KWARA STATE POLYTECHNIC

DEVELOPMENT AND TESTING OF A SINGLE SCREW EXTRUDER FOR PRODUCTION OF WASTE PLASTIC – SAND COMPOSITE MIX

BY

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HND/23/MEC/FT/0082

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING, INSTITUTE OF TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN MECHANICAL ENGINEERING TECHNOLOGY

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CERITIFICATION

The undersigned certified that this project report is prepared by **AKINWANDE SODIQ ADEKUNLE, HND/23/MEC/FT/0082** Entitled: “Development and testing of a single screw extruder for production of waste plastic – sand composite mix” meets the requirement of the Department of Mechanical Engineering for the award of Higher National Diploma (HND) in Mechanical Engineering.

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DEDICATION

This project is dedicated to Almighty Allah for his everlasting grace, infinite mercies, knowledge and wisdom given to me throughout my academic sessions, may he lead me through the right path (Amin)

Also dedicated to my beloved parents mr and Mrs Akinwande for their financial and spiritual support. May Almighty Allah Grant them the grace to witness more of my success and to enjoy the fruit of their labour (Amin)

Also dedicated to my beloved brothers and my family as a whole. May God continue to shower his hund of blessings on everyone of us (Amin).

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May the mercy and blessings of Allah continue to be upon the noblest of all mankind

MUHAMMAD ROSULULLAH (S.A.W) his household and companion.

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Nomenclature

Quantity/Symbols	Unit/Symbol
Density ρ	kg/m^3
Gravity g	m/s^2
Mass m	Kg
Stress σ	N/m^2
Strain E	
Volume V	m^3/cm^3

ABSTRACT

The use of polymers in laboratories and industries is imperative resulting to the constant need for homogenize melting and mixing of materials. The efficiency, complexity and cost of already existing single screw extruder machine have discouraged individuals, institutions and industries from mass usage of the machine and this necessitated the development of this single screw extruder machine in view of evaluating and improving on the efficiency of existing machines. A single screw extruder was designed and constructed for melting and mixing of various types of polymer. The machine which is easy to use has a heating element incorporated into its screw and a thermostat to control and determine the amount of temperature in the barrel, so as to overcome the shortcomings observed on already existing single screw extruder machine. Results from the test conducted showed that the extruder is capable of handling 1000cm^3 of polymer of 353wt% in 16 minutes. Also, results showed that the machine provides a faster, easier and more profitable means of obtaining molten polymer. Results further showed that the efficiency of the machine using a molten polymer of 285wt% was 81%. In conclusion, the machine is very applicable for local production, operation, repair and maintenance. The operation of this machine manually makes it a unique type compare to others. The operation save energy and does not require high skilled labour.

CHAPTER ONE

1.0.1 History of plastic production and uses

Early Developments (Pre-1900s)

- 1862 – Parkesine: Alexander Parkes unveiled the first man-made plastic, called Parkesine (a form of cellulose nitrate), at the Great International Exhibition in London. It was derived from plant cellulose.
- 1870 – Celluloid: John Wesley Hyatt developed celluloid, considered the first semi-synthetic plastic, as a substitute for ivory in billiard balls.

First Synthetic Plastics (1900–1940)

- 1907 – Bakelite: Leo Baekeland created Bakelite, the first fully synthetic plastic made from phenol and formaldehyde. It was heat-resistant and electrically nonconductive, making it ideal for electrical insulators, radios, and telephones.
- 1920s–30s – Rapid development of plastics like:
- Polystyrene (PS): Lightweight and moldable.
- Polyvinyl chloride (PVC): Durable and used in plumbing and insulation.
- Polyethylene (PE): First created in 1933; became widely used after WWII.

World War II and Expansion (1940–1950s)

- Plastics saw explosive growth during WWII due to metal shortages and the need for lightweight, durable materials.
- Nylon (1935 by DuPont) was used in parachutes, ropes, and clothing.
- Acrylics and polyesters were used for aircraft windows and coatings.

