation forced researchers to look for other raw materials including wood residues, such as sawdust and waste woodchips to fill in the gap. The use of these two wood residues improved some of the boards properties, especially those used in the furniture industry. In the beginning of 1990s, considerable market stimulation was noticed in the bast fiber industries in many parts of the world. This can be explained by the trend towards the preference of natural products. Another reason was the discovery that fibrous plants cultivated on polluted areas can naturally decontaminate the soil from the heavy metals. Such plants can be used for lignocellulosic boards with no negative effect on the environment (Kozlowski et al. 1992).

2.2 Potential of Maize in Ethiopia

Shahidur et al., (2017) reports that reaffirms that maize continues to be a significant contributor to the economic and social development of Ethiopia. As the crop with the largest smallholder coverage at 8 million holders (compared to 5.8 million for teff and 4.2 million for wheat), maize is critical to smallholder livelihoods in Ethiopia. In addition,maize is the staple crop with the greatest production at 4.2 million tons in 2015/16,compared to teff at 3.0 million tons and sorghum at 2.7 million tons. Moreover, maizeplays a central role in Ethiopia's food security. It is the lowest cost source of cereal calories, providing $1\frac{1}{2}$ times and two times the calories per dollar compared to wheat and teffrespectively. An effective maize sector could propel Ethiopia's food production to quickly reduce the national food deficit and keep pace with a growing population. However, the maize cobs are organic wastes and deplete environmental pollutions, there is no processing industries maize cob organic wastes in Ethiopia.

2.3 Potential of Maize in Ethiopia

Particleboard is a wood-based panel produced under pressure and sometimes temperature using wood particles or other lingo cellulosic materials and an adhesive. It is commonly used in the production of furniture. The high rate of demand for forest wood consumption is considered as a main reason for the high rate of deforestation as well as serious impact on the environment which has resulted to global warming. Starting 1980s the growing demand for wood-based particleboards have raised serious challenges on the issue regarding the sustained supply of raw materials to this sector for quite some time.

However, the need to reduce the dependence on wood and forest resources has resulted in a great interest for alternative resources substitute, wood raw material for agricultural residues and wastes for particleboard production. The alternative fibers such as agricultural residues and non-wood plant fibers could serve as the balance between supply and demand for the manufacturing of composite panels such as particleboard. The need to reduce the dependence on wood and forest resources has gained interest in the utilization of agricultural residues and wastes for particleboard production. Many researchers have conducted studies on a wide variety of agricultural wastes and residues from many different regions of the world. It enhances total wastes utilization, reduces cost of production, promotes a cleaner environment and enhances the earning of the farmers. It also prevents burning of agricultural residues and wastes and thus mitigates climate change. Different value-added products has been produced from agricultural residues (Davies & Davies,2017).

2.4 Chemical and physical composition of corn cob

Maize cobs which are now the area of interest in this research are part of the maize plant.The maize grain is arranged around the outside of blast cob. The cobs of the common varieties of maize generally are 17 - 20 cm long and 2 - 4 cm in diameter at the bottom. The cob tappers to about 2 cm near the opposite end (Mantell, 1975).

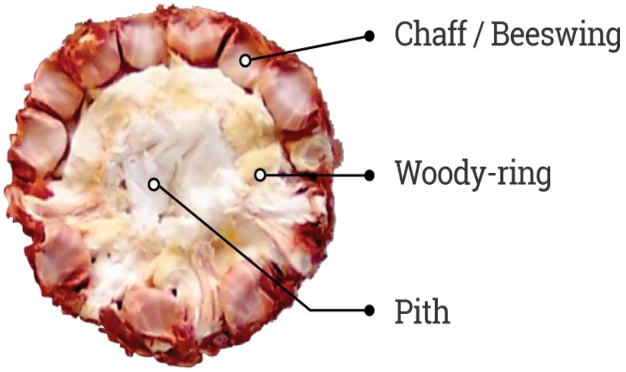


Figure 2.1 Cross section of maize cob

(I) The Cortical Layer: This is the outer layers of the cob on which corn grains are arranged, it consists of fine and coarse chaff. It is yellowish in colour and is good for making fibres.

(II) The Wood Blast: This is the main part of the cob. It is a hard tough woody layer surrounding a center of pith. It is good for board making, its proportion increases from top
to the bottom.

(III) The Pith: This is the central portion of the cob, it composed of soft tissues. It easily becomes powdered during grinding process.

Portion of maize cob	**Average %**
Cortical Layer	24.97
Wood Blast	73.36
Pith	1.67

Table 2..1 Physical composition of maize cob (Zubairu, 1989)

According to Watson and Ramstad (1987), CC are comprised of four elements which are the pith (1.9 %), the woody ring (60 %), the coarse chaff (33.7 %) and the light chaff (4.1%). Concerning the chemical composition of CC, data provided by different authors vary greatly. Compared to RH it is striking that the proportion of the basic components cellulose,hemi-cellulose and lignin is higher and thus nearer to the one of wood and that the ash content is significantly lower. Amounting 69 % to dry solids, the water absorption capacity of CC is very high which may be a good prospect for adhesive application with waterbased adhesives (Watson and Ramstad, 1987).

Softwood	**Average**
Cellulose	42-49%
Hemi-cellulose	24-30%
Lignin	25-30%
Ash	0.2-0.8%
Fat	0.3-0.4%

Table 2.2 Composition of softwood (Zubairu, 1989)

From composition of soft wood, cellulose and lignin is the most important property to prepare the particle boards.

2.5 Manufacturing Process

The process consists of the following steps:

Sort and store—wood residue is delivered to the mill normally by truck; the residue, also referred to in the industry as wood furnish, consists of shavings, sawdust, ply trim, fines, and chips of various moisture contents; the residue is sorted by geometry and moisture content and stored under cover; the moisture content of the residue can range from 10 to 100% on an oven-dry weight basis.

Screening—the wood residue is passed through a set of screens that sort them by size, with oversize particles going to refining; desired sized particles can be sorted for use in face and core layers, and undersized particles referred to as fines can either be put into the board which is the most common practice, or sometimes used as fuel for dryers.

Refining—wood residue is then refined, a process of mechanically reducing the residue geometry into

uniform sizes of desired dimensions; this process is usually accomplished with the use of refiners, hammermills and occasionally flakers and hogs. Particulate emissions are addressed by baghouses and cyclones.

Drying—the particles are sent through dryers, normally rotary dryers of either single pass or triple pass configuration, the particles enter the dryers at moisture contents of 10-100% oven-dry wood basis, and are dried to a targeted moisture content of about 3-5% depending on whether the particles will be used for face or core layers. The dryers are normally fired directly with natural gas, although some dryers also use sander dust from a later process step. As wood dries at elevated temperatures in the dryers, particulates and air emissions of volatile organic compounds (VOCs) are released. Emissions from dryers go to cyclones and control devices such as regenerative thermal oxidizers (RTOs), catalytic regenerative oxidizers (RCOs), and biofilters.

Blending—a process whereby resin, wax, catalyst, and scavengers are distributed onto the particles in the form of discrete droplets. The resin most used is urea-formaldehyde, however some products are made with either melamine-urea-formaldehyde or polymeric isocyanate resins for those products where moisture resistance is desired.

Forming—the blended particles are distribute into a flat mat in usually multiple layers of three or five consisting of face and core layers—the size of particles, their moisture and resin content are controlled for the face and core layers to obtain desire panel properties.

Hot pressing—the formed mats are conveyed into large presses, most are stack presses of multiple openings, presses operate at sufficient temperature (about 340°F) and duration to cure the resin, and sufficient pressure (about 750 psi) to consolidate the mat to a desired density of 37 to 50 lb/ft3 ; the physical properties of the panel are controlled during pressing. As a result of the elevated temperature and resin curing, particulates and air emissions of VOCs, HAPs, and other resin related emissions are generated. Emissions, if treated, go to control devices such as RTOs, RCOs, and biofilters.

Cooling—hot panels exiting the press are placed on a cooling wheel to enable the temperature of the panels to drop below a value where the UF resin will start to break down with time and emit formaldehyde gas. Limited amounts of air emissions occur at this point.

Sanding—panels are sanded on both major surfaces to targeted thickness and smoothness. Sander dust coming off this process can either be put back into residue prior to the mat at the forming process, or it is used as fuel for the dryers.

Sawing—relatively large panels are sawn to dimensions of panel widths of 4 or 5 ft and lengths of 8 or 9 ft or even longer lengths. Panel trim is hammermilled into particles and sent back with the sawdust into the process prior to the former.

2.6 Adhesives

Adhesive is a substance capable of holding materials together by surface attachment (Blowquist, 1999). An assembly formed with an adhesive consists of two objects, adherends, connected to each other by a layer of an adhesive material. Adhesion is the state held two surfaces together by some forces, which are interfacial forces, physical attraction, and chemical bonding (Vick, 1999). Mechanical interlocking may have the main effect on bonding porous structure together, resulting from the penetration of an adhesive into materials and then solidifying of the adhesive. The most efficient mechanical interlocking is when the adhesive penetrates the wood around two to six cells deep. An increase in the surface area for the molecular interaction between an adhesive and wood fibers is the most effective way of enhancing the mechanical interlocking forces (Gollob and Wellons, 1990). Van der Waals forces play important roles in wood bonding. The Van der Waals forces include dipole-dipole interactions and hydrogen bonding. Hemicelluloses and cellulose are rich in hydroxyl groups for forming hydrogen bonding. Hence, the hydrogen bonding could make a major contribution to the adhesive strength of wood (Pizzi, 1994). Currently, many people believe hydrogen bonding is the major adhesion force in wood composites. There may exist covalent bonds between the adhesive and wood substrates. However, there is no specific proof that covalent bonds play an important role in the strength of wood composites (Vick, 1999).

2.6.1 Types of wood adhesives

The wood adhesives can be basically categorized into natural adhesives and synthetic adhesives.

2.6.1.1 Natural adhesives

2.6.1.1.1 Plant-material-based adhesives

Soybeans have been used as diets for around 5000 years. They have not been developed as adhesives until 1920s, (Sellers, 1985). Soy-based wood adhesives had many excellent properties such as low press temperatures, the ability to bind wood with relatively high moisture content, ease of handling, and low cost. The soy-based adhesives were more durable than starch-based adhesives but were less moisture-resistant than casein-based adhesives. Therefore, soy-based adhesives were primarily used for making interior-graded plywood panels.

Another major plant-material-based adhesive is derived from starch. Starch is very abundant and inexpensive. Starch is a very strong adhesive for cellulose materials such as paper because starch has abundant hydroxyl groups that can easily form hydrogen bonds and the Van der Waals interactions with wood components. Starch-based adhesives are presently widely used for making many paper products such as paper bags, paperboards, tapes, corrugated boxes, textiles, labels, envelopes, and wallpapers. However, the starch-based adhesives cannot be used for making wood composite panels because of their poor water-resistance.