Post-War Consumer Boom (1950s–1970s)

- Plastics entered everyday consumer life:
- Tupperware, synthetic fabrics (polyester, nylon), packaging (cling films, bottles).
- Expanded use in cars, electronics, and household goods.
- Polypropylene (PP) was developed in the 1950s and found widespread use in packaging and textiles.

Environmental Awareness and Diversification (1970s–1990s)

- Concerns about plastic waste and pollution began to rise.
- Recycling codes were introduced in the late 1980s.
- Development of engineering plastics (e.g., polycarbonate, ABS) for use in automotive, aerospace, and electronics.

1.0.2. Circular economy of plastic waste

The circular economy of plastic waste is an approach aimed at minimizing plastic pollution by redesigning how plastic is produced, used, and managed after its useful life. Instead of the traditional linear economy (make–use–dispose), the circular economy seeks to keep plastic in use longer, reduce waste, and regenerate natural systems (1970s—1990s).

1.0.3 Plastic waste recycling methods

1.0.3.1 Mechanical Recycling (Physical Recycling)

Process: Plastics are sorted, cleaned, shredded, melted, and remolded into new products.

Used for: Common thermoplastics like PET, HDPE, PP.

1.0.3.2 Chemical Recycling (Advanced Recycling)

Process: Plastics are broken down into monomers or other chemical feedstocks via methods like:

- Pyrolysis – Heating plastics in the absence of oxygen to produce oil or gas.
- Gasification – Converts plastics into syngas ($CO + H_2$).
- Depolymerization – Breaks down polymers into original monomers (used for PET, nylon).
- Solvolysis – Uses solvents to dissolve and recover plastics.

1.0.3.4 Energy Recovery (Incineration with Energy Capture)

Process: Burning plastic waste in waste-to-energy plants to generate electricity or heat.

1.2 Types of Plastics

Plastics are broadly categorized into two main types: thermoplastics and thermosetting plastics

1.3 Most prominent of plastic waste and their applications

1.3.1 PET (Polyethylene Terephthalate)

- Prominence in Waste: Very high – especially in single-use products
- Common Applications:
- Water and soda bottles
- Food containers
- Packaging for personal care products
- Waste Challenge: Large volumes from beverage industries; often discarded after one use
- Recyclability: Highly recyclable into fiber, containers, carpets

1.3.2 HDPE (High-Density Polyethylene)

- Prominence in Waste: High – durable products used widely
- Common Applications:
- Milk jugs
- Detergent and shampoo bottles
- Grocery bags
- Waste Challenge: Frequently landfilled if not separated for recycling
- Recyclability: Excellent; used to make piping, plastic lumber, and new containers

1.3.3 LDPE (Low-Density Polyethylene)

- Prominence in Waste: Very high in retail and food industries
- Common Applications:
- Plastic bags
- Cling film
- Bread bags and six-pack rings
- Waste Challenge: Light and flexible—easily becomes litter or marine debris
- Recyclability: Limited; can be turned into garbage can liners, floor tiles

1.3.4 PP (Polypropylene)

- Prominence in Waste: Increasing rapidly with food packaging growth
- Common Applications:
- Yogurt containers
- Straws
- Bottle caps
- Take-out containers
- Waste Challenge: Low recycling rates despite valuable properties

- Recyclability: Moderately recyclable; used in automotive parts, storage bin

1.3.5 PS (Polystyrene / Styrofoam)

- Prominence in Waste: High in food service sector
- Common Applications:
- Disposable cups, plates, trays
- Food packaging
- Packing peanuts
- Waste Challenge: Not biodegradable, breaks into microplastics, rarely recycled
- Recyclability: Technically recyclable but not widely accepted

1.3.6 Recycling and associated problems

A. Contamination

- Food residues, labels, and dirt make plastics unsuitable for recycling.
- Contaminated plastics can spoil entire batches during processing.

B. Sorting Difficulties

- Plastics look similar but differ in composition (#1–#7 types).
- Mixed plastics are hard to separate and often end up in landfills or incinerators.

C. Low Recycling Rates

- Globally, less than 10% of plastic is recycled.
- Many countries lack infrastructure or market demand for recycled materials.

D. Downcycling

- Recycled plastics often have lower quality than virgin plastics.
- Example: PET bottles may be recycled into fibers, not new bottles.

E. Economic Barriers

- Virgin plastic is often cheaper than recycled plastic.
- Oil prices affect plastic production costs, impacting recycling markets.

F. Limited Recycling for Certain Types

- PVC, LDPE, and PS are rarely recycled due to:
- Toxicity (PVC)
- Lightweight litter (LDPE)
- Fragility and bulkiness (PS foam)

G. Microplastic Generation

- Mechanical recycling can fragment plastics, contributing to microplastic pollution.
- These microplastics enter waterways, soil, and even food.

1.3.7 Advantages and Disadvantages of plastic waste

1.3.7.1 Advantages of Plastic Waste (or managing it effectively)

1. Resource for Recycling
    - Plastic waste can be reused to create new products (e.g., clothing fibers, furniture, road materials).
    - Reduces demand for virgin plastic production.

2. Energy Recovery Potential
   - Certain plastic types can be incinerated for energy generation in waste-to-energy plants.
   - Converts waste into a usable energy source.
3. Job Creation
   - The recycling and waste management industry creates jobs in sorting, processing, and product development.
4. Drives Innovation
   - Challenges with plastic waste have spurred research in bioplastics, circular economy models, and eco-friendly materials.
5. Building Material in Low-Income Areas
   - Recycled plastic waste is used to produce low-cost bricks, tiles, and housing materials, offering affordable construction solutions.

1.3.7.2 Disadvantages of Plastic Waste

1. Environmental Pollution
   - Accumulates in landfills, oceans, and rivers.
   - Causes soil and water contamination.
   - Leads to marine animal deaths through ingestion or entanglement.

2. Microplastic Contamination

- Plastics break down into microplastics, entering the food chain and harming both humans and wildlife.
- Found in water, food, and even air.

3. Non-Biodegradability

- Most plastics take hundreds of years to decompose.
- Persistent in the environment, causing long-term pollution.

4. Harmful Emissions

- Burning plastic waste releases toxic gases like dioxins and furans.
- Poses serious risks to human health and air quality.

5. Recycling Challenges

- Difficult to recycle certain plastics due to contamination or complex structures.
- Many plastics end up in landfills or incinerators despite recyclability.

6. Economic Burden

- Improper plastic waste management increases municipal waste handling costs.
- Export bans (e.g., China’s National Sword policy) have made plastic waste harder to dispose of globally.

1.4 Aim and Objectives

1.4.1 Aim:

To design and fabricate a cost-effective and efficient plastic extruder machine for converting plastic waste into reusable products or filament, thereby promoting sustainable waste management and circular economy practices.

1.4.2 Objectives:

1. To design a compact and efficient extruder machine suitable for small-scale or community-based recycling operations.
2. To select appropriate materials and components (e.g., screw, barrel, heaters, motor) that ensure durability, consistent melting, and smooth extrusion.
3. To construct a temperature-controlled heating system capable of melting common thermoplastics (e.g., PET, HDPE, PP) safely and uniformly.
4. To fabricate a screw and barrel mechanism that facilitates continuous plastic feeding, melting, and extrusion.
5. To develop a simple and user-friendly control system for regulating temperature, speed, and pressure during operation.

1.5 Problem Statement

Plastic waste has become a critical environmental challenge worldwide due to its non-biodegradable nature and the increasing consumption of single-use plastics. Despite growing awareness and recycling efforts, a significant portion of plastic waste ends up in landfills, oceans, and open environments, causing severe ecological and health hazards.

Conventional recycling systems are often expensive, centralized, and inaccessible to small communities or individuals. This limits local efforts to manage plastic waste effectively. There is a need for a low-cost, efficient, and scalable solution that can convert plastic waste into reusable materials or products on a small to medium scale.