2.6.1.1.2 Animal adhesives

The earliest adhesives that people used were animal glues. They derived from the collagen of animal skins, bones and tissues (Sellers, 1985). Proteins or polypeptides are the major components of animal glues. The adhesive properties such as viscosity and adhesive strengths are strongly dependent on the interactions of functional groups of amino acids (Subramanian, 1983). The properties of animal glues also depend upon the source where they are derived.

Animal glues can be obtained from boiling animal skins or animal bones in water. The resulting sticky solution was widely used for binding the small woody parts. Animal glues are still used in some furniture, crafting products, and paper tapes. Nevertheless, the quick gelation of the animal glues prevents them from being used in production of plywood. The availability of these protein-based adhesives is highly dependent upon the meat processing industry and hard to meet the huge demands of the wood composite industry (Sellers, 1985).

Other widely used animal glues are derived from casein, a milk protein. Casein has a much higher content of carboxylic acid groups than proteins from collagen. For this reason, casein is easily dissolved in an alkaline solution. Commonly used casein-based adhesives are called as casein-lime glues because they are prepared from reactions of casein and calcium hydroxide solution. Divalent calcium crosslinks the carboxylic acid groups in the casein to form water-insoluble calcium caseinate. Other polyvalent metal ions are able to work as cross-linkers. The adhesives can provide relatively strong joints but are not very water-resistant. For instance, wood composites bonded with casein-lime glues might lose their integrity as the moisture content of the wood composites reaches 18% and remains at this level for some period of time (Subramanian, 1983). The casein-lime glues were mainly used for bonding joints in assemblies such as arches, doors, and beams before they were replaced by synthetic resins.

Protein-based adhesive can be derived from animal blood. The adhesive was prepared by spray-drying the soluble blood of domestic animals. This preparation process needed specialized equipment's which were available at no more than a dozen meatpacking facilities in the U.S. (Sellers, 1985). Proteins from animal blood contain a high amount of polar functional groups, but their structures are globular. For achieving the full adhesive strength, the proteins have to be unfolded by dispersing them in an alkaline solution because amino acids in blood proteins are tightly held together through intermolecular interactions. The blood adhesives were ever used for the production of plywood. Combinations of blood protein and soy protein appeared to be better than blood adhesives or soy adhesives in terms of improving the water-resistance of the resulting wood composites (Subramanian, 1983). However, blood adhesives have been completely replaced by synthetic resins because of the low strength, low water-resistance of the resulting wood composite panels.

2.6.1.2 Synthetic resins

There are two types of synthetic resins: thermoplastic resins and thermosetting resins. The differences between thermoplastic resins and thermosetting resins are their chemical structures and responses to heat.

2.6.1.2 .1 Thermoplastic resins

Thermoplastic resins are polymers that can soften or melt when heated and solidify when cooled down. The softening and solidifying behaviors are reversible; hence, thermoplastic polymers can be melted and solidified many times without degradation (Eckel man, 1997). When used as adhesives, they are called hot-melt adhesives. Mechanical interlocking is the key adhesion mechanism. In the use of hot-melt adhesives, organic solvent is not involved, and little volatile organic compounds are emitted. Environmental pollution is thus not a concern for hot-melt adhesives. The biggest drawback of hot-melt adhesives is their thermoplastic property. Wood composite panels bonded with hot-melt adhesives cannot be used in hot environment. Hot-melt adhesives used in wood composite panels can be derived from polyamides, poly(ethylene-vinyl acetate), polyvinyl acetate, and polyacrylate.

The polyamide-based hot-melt adhesives are used in furniture manufacturing, and the poly(ethylene-vinyl acetate)-based adhesives are extensively used in book-binding, carpet, and shoe making. Poly(ethylene-vinyl acetate) is a random copolymer, its adhesive properties depend upon the ratio of ethylene and vinyl acetate.

Poly(vinyl acetate) (PVA) or “White glue” is another widely used wood adhesive. PVA is typically prepared from emulsion polymerization of vinyl acetate. PVA provides durable and invisible glue lines, and can provide strong bonding for cellulosic materials, especially wood. PVA is commonly used in furniture assembly, paper gluing, and wood working. Nonetheless, poor gap-filling, water-, and heat-resistant properties limit the application of PVA.

Polyacrylate-based adhesives, simply called acrylic adhesives are also used for bonding wood. Acrylic adhesives can be used by *in situ* polymerization of acrylate monomers. For example, acrylic adhesives are used to tightly fasten wooden nuts and bolts. Air has to be excluded for this application because oxygen in air inhibits the polymerization. The best-known example of this acrylic adhesive is Super Glue. Super Glue consists of highly reactive α-cyanoacrylate that rapidly polymerize by moisture or water adsorbed on adherend surfaces (Subramanian, 1983).

2.6.1.2.2 Thermosetting resins

Thermosetting resins cross-link while heating and cannot go back to their original chemical structures while cooling. Phenol-formaldehyde (PF) resins and urea-formaldehyde (UF) resins are the major thermosetting resins used in the production of wood composites.

PF resins are prepared from polymerization of phenol and formaldehyde. The adhesive properties of the PF resins highly depend upon the molar ratio of phenol to formaldehyde as well as a catalyst used in the reaction. Alkali-catalyzed PF resins are called resole, and acid-catalyzed PF resins are called novolak. Resole can be directly used for bonding wood, whereas an additional amount of formaldehyde has to be added to novolak before being used for bonding wood. The PF resins are extensively used for the production of exterior structural wood composites such as laminated veneer lumber (LVL) and softwood plywood because the resulting wood composites are strong, durable and water-resistant even under severe weather conditions. The PF resins in making wood composites are typically cured at 130°C-150°C for a few minutes. The PF resins have brownish to dark color after cured, which makes wood composite panels bonded with the PF resins not being aesthetic for interior application

UF resins are most commonly used adhesives for making wood composition panels. The UF resins are prepared from polymerization of urea and formaldehyde. The molar ratio of formaldehyde to urea is typically around 1.5 to 2. Structures (Linear vs. branched) and molecular weights of the UF resins are highly dependent upon the formaldehyde/urea ratio and reaction conditions. The UF resins are cured under slightly acidic conditions. The commonly used catalysts for curing the UF resins include ammonium chloride, ammonium sulfate, and some organic acids such as tartaric acids and citric acids (Subramanian, 1983). The UF resins are water-soluble, light in color, inexpensive, non-flammable, and easy to cure. Approximately 85% of the UF resins is used in the production of wood composites. Interior grade plywood, medium density particleboard (MDF), and particleboard are almost exclusively made with the UF resins. Other thermosetting adhesives such as polyurethanes, epoxy resins, and isocyanates are also used in the wood composite manufacturing.

2.7 Factors Affecting the Properties of Particleboard

There are many factors affecting the characteristics of the particleboards and the most prominent among them are species of wood, fiber structure, density, hardness, compressibility, type and size of particles and technique of particle drying. 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. Based on the findings of different researchers.

2.7.1 Physical and Mechanical Properties of Particleboards

2.7.1.1 Physical Property of the board

During characterization of the board produced from Maize cob it can be evaluated its physical properties compering to the standards. Some physical properties can be determined in accordance with appropriate standards like moisture content (MC), density, water absorption (WA), thickness swelling (TS), for 2 hour and 24 hour immersion. This investigation is important for checking that the Maize Cob will substitute the raw material for the wood based forests used as input for particle board.

i. Density of particle board

The two most important factors controlling the average final density of a particleboard are the raw material density and the compaction of the mat in the hot press. Any change in one of these factors requires an adjustment of the other if the average board density is to remain constant. Likewise, either of these factors can be changed to increase or decrease the average particleboard density. However, a higher density panel produced by increasing the compaction level will not have properties equal to the same-density panel produced with higher density wood furnish. This is only one example of the interdependence of processing parameters on the properties of the resultant particleboard. Isolation of the effect of individual processing parameters on particleboard properties is extremely difficult and can, at best, be only approximated.The pressing operation consolidates the particle mat to the desired thickness and polymerizes the binder system between individual particles. The first function eliminates many of the voids in the mat and compresses the wood structures; the latter function ensures retention of the consolidated mat upon release of the pressure. The amount and condition of the material in the mat, together with the pressing techniques, determine the average resultant board density. Thickness control of most particleboard production is attained by using “stops”: Incompressible material of the appropriate thickness is placed on two sides of each press opening and the platens are closed against these stops, resulting in a gap between the two platens equal to the desired particleboard thicknes.

The maximum pressure employed for particleboard in a press equipped with stops controls the rate of press closing, assuming the pressure exceeds the minimum required to compact the mat to the desired thickness. The rate of press closing on a given weight of wood furnish does not affect the average final particleboard density. That density is independent of the pressing operation when the press temperature and pressing time are sufficient to polymerize the adhesive system and allow evaporation of the excess water. The average particleboard density is dependent upon the quantity and density of the wood furnish used to make a particleboard of a given thickness, but the maximum pressure--and hence the rate of closing to stops--has an extremely critical effect on the vertical density gradient, as shown in the next section. The final average density of particleboard is dependent not only upon the amount of woody material in the mat but also upon processing conditions prior to the pressing operation--specifically, furnish species, preparation and drying, adhesive content, and other additives

ii. Resin content

There appear to be no consistent data available which indicate a particular adhesive level is optimum. Much of this inconsistency is due to the lack of uniformity in stating the adhesive content levels. Adhesive contents based on the ovendry wood weight are extremely dependent upon particle configuration; however, the experimental difficulties inherent in determining the particle surface area per unit wood weight limits the usefulness of calculating spreads per unit of particle surface area. Consequently, each particle configuration will have an optimum adhesive content dependent upon the desired panel products and the economics of production. Multi-layer particleboard with different adhesive levels in the core and surface layers is one widely-used technique to obtain satisfactory board properties with the most economic use of adhesive

iii. Moisture And Dimensional Properties

Particleboard is hygroscopic and dimensionally unstable when exposed to water vapor or liquid water. Because the material possesses hygroscopic properties similiar to solid wood, it will adsorb moisture from high humidity atmosphere and increase in volume; however, subsequent drying does not result in a return to the original volume. Excessive dimensional changes in the material after installation can be disastrous; proper installation and efforts to eliminate large moisture fluctuations are mandatory for satisfactory utilization of particleboard.

Solid wood shrinks and swells when subjected to environmental conditions causing desorption or adsorption of water. Particleboard also shrinks and swells under the same conditions, but the magnitude of this dimensional change is much greater in the thickness direction of conventionally flat-pressed particleboard than would be expected from the normal shrinking and swelling of wood material. The linear dimensional changes in particleboard are normally slightly greater than the longitudinal changes found in solid wood.

2.7.1.2 Mechanical Property

The other investigation of the products is the mechanical properties such as modules of elasticity (ME), internal bond strength (IB), dry modulus of rupture or screw holding strength (SH) are the main properties that can be analyzed (L et al., 2011). During the particle board productions all to measures of the mechanical properties can be analyzed according to standards of the particle boards. In general the physical and mechanical properties of the boards are very important for the recommendations of the study in order to differentiate the application of the material and to conclude weather the stalk serve as alternative material or not.

i. Strength Properties

The various processing parameters have various effects on the resultant panel strength properties. A number of difficulties are encountered when reviewing the literature for this information. Foremost of these difficulties are the reports which do not furnish sufficient information as to experimental procedures and conditions. Many instances were found in which important processing parameters, such as mat moisture content and distribution, rate of press closing, and particle configuration, were not given. As pointed out in the vertical density gradient section, the above variables are extremely important in controlling this gradient, and bending and internal bond properties are strongly influenced by this gradient.

ii. Hardness

Hardness of Particleboard is the ability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation is measured. The most commonly used hardness tests are defined by the shape or type of indent, the size, and the amount of load applied. The hardness numbers referenced constitute a nondimensioned, arbitrary scale, with increasing numbers representing harder surfaces. Hardness and micro hardness are some of the most important parameters describing the tribological characteristics of a material. Friction and wear tests involve almost all known materials ranging from the hardest diamond to extremely soft materials such as human cartilage. If the hardness of the test specimens diverges from either practical values or an intended level for study, then misleading results will most probably be obtained.

iii. Flexural strength (Static bending)

The bending properties of the particleboards were strongly dependent on the density, and two regions of MOR and MOE are shown in Figs 7. Increased density resulted in significant improvement of the bending properties. The higher density of the particleboards generates a higher number of contact points (inter-bonding between fibers), which consequently improve the bending strength.

2.8 History of Agricultural Residue Particle Board

Particleboard is a wood-based panel produced under pressure and sometimes temperature using wood particles or other lingo cellulosic materials and an adhesive. It is commonly used in the production of furniture. The high rate of demand for forest wood consumption is considered as a main reason for the high rate of deforestation as well as serious impact on the environment which has resulted to global warming. Starting 1980s the growing demand for wood-based particleboards have raised serious challenges on the issue regarding the sustained supply of raw materials to these sectors for quite some time. However, the need to reduce the dependence on wood and forest resources has resulted in a great interest for alternative resources substitute, wood raw material for agricultural residues and wastes for particleboard production. The alternative fibers such as agricultural residues and non-wood plant fibers could serve as the balance between supply and demand for the manufacturing of composite panels such as particleboard. The need to reduce the dependence on wood and forest resources has gained interest in the utilization of agricultural residues and wastes for particleboard production. Many researchers have conducted studies on a wide variety of agricultural wastes and residues from many different regions of the world. It enhances total wastes utilization, reduces cost of production, promotes a cleaner environment and enhances the earning of the farmers. It also prevents burning of agricultural residues and wastes and thus mitigates climate change

2.9 Uses of Particle Board

Common Uses of Particleboards are domestic and industrial users the consistent quality and design flexibility to improve the quality of consumer products. Particleboard panels are produced in different dimensions. particleboards have been found to useful in office and residential furniture, soundproof, home decking, ceiling, roofing, shuttering, cabinets, partitioning, prefabricated houses, cladding stair treads, underlying floor, table, shelving, store fixtures, counter and desktops, office dividers, wall bracing, boarding, sliding doors, kitchen worktops, interior signs, exam pad, photo lamination, low cost cabins peaked box, bulletin boards, packing boxes, thermal insulation and other industrial products. The particle boards from cotton stalks possess all the desirable properties sought for internal as well as external applications. However, it may be mentioned that boards made from cotton stalks using urea formaldehyde as binder lack in water resistance properties as compared to boards made from other raw materials, which is mainly, due to higher percentage of bark having more fibers resulting in increased absorption of water. These boards can also be made fire resistant, termite resistant, etc. by use of chemical additives (M.R Gurjara et.al., 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials and Chemicals

The materials used were Maize cob, urea formaldehyde bought from Addis Ababa, Metallic Mold, Metallic plate, Aluminum foil, distilled water,was bought from Addis Ababa market equipment shops.

3.2 Material Collection and Preparations

The raw material Maize Cob was collected from Addis Ababa. After collection of the cob cleaned and chopped using knife to the appropriate size of 5 cm to 10 cm as shown in Figure 3.2 to dry to the required moisture content of 12-15% (Chen et al., 2007).

3.3 Equipment used

The equipment's that are used for preparation of testing samples were indicated below

- Material handling (plastic bag)
- Grinder machine (attrition mill)
- Measuring cylinder (plastics)
- Plastic stirrer
- Spoon or wood stirrer
- Metal mould
- Temperature reader
- Resin impregnation unit (mixer)
- Heating mantle (stove)
- Manually hydraulic press
- Knife
- Fiber flask
- Metal plates

3.4 Reasons for selecting urea formaldehyde

There are many reasons that make urea formaldehyde resin and melamine formaldehyde resin superior to other glues

- Low cost
- Easy to use in many different curing conditions
- Low energy consumption during the production with low curing temperature
- Being soluble in water
- Resistance against microorganisms and abrasion
- Hardness
- Excellent thermal features
- Being colourless

3.5 Procedures of Preparation

A, Sun Drying

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

Fig 3.1 Sun dried Maize Cob

B) Crushing

Dry cobs are brittle, and it was supposed that for their size reduction, crushing would be more convenient. In order to make suitable for milling machine the cob should be crushed to the desired size of 15-20 mm. The crushing of the pre-crushed mass can be carried out using knife or hammer mills.

Fig 3.2 Crushed Maize cob

C) Milling

Shredders vary in many ways according to the functions they perform. Shredding also employs grinder, chipper, granulator, hammer mills, shear shredder, speciality shredder and all-purpose shredders for size reduction, pulverization of materials to produce granulated products or powdered products of corn cob. The shredding process makes the handling of waste ease for the particle board making.

Fig 3.3 Milling Machine

Fig 3. 4 Milled Mazie Cob

D) Blending with a resin and additives

The blending process can be done by Considering the ratio of (25%, 30% & 35 %) resin content. By using the indicated ratio, the milled maize cob and urea-formaldehyde (UF) can be blended.

Cob powder- urea-formaldehyde exhibit better chemical and mechanical properties when compared to conventional wood. These particle boards would come out with better dimensional stability and fungal resistance when exposed to moist whether and they exhibit thermal linear expansion at adverse environmental condition.

Mixing procedure

Following is the procedure for mixing the constituents of cob powder with epoxy.

1. The volume of the square mold is calculated, and the corresponding proportions of cob powder, epoxy and hardener are measured according to the composition.
2. The weighed mixture of cob powder, resin is poured into a clean moisture free bowl and mixed well uniformly.
3. The hardener, corresponding to the amount of resin used is then poured and mixed well and left for few minutes.
4. The molten wax is applied to the inner walls of the mould for easy removal of casting.
5. The mixture is then poured into the mold and the surface is flattened with the flattener.
6. The flat plate is removed after 2 days by removing the side plates of the mold.

Fig 3.5 Mixing Maize Cob and urea formaldehyde

E) Forming (Molding)

Laying up the “furnish” prior to pre-pressing and hot pressing (consolidation). It is Important process in the formation of the structure of the board and therefore strongly affects the board properties by giving improved bending properties, good surface finish & Optimized density.

Molds are made to size of specimen concerned to the various tests conducted. Here, metal mold size 15cmx5cmx1cm (LxWxH is used for preparing the particle board (Figure 3.6).

Fig 3.6 Mold for the sample preparation

F) Pre-pressing & hot pressing

Pre-pressing undertaken to Reduce the thickness of the mattress (i.e. increase the bulk density of the mattress .To Give the mattress some mechanical strength for handling & to Speed up the hot press process.

Hot pressing is main mechanism for consolidation of the mattress, the development of the board internal structure (in combination with forming etc. and curing the adhesive binding the particles together Part of the consolidation process.
In order to prepare experimental design, the hot pressing should be done on 100°C,150°C& 180°C

Fig 3.7 Mechanical Hydraulic Press

Fig 3.8 Stove for heating the specimen to the desired temperature

G) Cooled and finished

Cooling and ventilating the Fiber board is the final step for preparing samples for testing.

Fig 3.9 Experimental samples

3.6 Experimental Design

The Taguchi method has been described as an efficient design of experiment (DOE) technique for a systematic approach and for optimizing parameters with a minimum number of experiments. Some of these losses are caused by the variation of the product's actual functional characteristics and these uncontrollable characteristics are called noise factors. The response values are transformed into a signal to noise ratio to measure the quality characteristics deviating from desired value; a larger S/N ratio has higher quality characteristics. The optimum process parameter is determined on the S/N Raito, given in Eq having a greater value, and in the available there types, larger ratios are preferred.

$$S/N= - \log \frac{1}{n} \sum \frac{1}{y^2} \quad \ldots\ldots 3.1$$

3.7. Orthogonal Array Selection

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factors effects on output. The following standard orthogonal arrays are commonly used to design experiments:

2-Level Arrays: L4, L8, L12, L16, L32

3-Level Arrays: L9, L18, L27

4-Level Arrays: L16, L32

Before selecting an orthogonal array, the minimum number of experiments to be conducted is to be fixed based on the formula below

$$N_{taguchi} = 1 + NV (L-1) \text{..........} 3.2$$

$N_{Taguchi}$ = Number of experiments to be conducted

NV = Number of parameters

L = Number of levels

In the present study, pressing pressure, Pressing temperature and Percentage of resin, of are selected as the process parameters, which affect the mechanical properties, namely, Hardness & flexural rigidity of maize cob particles reinforced polymer composite materials. There are three numbers of parameters. Each parameter was examined at three levels to study the non-linearity effect of the process parameters. Considering the equation- (3) the minimum no. of experiments is 9 and 3-Level arrays L9 is the minimum one. Hence, minimum 9 experiments were required. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. In the present study, the selected process parameters and their levels are given in Table 1 and the three parameters at three levels each, *L9* (3_4) orthogonal array (OA) was used and accordingly nine Maize cob particle board specimens were prepared as per the experimental layout plan (Table 2).

Parameters	**Levels**		
	1	**2**	**3**
Pressing temperature (°C)	120	140	160
Presure (Mpa)	3	5	7
Resin(%)	25	30	35

Table 3.1. Process parameters and their levels

Pressing Temperature	**Presure (Mpa)**	**Resin(%)**
120	3	25
120	5	30
120	7	35
140	3	30
140	5	35
140	7	25
160	3	35
160	5	25
160	7	30

Table 3.2 Experimental layout plan

3.7 Flexural strength (Static bending)

For flexural test, a universal testing machine (ISO 14125) was used (Figure 3.10). The distance between the specimen supports was 14 cm and the loading force was applied to the specimens at a crosshead speed of 5 mm/min until the specimens fractured. The diameter of loading and supporting plunger was 20 mm. The maximum load exerted on the specimens was recorded, and the flexural strength was calculated according to the following formula

$$F=\frac{3WL}{2bd^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

F: flexural strength.