The lack of affordable and easy-to-operate extruder machines further constrains the ability to recycle plastics at the grassroots level. Addressing this gap requires the development of a plastic extruder machine that is simple to build, energy-efficient, and capable of processing commonly used thermoplastics (such as PET, HDPE, and PP) into usable outputs like filament, sheets, or rods.

1.6 Justification for the Project

The increasing accumulation of plastic waste poses a serious threat to the environment, human health, and sustainable development. Traditional recycling methods are often centralized, costly, and inaccessible to many communities, especially in developing regions. There is an urgent need for decentralized, affordable, and efficient technologies that empower local recycling efforts.

The development of a plastic extruder machine provides a practical solution by enabling the transformation of waste plastics into reusable products such as 3D printing filament, building materials, or plastic components. This not only reduces environmental pollution but also creates opportunities for small-scale manufacturing, income generation, and educational innovation.

Additionally, the project supports circular economy principles by closing the loop on plastic use, encouraging responsible consumption, and promoting resource efficiency. By building a locally made, low-cost extruder, the project demonstrates the feasibility of grassroots recycling and supports broader sustainability goals.

1.7 Scope of the Project

This project focuses on the design, fabrication, and testing of a small-scale plastic extruder machine capable of processing commonly used thermoplastics such as PET, HDPE, and PP. The machine will be designed to melt and extrude plastic waste into uniform filaments peor rods that can be reused for various applications including 3D printing, molding, and construction materials.

The project will cover:

1. Design and modeling of the extruder components (screw, barrel, frame, die, hopper).
2. Selection and integration of mechanical and electrical components, including heaters, temperature control system, and motor.
3. Fabrication of the machine using locally available materials to ensure cost-effectiveness.
4. Testing and performance evaluation of the machine with different types of plastic waste.
5. Analysis of output quality, extrusion rate, energy consumption, and operational safety.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 S.P. Ladamy, K.C. So, "Optimal Recycling of Waste Materials in a Plastic Extrusion.

Production Process". May 2001, Vol. 31, No. 3.

Recycling process overview.

Recycled plastic mixed with virgin material to retain engineering properties

Less virgin material in plastic each cycle

Authors attempt to determine optimal number of cycles of mixing reclaimed and virgin material

Based on factors such as sale price, value of recovered waste material, raw material cost, production, etc.

Numerical model developed to determine optimum cycling.

Relevance:

Some useful insights into engineering properties of recycled plastics.

Virgin material mixing may be utilized.

The study aimed to determine the best strategies for incorporating recycled plastic into the production process to minimize costs and maximize efficiency.

The research likely explored various aspects of the recycling process, including:

Types of waste: The study likely considered different types of plastic waste, such as postconsumer waste, production scrap, and post-industrial waste.

Waste preparation: This could involve sorting, cleaning, and processing the waste materials to ensure compatibility with the extrusion process.

Recycled plastic blending: The paper may have investigated the optimal ratios and combinations of recycled plastic with virgin plastic to achieve desired product properties.

Process optimization: The study may have looked at how to optimize the extrusion process itself, such as temperature, pressure, and speed, to accommodate the use of recycled materials.

Cost analysis: The researchers likely conducted a cost analysis to compare the economic benefits of recycling versus using virgin materials.

Environmental impact: The study may have also considered the environmental benefits of recycling, such as reduced energy consumption and waste generation.

Optimal recycling of waste materials in a plastic extrusion production process," by S.P. Ladany and K.C. So, focuses on the economic benefits of incorporating recycled plastic into the extrusion process.

The recycling process would need to be designed to ensure that the recycled plastic is produced at a lower cost than imported alternatives.

2.2 R. Hettema, J. Pasman, L.B.P.M Janssen, “Reactive Extrusion of Recycled Bottle Waste

Materials”, Polymer Engineering and Science, April 2002, Vol. 42, No. 4.