W: load at fracture.

L: distance between supporting points (40 mm)

b: width of specimens (mm)

d: specimen thickness (mm)

Flexural strength was calculated in MPa.

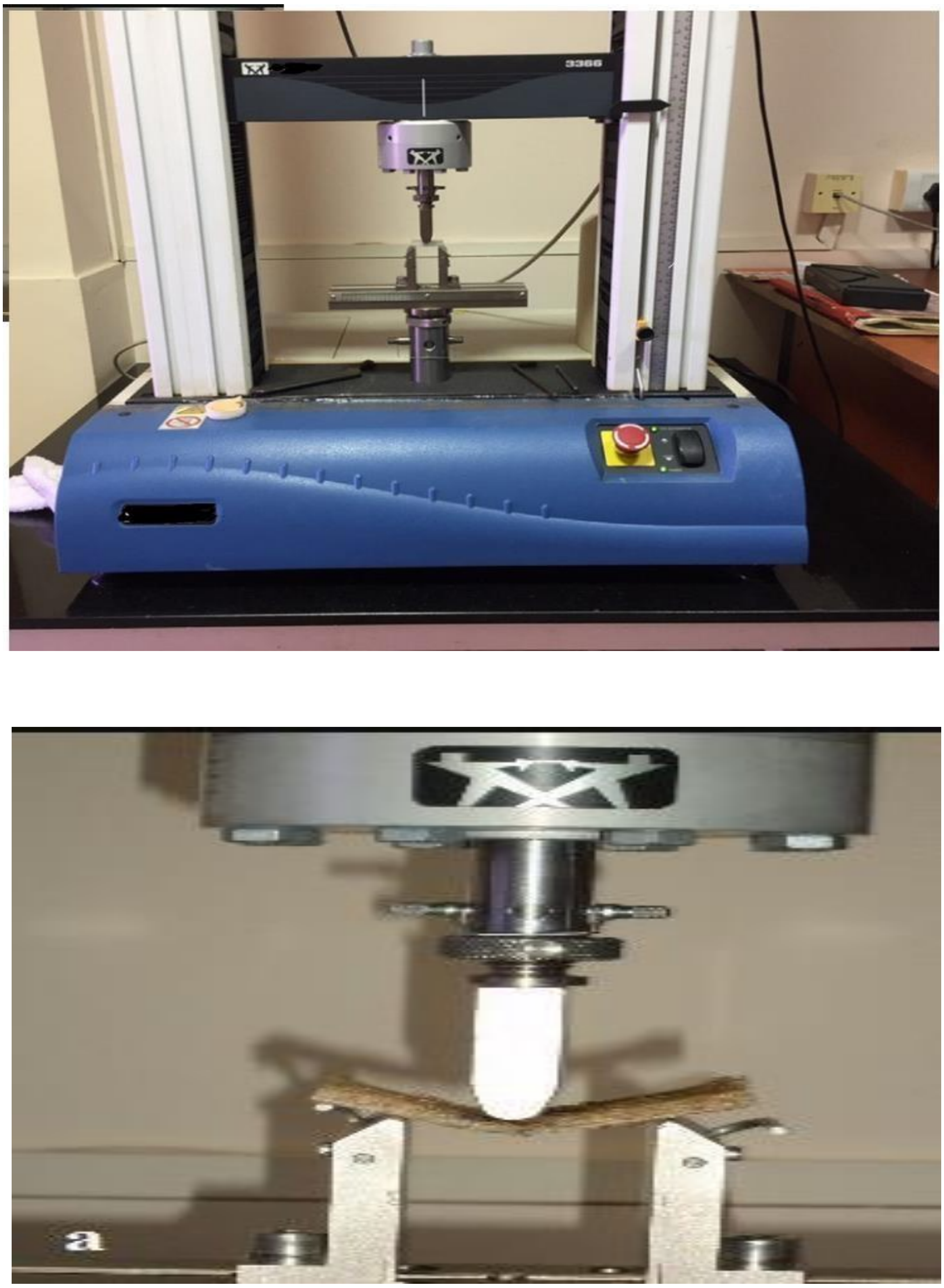

[redacted]
[redacted]

Figure 3.10 Universal testing machine for testing of flexural strength

3.8 Hardness test

The mechanical property in terms of hardness is determined by employing ASTM D2583 standard for determining the Barcol hardness of a Maize Fiber board . Nine specimens with 15cmx5cmx1cm (LxWxH) dimension. The specimens are dry conditioned at room temperature for 48h before testing as per the requirement of ASTM 2583 standard. The hardness test is then conducted in the laboratory at ambient atmospheric conditions. The indentation is done only on the smooth surface. On each specimen, Nine readings are recorded. The specimens prepared and tested for hardness is shown in Fig 3.1.

Fig. 3.11 Hardness testing machine

CHAPTER FOUR

RESULT AND DISCUSSION

4 .1 Taguchi Experimental Calculation

Table 4.1 summarizes the experimental results of hardness & flexural strength of Maize cob particles. It is observed that the materials have hardness and flexural strength in the range 72 to 90 shore and 2 to 5.5 MPa respectively. The specimens with a pressing time of 160 min, pressing pressure of 5MPa and 25% of resin content has the highest Hardness. In the meantime, the specimens with pressing time of 160 min, pressing pressure of 7MPa and 30% of resin content has the highest flexural strength.

Trial No.	FLEXURAL(MPa)	Hardness(Shore)
1	3.5	72
2	5	78
3	4	82
4	2	70
5	3.9	75
6	3	83
7	3.8	73
8	4.5	90
9	5.5	86

Table 4.1. Experimental values of mechanical properties

4.2 CALCULATION OF S/N RATIO FOR THE RESPONSES

The signal-to-noise (S/N) ratio) is an effective representation to find significant parameters by evaluating minimum variance. A higher S/N means the better performance. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the higher-the-better, and the-nominal-the-better. The S/N ratio characteristics given by

Nominal is the best characteristic

$$\frac{S}{N} = 10\log \frac{\bar{Y}}{SY^2} \text{ ………………………………………………….………4.1}$$

Smaller the better characteristics

$$\frac{S}{N} = 10 \log \frac{1}{n} (\sum y^2) \text{ ……………………………………………… 4.2}$$

and larger the better characteristic

$$\frac{S}{N} = - \log \frac{1}{n} (\sum \frac{1}{y^2})\text{……………………………………...………4.3}$$

where $\bar{y}$ is the average of observed data, **Sy²** the variation, n the number of observations, and **y** the observed data. The responses considered in the experiment are surface roughness and cutting force, which are having smaller-the-better characteristics. The S/N ratio of the responses considered are calculated and presented in Table 4.2

Trial N0.	S/N raito (dB) for mechanical properties	
	Flexural Strength	Hardness
1	6.319406909	37.2664572
2	6.729194677	37.7298145
3	6.848453616	37.5012253
4	6.020599913	37.1466499
5	6.729194677	37.6162718
6	6.485649106	37.8418921
7	6.648769198	37.3846344
8	6.402925722	38.0617997
9	6.567592069	37.9525418

Table 4.2 Computed values of S/N ratios for mechanical properties.

4.3 Grey Relational Analysis

The GRA can be defined as a multistep procedure to optimize uncertain systems and fragmentary problems. It is typically utilized for determining the process parameters and measuring the correlation between multi responses. The concept of grey theory was first proposed by Prof. Deng from the grey set in combination with systems theory, theory of space, and control theory.

The remarkable characteristics about grey theory are its capability to overcome the inconclusiveness and confusion of human decisions through mathematical protocol or language. The GRA exhibits numerous benefits, including satisfactory results with lesser data and computational simplicity. It is especially useful when the experiments cannot be performed precisely, and it aids to compensate the limitations in statistical regression.

4.4 Normalization Of The Experimental Results (Data Preprocessing)

Depending on the characteristics of a data sequence, there are various methodologies of data preprocessing available for the grey relational analysis. For target value of the original sequence is infinite, then it has a Multi-criteria Optimization characteristic of the 'higher is better'. The original sequence can be normalized as follows:

$$X^*(K)=\frac{X°i(K)-minX°i(K)}{maxX°i(K)-minX°i(K)}\text{.................................}4.4$$

S/N		DATA NORMALIZTION	
SNRA1	**SNRA 2**	**FLEXURAL**	**Hardness**
10.881	37.147	0.553	0.112
13.979	37.842	0.906	0.431
12.041	38.276	0.685	0.630
6.021	36.902	0.000	0.000
11.821	37.501	0.660	0.275
9.542	38.382	0.401	0.678
11.596	37.266	0.634	0.167
13.064	39.085	0.802	1.000
14.807	38.690	1.000	0.819

Table 4.3 Data normalization

4.5 Calculatation Of The Deviation Sequence

In grey relational analysis, the measure of the relevancy between two systems or the sequences is defined as the grey relational grade (GRG). The definition of the GRG in the grey relational analysis is to show the relational degree between the sequences of $x_o(k)$ and $x_i(k)$, (i =1, 2, . . . , m; k=1, 2, . . . , n), where m is the total number of experiment to be considered, and n the total number of observation data. The grey relational coefficient ξ (k) can be calculated as follows:

$$\xi\ (k)=\frac{\underline{\Delta}min+\xi\underline{\Delta}max}{\underline{\Delta}oi(K)+\xi\underline{\Delta}max}\text{...}4.5$$

where ΔOi denotes the absolute value of the difference between $x_0(k)$ and $x_i(k)$ and is also known as the deviation sequence, and ξ the distinguishing coefficient. A value of the ξ is the smaller and the distinguished ability is the larger ξ =0.5 is generally used.

$$\Delta o(k)= ||X^*_0(k)-X^0_i(k)||$$

S/N		Devation sequence	
SNRA1	**SNRA 2**	**FLEXURAL**	**Hardness**
10.881	37.147	0.446801815	0.887906
13.979	37.842	0.094217175	0.56941
12.041	38.276	0.314801744	0.370414
6.021	36.902	1	1
11.821	37.501	0.33982921	0.725472
9.542	38.382	0.599184715	0.322182
11.596	37.266	0.365506813	0.833021
13.064	39.085	0.198369429	0
14.807	38.690	0	0.180898

Table 4.4 Deviation Sequence

4.6 Calculation Of The Grey Relational Coefficient

After the grey relational coefficient is derived, it is usual to take the average value of the grey relational coefficient as the GRG. The GRG is defined as follows

$$\xi(X_0^*(k),Xi^*(k))=\frac{\Delta min+\xi\Delta max}{\Delta 0i(K)+\xi\Delta max}\text{………………………………………} 4.7$$

4.7 Grey relational grade (GRG)

The overall evaluation of the multi objective problem depends upon Grey relational grade (GRG). Mean value of the grey relational coefficient for each response was calculated for determining the GRG. The GRG with highest rank determines the optimum combination of the experiments.

$$\gamma(x^{*}_{0}, X^{*}_{1}) = \frac{1}{n}\sum_{i=1}^{n} x_o^{*}(k)\, x_i^{*}(k) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

GRC		GRG
FLEXURAL	**Hardness**	
0.528094	0.360255	0.444174
0.841443	0.467548	0.654495
0.613646	0.574439	0.594043
0.333333	0.333333	0.333333
0.595359	0.408006	0.501683
0.454883	0.608138	0.53151
0.577696	0.375088	0.476392
0.715953	1	0.857977
1	0.734324	0.867162

Table 4.5 Gray rational Grade

4.8 Determination of the optimal level of each parameter

The main effect analysis of GRG is adopted to figure out the response table for grey relational analysis, as indicated in Table 4.11 shows the average of each response characteristic for each level of each factor. The delta static is shown that the highest minus the lowest average of each factor. Minitab assigns the ranks of optimum parameters based on delta values, for instance, rank 1 is the highest delta value, rank two is the second delta value and so on. These ranks indicate that the relative importance of each factor to the response and the mean response refers to the average value of the performance characteristic for each parameter at different levels.