States challenges of plastic recycling mixing waste streams i.e High Density Polyethylene (HDP) and PolyPropylene(PP) results in undesirable engineering properties hard to recreate properties of virgin material

Authors conducted experiments with reactive extrusion (chemicals added during process) peroxides added during extrusion process found to be beneficial in improving properties such as toughness

Extrusion settings also tested for effects on material properties. mass flow rate, screw speed and termperature tested.

Reactive extrusion could be explored to improve properties of expanded materials. Need to ensure such chemicals are domestically available in a development setting.

Extrusion parameters will have to be tested to determine optimal conditions for quality feedstock production.

2.3 The study "Reactive Extrusion of Recycled Bottle Waste Material" by R. Hettema, J. Pasman, and L.B.P.M. Janssen, published in April 2002, explores the process of reactive extrusion in recycling bottle waste materials.

Study Focus: The researchers investigated the challenges of plastic recycling, particularly when mixing waste streams like HDPE and PP, which can result in undesirable engineering properties.

Reactive Extrusion: This process involves using an extruder as a reactor to convert waste plastic materials into valuable products, potentially improving their properties

2.4 MUY zhao G 2013 "optimization approach for processing design in the extrusion process of plastic profile with metal insert".

The extrusion process of plastic profile with metal insert is a kind of novel and advanced plastic processing method which requires rigorous control on processing conditions to ensure the quality and performance of final products. However, it is still difficult to achieve an optimal processing design by using traditional "trial and error" method. An optimization approach for the processing design in the extrusion process of plastic profile with metal insert is proposed based on finite element simulation, back propagation neural network and genetic algorithm in the study. The finite element simulation is conducted to predict polymer melts flow in the extrusion process. The simulated results are extracted for the establishment of neural network. The genetic algorithm is performed for the search of globally optimal design variable with its objective function evaluated by using the established neural network model. The proposed approach is adopted for the optimization of processing conditions in the extrusion process of plastic profile with metal insert. According to the flow balance principle, the uniformity of outlet flow distribution is taken as the optimization objective with a constraint condition on the maximum shear stress. The optimization of two processing parameters including the volume flow rate and the metal insert moving velocity is conducted in the extrusion process of plastic profile with metal insert and the optimization objective is successfully achieved.

Optimization approaches for extrusion processes involve using computational fluid dynamics (CFD) and finite element analysis to improve die design, flow balance, and product quality.

- Improving Die Design: Optimizing die geometry to achieve balanced flow and reduce defects
- Flow Balance: Ensuring uniform flow at the die exit to enhance product performance
- Multi-Objective Optimization: Balancing competing objectives like seam weld quality, die lifetime, and production rate.

2.5 Khan A “Improvement of plasticity index value of swelling clay soil by lime stabilization 2014.

Swelling soils account for large volume of the ground. These soils are Swelled due to moisture changes in different seasons of the year which leads to damage and Crack to structures built on these soils and considerable financial loss would be incurred. Thus this phenomenon may be described as dangerous like other natural disasters. Soil Stabilization is a good technique for reducing such loss. Mechanical techniques such as Concentration leads to improved soil characteristics.

Improvement of Plasticity Index Value of Swelling Clay Soil by Lime Stabilization explores how adding lime to clay soil can enhance its properties

i) Soil Properties : The addition of lime improves soil properties, reducing the plasticity index and swelling potential. This makes the soil more stable and less prone to settlement issues.

ii) Lime Stabilization: The reaction between lime and clay soil leads to a decrease in maximum dry density up to a certain percentage, after which it starts increasing again. This suggests that lime can alter the compaction behavior of soils.

iii) Geotechnical Applications: Understanding the influence of lime on soil plasticity is crucial for civil engineering projects, such as road construction, embankments, and foundation design. By adding lime, engineers can potentially improve soil stability and reduce settlement issues.

KEY BENEFITS

i) Enhance Strength: Improve shearing strength and compressive strength

ii) Reduce Volume Instability: Mitigate swelling potential and control shrinkage

iii) Decrease Plasticity Index: Lower the plasticity index, making the soil more stable

iv) Reduce Permeability : Decrease soil compressibility and deformation.