Level	Pressing temperature	Pressing pressure	Resin amount
1	0.5642	0.4180	0.6112
2	0.4555	0.6714	0.6183
3	0.7338	0.6642	0.5240
Delta	0.2783	0.2534	0.0943
Rank	**1**	**2**	**3**

Table 4.6 Mean table for GRG

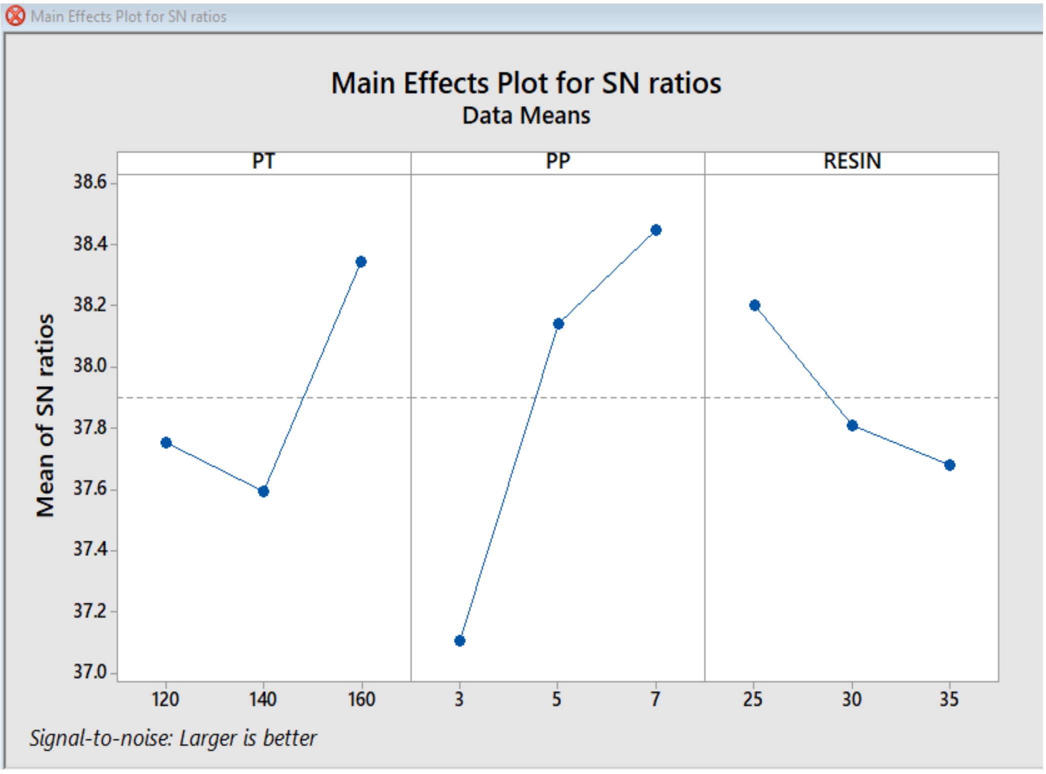


Fig 4.1 Main effects plot for SN ratios

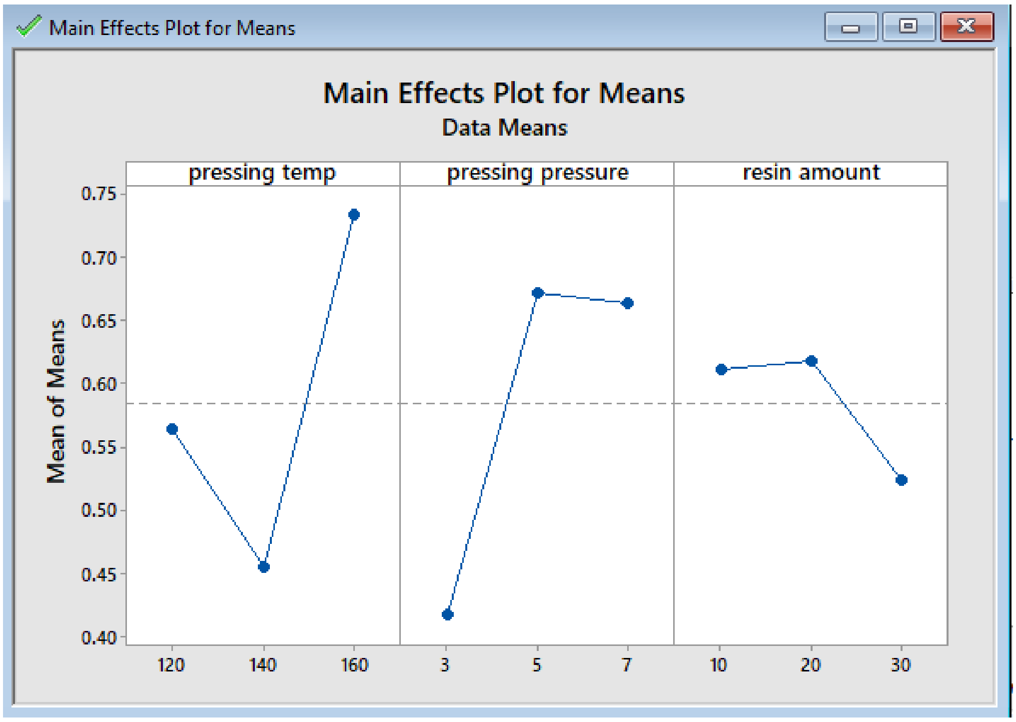


Fig 4.2 Main effects plot for Means

4.9 Performing Analysis of Variance

The Analysis of Variance (ANOVA) was done to indicate significant parameters. The ANOVA results used in finding out the effect of the factors on the grey relational grade. If the P-value for a factor becomes less than 0.05 at a 95% confidence level and if the ANOVA table F-value is greater than the F-value reading from a standard table, then the factor or parameter is considered as a significant factor (Gupta and Kumar, 2013, Mohamed et al., 2014). Statistical software with an analytical tool of ANOVA is used to determine which parameter significantly affects the performance characteristics. The results of ANOVA for the grey relational grades are listed in Table 4.7.

SOURCE	DF	ADJ SS	ADJ MS	F-value	P-Value	%	Remark
PRESSING Temp	2	0.118058	0.059029	11.33647	0.035	44%	Significant
PRESSING PRESURE	2	0.124922	0.062461	11.99558	0.033	51%	Significant
RESIN	2	0.016542	0.008271		0.206		Insignificant
ERROR	2	0.004286	0.002143			5%	
Error Pooled	4	0.020828	0.005207				
TOTAL	8	0.263808					
F 0.05(2,4)=6.94							

Table 4.7 Analysis of variance

4.10 Confirmation Experiment

The confirmation test was conducted on Five samples at optimal setting conditions of FSW parameters: Pressing temperature 160°c, Pressing Pressure 5 Bar, and Resin amount 20 %. A 95% confidence interval for the predicted mean of grey relational grade (μGRG) on a confirmation test was calculated using the following equations (Kumar, 2013, Kuo et al., 2007):

$$\mu_{A1B2} = \acute{\Gamma}_{GRG} + (A_1 - \acute{\Gamma}_{GRG}) + (B_2 - \acute{\Gamma}_{GRG}) = A_1 + B_2 - \acute{\Gamma}_{GRG} \text{ ....} 4.9$$

Where $\acute{\Gamma}$GRG is the overall mean of grey relational grade = 0.58453, $\acute{\Gamma}$GRG is equal to the overall mean of grey relational grade = 0.6442. A1 and B2 are the mean values of grey relational grade with parameters at optimum levels.

$$\mathbf{\mu = 0.7338 + 0.6714 - ((2\text{-}1)\ (0.58453)) = 0.82067} \text{ ....} 4.10$$

The predicted mean of the grey relational grade in the confirmation test is estimated by the following equation: confidence interval for the predicted mean on a confirmation run is calculated using the below equation (Kumar, 2013).

$$CI = \mu \pm \sqrt{F\square; (1; fe) * Ve(\frac{1}{neff} + \frac{1}{r}} \quad \text{……….…………………………4.11}$$

Where Fa; (1, fe) = F0.05; (1, 9) = 10.56 (F-Table in the Appendices 8)

Where *Fa*; (1, *fe*) = F0.05; (1, 4) = 7.71 (F-Table)

α = Risk = 0.05

fe = Error DOF = 4 (F-Table)

Ve = Error adjusted mean square (Table 4.12) = 0.005207

neff = Effective number of replications

R = Number of replications for confirmation experiment = 9

$$n_{eef} = \frac{Tn}{1+Ts} = \frac{9}{1+4} = 1.8 \quad \text{…………………………………………4.12}$$

$$R = \frac{1}{r} = \frac{1}{5} = 0.2 \text{ ………………………………………………4.13}$$

$$0.82067 \pm \sqrt{7.71 * 0.005207(\frac{1}{1.8} + \frac{1}{5})} \quad = 0.1829 \text{ ……………………………4.14}$$

$$(\mu - CI) < \mu < (\mu + CI) \text{ ………………………………………………4.15}$$

= (0.82067-0.1829) < 0.82067< (0.82067+0.1829)

- Mean of GRG for confirmation test =0.891
  Is in B/N

  0.6777<0.82067<1.00957

	Flexural Strength	**S/N ratio**	**Hardness (shore)**	**S/N Ratio**
Replication 1	5.5	14.607	86	38.87
Replication 2	5.4	14.51	86	38.87
Replication 3	5.5	14.607	85.9	38.53
Replication 4	5.48	14.602	86.2	38.90
Replication 5	5.467	14.59	85.7	38.50
Average	**5.467**	14.59	**85.97**	38.82
Mean of GRG for confirmation test = 0.891				

Table 4.8 Result of confirmation test

At 95 % of the confidence interval of the predicted GRG at optimum condition is between 0.6777and 1.00957. If the predicted and observed GRG values of the multiple performance parameters are close to each other, the effectiveness of the optimal condition can be ensured. In order to the test, the predicted results confirmation experiments were conducted five times at the optimum condition. The grey relational grade for the experiment is 0.891, which is in the range of the 95 % confidence interval and achieved hardness and flexural strength of 8.597 MPa and 5.467 HR respectively. Hence, the results of the confirmatory experiment tests show that the experiment is safest

	Optimal parameters	
	Prediction	**Experiment**
Setting levels	**Optimum**	**Optimum**
flexural strength		5.467 MPa
Hardness		8.597 HR
Grey relational grade	1.00957	**0.891**

Table 4.8.1 : Results of the confirmation tests

5. CONCLUSION AND RECOMMENDATIONS

Conclusion

The aim of this study was to find out the optimized combination of pressing time, pressing temperature and resin content. So that the hardness and flexural strength can be maximized. The conclusion can be summarized as follows

1. The optimal hardness & flexural strength can be attained at pressing temperature of 160 7 Mpa Pressing pressure & 30% of resin content.
2. Analysis of variance shows that the pressing pressure is the most significant parameter followed by pressing temperature, affecting selected response characteristics.

   i.e Pressing pressure and pressing temperature 51% and 44% influence respectively

Recommendations

In this research preparation of particle board was done starting from selection of resin type, testing of hardness and flexural strength but further investigation is recommended to understand its behavior and to explore commercial application.

1) Water absorption and thickness swelling, which are two of the key qualities compared to commercial usage, has their limits much lower than the standard range and comparable to boards made from other proved materials by adding wax reducing, the particle geometry to reduce the spring back effect not to destroy the adhesive line bonded well, And reduce the thickens swelling and water absorption also recommendable.
2) There is the possibility of combining wood with other lignocellulosic materials aiming at obtaining preferable products and with environmental marketing strategies, without reducing its quality. The fabrication procedure of this type of particleboard was standardized with those bonded with conventional resin to equivalently compare the physical, mechanical, and morphological properties of the boards.

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ቀን/Date: 28/12/2012

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ለኢትዮጲያ ትንሙድ እና ፈርኒቸር ሸር ካምፓኒ
አዲስ አበባ

ጉዳዩ:- ትብብር ስለመጠየቅ

ተማሪ ዮሴፍ ብርሃኑ በቀን 25/12/2012 በተፃፈ ማመልከቻ ተማሪያችን መሆኑን በመጥቀስ ለድርጅታችሁ የትብብር ደብዳቤ እንድንጽፍለት ጠይቆናል።

በመሆኑም ተማሪ ዮሴፍ ብርሃኑ አ/አበባ ላይ በሚሰጠው የሳምንቱ መጨረሻ የ2ና ድግሪ የማኑፋክቸሪንግ ምህንድስና ተማሪያችን ሲሆን በአሁኑ ሰዓት የመመረቂያ ስራውን እየሰራ ያለ መሆኑን እየገለፅን በመመረቂያው ስራ ጋር በተያያዘ ለሚደረገው እገዛ አስፈላጊውን ትብብር እንድታደርጉለት በአክብሮት እንጠይቃለን።

ከሠላምታ ጋር

ሮቤል ንጉሴ ወርቅአለማሁ
Robel Nigussie Workalem
ፋኩልቲ ዲን
Faculty Dean

ግልባጭ//

- ለሜካኒካል እና ኢንዱስትሪያል ምህንድስና ፋኩልቲ
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Table entry for p is the critical value F^* with probability p lying to its right.

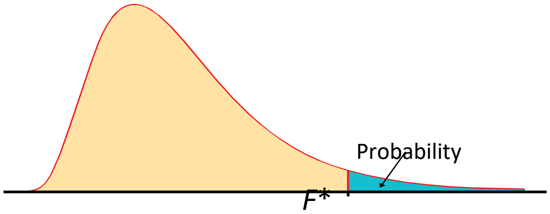
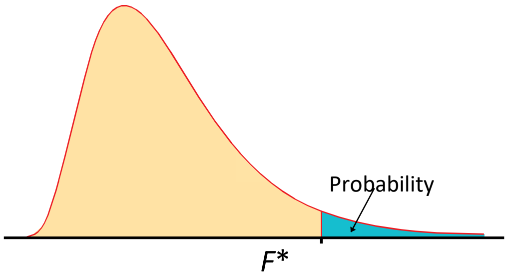


TABLE E

F critical values

Degrees of freedom in the denominator		Degrees of freedom in the numerator								
	p	1	2	3	4	5	6	7	8	9
1	.100	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86
	.050	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54
	.025	647.79	799.50	864.16	899.58	921.85	937.11	948.22	956.66	963.28
	.010	4052.2	4999.5	5403.4	5624.6	5763.6	5859.0	5928.4	5981.1	6022.5
	.001	405284	500000	540379	562500	576405	585937	592873	598144	602284
2	.100	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38
	.050	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
	.025	38.51	39.00	39.17	39.25	39.30	39.33	39.36	39.37	39.39
	.010	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39
	.001	998.50	999.00	999.17	999.25	999.30	999.33	999.36	999.37	999.39
3	.100	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24
	.050	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
	.025	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47
	.010	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35
	.001	167.03	148.50	141.11	137.10	134.58	132.85	131.58	130.62	129.86
4	.100	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94
	.050	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
	.025	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90
	.010	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66
	.001	74.14	61.25	56.18	53.44	51.71	50.53	49.66	49.00	48.47
5	.100	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32
	.050	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
	.025	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68
	.010	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16
	.001	47.18	37.12	33.20	31.09	29.75	28.83	28.16	27.65	27.24
6	.100	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96
	.050	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10
	.025	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52
	.010	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98
	.001	35.51	27.00	23.70	21.92	20.80	20.03	19.46	19.03	18.69
7	.100	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72
	.050	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
	.025	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82
	.010	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72
	.001	29.25	21.69	18.77	17.20	16.21	15.52	15.02	14.63	14.33

Table entry for p is
the critical value F^*
with probability p
lying to
its right.



F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
60.19	60.71	61.22	61.74	62.05	62.26	62.53	62.69	62.79	63.06	63.30
241.88	243.91	245.95	248.01	249.26	250.10	251.14	251.77	252.20	253.25	254.19
968.63	976.71	984.87	993.10	998.08	1001.4	1005.6	1008.1	1009.8	1014.0	1017.7
6055.8	6106.3	6157.3	6208.7	6239.8	6260.6	6286.8	6302.5	6313.0	6339.4	6362.7
605621	610668	615764	620908	624017	626099	628712	630285	631337	633972	636301
9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.47	9.47	9.48	9.49
19.40	19.41	19.43	19.45	19.46	19.46	19.47	19.48	19.48	19.49	19.49
39.40	39.41	39.43	39.45	39.46	39.46	39.47	39.48	39.48	39.49	39.50
99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.48	99.49	99.50
999.40	999.42	999.43	999.45	999.46	999.47	999.47	999.48	999.48	999.49	999.50
5.23	5.22	5.20	5.18	5.17	5.17	5.16	5.15	5.15	5.14	5.13
8.79	8.74	8.70	8.66	8.63	8.62	8.59	8.58	8.57	8.55	8.53
14.42	14.34	14.25	14.17	14.12	14.08	14.04	14.01	13.99	13.95	13.91
27.23	27.05	26.87	26.69	26.58	26.50	26.41	26.35	26.32	26.22	26.14
129.25	128.32	127.37	126.42	125.84	125.45	124.96	124.66	124.47	123.97	123.53
3.92	3.90	3.87	3.84	3.83	3.82	3.80	3.80	3.79	3.78	3.76
5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.70	5.69	5.66	5.63
8.84	8.75	8.66	8.56	8.50	8.46	8.41	8.38	8.36	8.31	8.26
14.55	14.37	14.20	14.02	13.91	13.84	13.75	13.69	13.65	13.56	13.47
48.05	47.41	46.76	46.10	45.70	45.43	45.09	44.88	44.75	44.40	44.09
3.30	3.27	3.24	3.21	3.19	3.17	3.16	3.15	3.14	3.12	3.11
4.74	4.68	4.62	4.56	4.52	4.50	4.46	4.44	4.43	4.40	4.37
6.62	6.52	6.43	6.33	6.27	6.23	6.18	6.14	6.12	6.07	6.02
10.05	9.89	9.72	9.55	9.45	9.38	9.29	9.24	9.20	9.11	9.03
26.92	26.42	25.91	25.39	25.08	24.87	24.60	24.44	24.33	24.06	23.82
2.94	2.90	2.87	2.84	2.81	2.80	2.78	2.77	2.76	2.74	2.72
4.06	4.00	3.94	3.87	3.83	3.81	3.77	3.75	3.74	3.70	3.67
5.46	5.37	5.27	5.17	5.11	5.07	5.01	4.98	4.96	4.90	4.86
7.87	7.72	7.56	7.40	7.30	7.23	7.14	7.09	7.06	6.97	6.89
18.41	17.99	17.56	17.12	16.85	16.67	16.44	16.31	16.21	15.98	15.77
2.70	2.67	2.63	2.59	2.57	2.56	2.54	2.52	2.51	2.49	2.47
3.64	3.57	3.51	3.44	3.40	3.38	3.34	3.32	3.30	3.27	3.23
4.76	4.67	4.57	4.47	4.40	4.36	4.31	4.28	4.25	4.20	4.15
6.62	6.47	6.31	6.16	6.06	5.99	5.91	5.86	5.82	5.74	5.66
14.08	13.71	13.32	12.93	12.69	12.53	12.33	12.20	12.12	11.91	11.72

(*Continued*)

F critical values (continued)

Degrees of freedom in the denominator		Degrees of freedom in the numerator								
	p	1	2	3	4	5	6	7	8	9
8	.100	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56
	.050	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
	.025	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36
	.010	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91
	.001	25.41	18.49	15.83	14.39	13.48	12.86	12.40	12.05	11.77
9	.100	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44
	.050	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
	.025	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03
	.010	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35
	.001	22.86	16.39	13.90	12.56	11.71	11.13	10.70	10.37	10.11
10	.100	3.29	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35
	.050	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
	.025	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78
	.010	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94
	.001	21.04	14.91	12.55	11.28	10.48	9.93	9.52	9.20	8.96
11	.100	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27
	.050	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
	.025	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59
	.010	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63
	.001	19.69	13.81	11.56	10.35	9.58	9.05	8.66	8.35	8.12
12	.100	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21
	.050	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
	.025	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44
	.010	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39
	.001	18.64	12.97	10.80	9.63	8.89	8.38	8.00	7.71	7.48
13	.100	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16
	.050	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
	.025	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31
	.010	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19
	.001	17.82	12.31	10.21	9.07	8.35	7.86	7.49	7.21	6.98
14	.100	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12
	.050	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
	.025	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21
	.010	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03
	.001	17.14	11.78	9.73	8.62	7.92	7.44	7.08	6.80	6.58
15	.100	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09
	.050	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59
	.025	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12
	.010	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89
	.001	16.59	11.34	9.34	8.25	7.57	7.09	6.74	6.47	6.26
16	.100	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06
	.050	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54
	.025	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05
	.010	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78
	.001	16.12	10.97	9.01	7.94	7.27	6.80	6.46	6.19	5.98
17	.100	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03
	.050	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49
	.025	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98
	.010	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68
	.001	15.72	10.66	8.73	7.68	7.02	6.56	6.22	5.96	5.75

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
2.54	2.50	2.46	2.42	2.40	2.38	2.36	2.35	2.34	2.32	2.30
3.35	3.28	3.22	3.15	3.11	3.08	3.04	3.02	3.01	2.97	2.93
4.30	4.20	4.10	4.00	3.94	3.89	3.84	3.81	3.78	3.73	3.68
5.81	5.67	5.52	5.36	5.26	5.20	5.12	5.07	5.03	4.95	4.87
11.54	11.19	10.84	10.48	10.26	10.11	9.92	9.80	9.73	9.53	9.36
2.42	2.38	2.34	2.30	2.27	2.25	2.23	2.22	2.21	2.18	2.16
3.14	3.07	3.01	2.94	2.89	2.86	2.83	2.80	2.79	2.75	2.71
3.96	3.87	3.77	3.67	3.60	3.56	3.51	3.47	3.45	3.39	3.34
5.26	5.11	4.96	4.81	4.71	4.65	4.57	4.52	4.48	4.40	4.32
9.89	9.57	9.24	8.90	8.69	8.55	8.37	8.26	8.19	8.00	7.84
2.32	2.28	2.24	2.20	2.17	2.16	2.13	2.12	2.11	2.08	2.06
2.98	2.91	2.85	2.77	2.73	2.70	2.66	2.64	2.62	2.58	2.54
3.72	3.62	3.52	3.42	3.35	3.31	3.26	3.22	3.20	3.14	3.09
4.85	4.71	4.56	4.41	4.31	4.25	4.17	4.12	4.08	4.00	3.92
8.75	8.45	8.13	7.80	7.60	7.47	7.30	7.19	7.12	6.94	6.78
2.25	2.21	2.17	2.12	2.10	2.08	2.05	2.04	2.03	2.00	1.98
2.85	2.79	2.72	2.65	2.60	2.57	2.53	2.51	2.49	2.45	2.41
3.53	3.43	3.33	3.23	3.16	3.12	3.06	3.03	3.00	2.94	2.89
4.54	4.40	4.25	4.10	4.01	3.94	3.86	3.81	3.78	3.69	3.61
7.92	7.63	7.32	7.01	6.81	6.68	6.52	6.42	6.35	6.18	6.02
2.19	2.15	2.10	2.06	2.03	2.01	1.99	1.97	1.96	1.93	1.91
2.75	2.69	2.62	2.54	2.50	2.47	2.43	2.40	2.38	2.34	2.30
3.37	3.28	3.18	3.07	3.01	2.96	2.91	2.87	2.85	2.79	2.73
4.30	4.16	4.01	3.86	3.76	3.70	3.62	3.57	3.54	3.45	3.37
7.29	7.00	6.71	6.40	6.22	6.09	5.93	5.83	5.76	5.59	5.44
2.14	2.10	2.05	2.01	1.98	1.96	1.93	1.92	1.90	1.88	1.85
2.67	2.60	2.53	2.46	2.41	2.38	2.34	2.31	2.30	2.25	2.21
3.25	3.15	3.05	2.95	2.88	2.84	2.78	2.74	2.72	2.66	2.60
4.10	3.96	3.82	3.66	3.57	3.51	3.43	3.38	3.34	3.25	3.18
6.80	6.52	6.23	5.93	5.75	5.63	5.47	5.37	5.30	5.14	4.99
2.10	2.05	2.01	1.96	1.93	1.91	1.89	1.87	1.86	1.83	1.80
2.60	2.53	2.46	2.39	2.34	2.31	2.27	2.24	2.22	2.18	2.14
3.15	3.05	2.95	2.84	2.78	2.73	2.67	2.64	2.61	2.55	2.50
3.94	3.80	3.66	3.51	3.41	3.35	3.27	3.22	3.18	3.09	3.02
6.40	6.13	5.85	5.56	5.38	5.25	5.10	5.00	4.94	4.77	4.62
2.06	2.02	1.97	1.92	1.89	1.87	1.85	1.83	1.82	1.79	1.76
2.54	2.48	2.40	2.33	2.28	2.25	2.20	2.18	2.16	2.11	2.07
3.06	2.96	2.86	2.76	2.69	2.64	2.59	2.55	2.52	2.46	2.40
3.80	3.67	3.52	3.37	3.28	3.21	3.13	3.08	3.05	2.96	2.88
6.08	5.81	5.54	5.25	5.07	4.95	4.80	4.70	4.64	4.47	4.33
2.03	1.99	1.94	1.89	1.86	1.84	1.81	1.79	1.78	1.75	1.72
2.49	2.42	2.35	2.28	2.23	2.19	2.15	2.12	2.11	2.06	2.02
2.99	2.89	2.79	2.68	2.61	2.57	2.51	2.47	2.45	2.38	2.32
3.69	3.55	3.41	3.26	3.16	3.10	3.02	2.97	2.93	2.84	2.76
5.81	5.55	5.27	4.99	4.82	4.70	4.54	4.45	4.39	4.23	4.08
2.00	1.96	1.91	1.86	1.83	1.81	1.78	1.76	1.75	1.72	1.69
2.45	2.38	2.31	2.23	2.18	2.15	2.10	2.08	2.06	2.01	1.97
2.92	2.82	2.72	2.62	2.55	2.50	2.44	2.41	2.38	2.32	2.26
3.59	3.46	3.31	3.16	3.07	3.00	2.92	2.87	2.83	2.75	2.66
5.58	5.32	5.05	4.78	4.60	4.48	4.33	4.24	4.18	4.02	3.87

F critical values (continued)

			Degrees of freedom in the numerator								
		p	1	2	3	4	5	6	7	8	9
Degrees of freedom in the denominator	18	.100	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00
		.050	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46
		.025	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93
		.010	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60
		.001	15.38	10.39	8.49	7.46	6.81	6.35	6.02	5.76	5.56
	19	.100	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98
		.050	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42
		.025	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88
		.010	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52
		.001	15.08	10.16	8.28	7.27	6.62	6.18	5.85	5.59	5.39
	20	.100	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96
		.050	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39
		.025	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84
		.010	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46
		.001	14.82	9.95	8.10	7.10	6.46	6.02	5.69	5.44	5.24
	21	.100	2.96	2.57	2.36	2.23	2.14	2.08	2.02	1.98	1.95
		.050	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37
		.025	5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80
		.010	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40
		.001	14.59	9.77	7.94	6.95	6.32	5.88	5.56	5.31	5.11
	22	.100	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93
		.050	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34
		.025	5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76
		.010	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35
		.001	14.38	9.61	7.80	6.81	6.19	5.76	5.44	5.19	4.99
	23	.100	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.95	1.92
		.050	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32
		.025	5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73
		.010	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30
		.001	14.20	9.47	7.67	6.70	6.08	5.65	5.33	5.09	4.89
	24	.100	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91
		.050	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30
		.025	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70
		.010	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26
		.001	14.03	9.34	7.55	6.59	5.98	5.55	5.23	4.99	4.80
	25	.100	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89
		.050	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28
		.025	5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68
		.010	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22
		.001	13.88	9.22	7.45	6.49	5.89	5.46	5.15	4.91	4.71
	26	.100	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88
		.050	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27
		.025	5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65
		.010	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18
		.001	13.74	9.12	7.36	6.41	5.80	5.38	5.07	4.83	4.64
	27	.100	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87
		.050	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25
		.025	5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63
		.010	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15
		.001	13.61	9.02	7.27	6.33	5.73	5.31	5.00	4.76	4.57

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
1.98	1.93	1.89	1.84	1.80	1.78	1.75	1.74	1.72	1.69	1.66
2.41	2.34	2.27	2.19	2.14	2.11	2.06	2.04	2.02	1.97	1.92
2.87	2.77	2.67	2.56	2.49	2.44	2.38	2.35	2.32	2.26	2.20
3.51	3.37	3.23	3.08	2.98	2.92	2.84	2.78	2.75	2.66	2.58
5.39	5.13	4.87	4.59	4.42	4.30	4.15	4.06	4.00	3.84	3.69
1.96	1.91	1.86	1.81	1.78	1.76	1.73	1.71	1.70	1.67	1.64
2.38	2.31	2.23	2.16	2.11	2.07	2.03	2.00	1.98	1.93	1.88
2.82	2.72	2.62	2.51	2.44	2.39	2.33	2.30	2.27	2.20	2.14
3.43	3.30	3.15	3.00	2.91	2.84	2.76	2.71	2.67	2.58	2.50
5.22	4.97	4.70	4.43	4.26	4.14	3.99	3.90	3.84	3.68	3.53
1.94	1.89	1.84	1.79	1.76	1.74	1.71	1.69	1.68	1.64	1.61
2.35	2.28	2.20	2.12	2.07	2.04	1.99	1.97	1.95	1.90	1.85
2.77	2.68	2.57	2.46	2.40	2.35	2.29	2.25	2.22	2.16	2.09
3.37	3.23	3.09	2.94	2.84	2.78	2.69	2.64	2.61	2.52	2.43
5.08	4.82	4.56	4.29	4.12	4.00	3.86	3.77	3.70	3.54	3.40
1.92	1.87	1.83	1.78	1.74	1.72	1.69	1.67	1.66	1.62	1.59
2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.94	1.92	1.87	1.82
2.73	2.64	2.53	2.42	2.36	2.31	2.25	2.21	2.18	2.11	2.05
3.31	3.17	3.03	2.88	2.79	2.72	2.64	2.58	2.55	2.46	2.37
4.95	4.70	4.44	4.17	4.00	3.88	3.74	3.64	3.58	3.42	3.28
1.90	1.86	1.81	1.76	1.73	1.70	1.67	1.65	1.64	1.60	1.57
2.30	2.23	2.15	2.07	2.02	1.98	1.94	1.91	1.89	1.84	1.79
2.70	2.60	2.50	2.39	2.32	2.27	2.21	2.17	2.14	2.08	2.01
3.26	3.12	2.98	2.83	2.73	2.67	2.58	2.53	2.50	2.40	2.32
4.83	4.58	4.33	4.06	3.89	3.78	3.63	3.54	3.48	3.32	3.17
1.89	1.84	1.80	1.74	1.71	1.69	1.66	1.64	1.62	1.59	1.55
2.27	2.20	2.13	2.05	2.00	1.96	1.91	1.88	1.86	1.81	1.76
2.67	2.57	2.47	2.36	2.29	2.24	2.18	2.14	2.11	2.04	1.98
3.21	3.07	2.93	2.78	2.69	2.62	2.54	2.48	2.45	2.35	2.27
4.73	4.48	4.23	3.96	3.79	3.68	3.53	3.44	3.38	3.22	3.08
1.88	1.83	1.78	1.73	1.70	1.67	1.64	1.62	1.61	1.57	1.54
2.25	2.18	2.11	2.03	1.97	1.94	1.89	1.86	1.84	1.79	1.74
2.64	2.54	2.44	2.33	2.26	2.21	2.15	2.11	2.08	2.01	1.94
3.17	3.03	2.89	2.74	2.64	2.58	2.49	2.44	2.40	2.31	2.22
4.64	4.39	4.14	3.87	3.71	3.59	3.45	3.36	3.29	3.14	2.99
1.87	1.82	1.77	1.72	1.68	1.66	1.63	1.61	1.59	1.56	1.52
2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.84	1.82	1.77	1.72
2.61	2.51	2.41	2.30	2.23	2.18	2.12	2.08	2.05	1.98	1.91
3.13	2.99	2.85	2.70	2.60	2.54	2.45	2.40	2.36	2.27	2.18
4.56	4.31	4.06	3.79	3.63	3.52	3.37	3.28	3.22	3.06	2.91
1.86	1.81	1.76	1.71	1.67	1.65	1.61	1.59	1.58	1.54	1.51
2.22	2.15	2.07	1.99	1.94	1.90	1.85	1.82	1.80	1.75	1.70
2.59	2.49	2.39	2.28	2.21	2.16	2.09	2.05	2.03	1.95	1.89
3.09	2.96	2.81	2.66	2.57	2.50	2.42	2.36	2.33	2.23	2.14
4.48	4.24	3.99	3.72	3.56	3.44	3.30	3.21	3.15	2.99	2.84
1.85	1.80	1.75	1.70	1.66	1.64	1.60	1.58	1.57	1.53	1.50
2.20	2.13	2.06	1.97	1.92	1.88	1.84	1.81	1.79	1.73	1.68
2.57	2.47	2.36	2.25	2.18	2.13	2.07	2.03	2.00	1.93	1.86
3.06	2.93	2.78	2.63	2.54	2.47	2.38	2.33	2.29	2.20	2.11
4.41	4.17	3.92	3.66	3.49	3.38	3.23	3.14	3.08	2.92	2.78

F critical values (continued)

			Degrees of freedom in the numerator								
		p	1	2	3	4	5	6	7	8	9
Degrees of freedom in the denominator		.100	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87
		.050	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24
	28	.025	5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61
		.010	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12
		.001	13.50	8.93	7.19	6.25	5.66	5.24	4.93	4.69	4.50
		.100	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86
		.050	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22
	29	.025	5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59
		.010	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09
		.001	13.39	8.85	7.12	6.19	5.59	5.18	4.87	4.64	4.45
		.100	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85
		.050	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21
	30	.025	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57
		.010	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07
		.001	13.29	8.77	7.05	6.12	5.53	5.12	4.82	4.58	4.39
		.100	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79
		.050	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12
	40	.025	5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45
		.010	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89
		.001	12.61	8.25	6.59	5.70	5.13	4.73	4.44	4.21	4.02
		.100	2.81	2.41	2.20	2.06	1.97	1.90	1.84	1.80	1.76
		.050	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07
	50	.025	5.34	3.97	3.39	3.05	2.83	2.67	2.55	2.46	2.38
		.010	7.17	5.06	4.20	3.72	3.41	3.19	3.02	2.89	2.78
		.001	12.22	7.96	6.34	5.46	4.90	4.51	4.22	4.00	3.82
		.100	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74
		.050	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04
	60	.025	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33
		.010	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72
		.001	11.97	7.77	6.17	5.31	4.76	4.37	4.09	3.86	3.69
		.100	2.76	2.36	2.14	2.00	1.91	1.83	1.78	1.73	1.69
		.050	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97
	100	.025	5.18	3.83	3.25	2.92	2.70	2.54	2.42	2.32	2.24
		.010	6.90	4.82	3.98	3.51	3.21	2.99	2.82	2.69	2.59
		.001	11.50	7.41	5.86	5.02	4.48	4.11	3.83	3.61	3.44
		.100	2.73	2.33	2.11	1.97	1.88	1.80	1.75	1.70	1.66
		.050	3.89	3.04	2.65	2.42	2.26	2.14	2.06	1.98	1.93
	200	.025	5.10	3.76	3.18	2.85	2.63	2.47	2.35	2.26	2.18
		.010	6.76	4.71	3.88	3.41	3.11	2.89	2.73	2.60	2.50
		.001	11.15	7.15	5.63	4.81	4.29	3.92	3.65	3.43	3.26
		.100	2.71	2.31	2.09	1.95	1.85	1.78	1.72	1.68	1.64
		.050	3.85	3.00	2.61	2.38	2.22	2.11	2.02	1.95	1.89
	1000	.025	5.04	3.70	3.13	2.80	2.58	2.42	2.30	2.20	2.13
		.010	6.66	4.63	3.80	3.34	3.04	2.82	2.66	2.53	2.43
		.001	10.89	6.96	5.46	4.65	4.14	3.78	3.51	3.30	3.13

F critical values (continued)

Degrees of freedom in the numerator										
10	12	15	20	25	30	40	50	60	120	1000
1.84	1.79	1.74	1.69	1.65	1.63	1.59	1.57	1.56	1.52	1.48
2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.79	1.77	1.71	1.66
2.55	2.45	2.34	2.23	2.16	2.11	2.05	2.01	1.98	1.91	1.84
3.03	2.90	2.75	2.60	2.51	2.44	2.35	2.30	2.26	2.17	2.08
4.35	4.11	3.86	3.60	3.43	3.32	3.18	3.09	3.02	2.86	2.72
1.83	1.78	1.73	1.68	1.64	1.62	1.58	1.56	1.55	1.51	1.47
2.18	2.10	2.03	1.94	1.89	1.85	1.81	1.77	1.75	1.70	1.65
2.53	2.43	2.32	2.21	2.14	2.09	2.03	1.99	1.96	1.89	1.82
3.00	2.87	2.73	2.57	2.48	2.41	2.33	2.27	2.23	2.14	2.05
4.29	4.05	3.80	3.54	3.38	3.27	3.12	3.03	2.97	2.81	2.66
1.82	1.77	1.72	1.67	1.63	1.61	1.57	1.55	1.54	1.50	1.46
2.16	2.09	2.01	1.93	1.88	1.84	1.79	1.76	1.74	1.68	1.63
2.51	2.41	2.31	2.20	2.12	2.07	2.01	1.97	1.94	1.87	1.80
2.98	2.84	2.70	2.55	2.45	2.39	2.30	2.25	2.21	2.11	2.02
4.24	4.00	3.75	3.49	3.33	3.22	3.07	2.98	2.92	2.76	2.61
1.76	1.71	1.66	1.61	1.57	1.54	1.51	1.48	1.47	1.42	1.38
2.08	2.00	1.92	1.84	1.78	1.74	1.69	1.66	1.64	1.58	1.52
2.39	2.29	2.18	2.07	1.99	1.94	1.88	1.83	1.80	1.72	1.65
2.80	2.66	2.52	2.37	2.27	2.20	2.11	2.06	2.02	1.92	1.82
3.87	3.64	3.40	3.14	2.98	2.87	2.73	2.64	2.57	2.41	2.25
1.73	1.68	1.63	1.57	1.53	1.50	1.46	1.44	1.42	1.38	1.33
2.03	1.95	1.87	1.78	1.73	1.69	1.63	1.60	1.58	1.51	1.45
2.32	2.22	2.11	1.99	1.92	1.87	1.80	1.75	1.72	1.64	1.56
2.70	2.56	2.42	2.27	2.17	2.10	2.01	1.95	1.91	1.80	1.70
3.67	3.44	3.20	2.95	2.79	2.68	2.53	2.44	2.38	2.21	2.05
1.71	1.66	1.60	1.54	1.50	1.48	1.44	1.41	1.40	1.35	1.30
1.99	1.92	1.84	1.75	1.69	1.65	1.59	1.56	1.53	1.47	1.40
2.27	2.17	2.06	1.94	1.87	1.82	1.74	1.70	1.67	1.58	1.49
2.63	2.50	2.35	2.20	2.10	2.03	1.94	1.88	1.84	1.73	1.62
3.54	3.32	3.08	2.83	2.67	2.55	2.41	2.32	2.25	2.08	1.92
1.66	1.61	1.56	1.49	1.45	1.42	1.38	1.35	1.34	1.28	1.22
1.93	1.85	1.77	1.68	1.62	1.57	1.52	1.48	1.45	1.38	1.30
2.18	2.08	1.97	1.85	1.77	1.71	1.64	1.59	1.56	1.46	1.36
2.50	2.37	2.22	2.07	1.97	1.89	1.80	1.74	1.69	1.57	1.45
3.30	3.07	2.84	2.59	2.43	2.32	2.17	2.08	2.01	1.83	1.64
1.63	1.58	1.52	1.46	1.41	1.38	1.34	1.31	1.29	1.23	1.16
1.88	1.80	1.72	1.62	1.56	1.52	1.46	1.41	1.39	1.30	1.21
2.11	2.01	1.90	1.78	1.70	1.64	1.56	1.51	1.47	1.37	1.25
2.41	2.27	2.13	1.97	1.87	1.79	1.69	1.63	1.58	1.45	1.30
3.12	2.90	2.67	2.42	2.26	2.15	2.00	1.90	1.83	1.64	1.43
1.61	1.55	1.49	1.43	1.38	1.35	1.30	1.27	1.25	1.18	1.08
1.84	1.76	1.68	1.58	1.52	1.47	1.41	1.36	1.33	1.24	1.11
2.06	1.96	1.85	1.72	1.64	1.58	1.50	1.45	1.41	1.29	1.13
2.34	2.20	2.06	1.90	1.79	1.72	1.61	1.54	1.50	1.35	1.16
2.99	2.77	2.54	2.30	2.14	2.02	1.87	1.77	1.69	1.49	1.22