2.6 Patil PM and Sadaphale PDB “A study of the plastic extrusion process and its defects. 2018.

Plastic extrusion process is a high-volume manufacturing process in which raw plastic is melted and formed into a continuous profile. This process starts by feeding plastic material (pellets, granules, flakes or powders) from a hopper into the barrel of the extruder. The material is gradually melted by the mechanical energy generated by turning screws and by heaters arranged along the barrel. The molten polymer is then forced into a die, which shapes the polymer into a shape that hardens during cooling. There are two basic types of plastic extrusion: screw extrusion and ram extrusion.

A ram extruder is an extruder where, instead of extrusion screw, a ram or plunger is used and a plunger goes through a barrel and pushes out the material under pressure. The ram extruder was the earliest extruder to be used in the plastics industry.

Screw extrusion involves a helical feed screw that turns inside a barrel. This is often called the feed screw or the extruder screw.

The screw is a single shaft with helical flights. Sometimes, when more thorough mixing is needed, two screws are used. The constantly turning screw moves the resin through the heated barrel where it is heated to proper temperature and blended into a homogeneous melt.

Defect is any form of deviation of the product's characteristic from the specification set up by the manufacturing process. It can be caused by a single source or the cumulative effect of several factors, which may arise at any stage of the processing. The common failure or defects which are normally occurring in plastic extrusion process are due to three main causes: mould design, material selection, and processing. [1]

Some of the common extrusion defects are Improper operation, Resin Defects, Trapped air, Overheating, Melt fracture, Moisture absorption, Poor Mixing, Surging, Improper Material Addition, Improper system engineering and installation.

2.7 Ugoamadi CC and OK Ihesiulor "Optimization of the development of a plastic extrusion machine. 2011.

This involves the design and construction of a plastic recycling machine that minimizes the limitations of the already existing (imported) ones to a great extent and at the same time ensuring effective waste management. The results of experimental analysis show that for every used plastic fed into the hopper, about temperature of 200oC is required to melt it. The machine employs the principle of conveying and heating to effect shredding and melting of the materials fed through the hopper, and requires only two persons to operate. The machine is designed using locally available raw materials which make it cheap and easy to maintain and repair. The performance test analysis carried out defines the characteristics of the machine and shows that at a speed of 268 rpm the machine functions effectively and efficiently in performing its task producing a high finishing recycling efficiency or recyclability of 97%, takes 2 minutes to recycle a batch of plastics and has a recycling capacity/throughput of about 265 Kg/hr which translates to a significant time. It is cost and energy saving since its specific mechanical energy consumption is low at about 30.23KJ/Kg.

Optimizing plastic extrusion machine design and performance is crucial for producing high quality plastic products, reducing waste, and increasing productivity.

2.8 Raju, Geo, Mohan Lal, Sharma and Makkhan Lal meena “Recent methods for Optimization of the plastic extrusion process. 2014.

Plastic extrusion has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. Faced with global competition in plastic-products industry, using the trial-and error approach to determine the process parameters for plastic extrusion is no longer good enough. During production, quality characteristics may deviate due to drifting or shifting of processing conditions caused by machine wear, environmental change or operator fatigue. Determining optimal process parameter settings critically influences productivity, quality, and cost of production in the plastic related industries. The complexity of extrusion process and the enormous amount of process parameters involved make it difficult to keep the process under control. The complexity and parameter manipulation may cause serious quality problems and high manufacturing costs. One of the main goals of extrusion is the improvement of quality of extruded parts besides the reduction of cycle time, and lower production cost.

CHAPTER THRE

3.0 Materials and Methods

3.1 Materials

3.1.1 Description of material used for the production of extruder machine (material selection)

Material selection is a critical aspect in the design and production of an extruder machine, especially for processing waste plastic-sand composites. The materials used must withstand high temperatures, pressures, mechanical stresses, and corrosion while maintaining good machinability and cost-effectiveness. The key components of the extruder machine and their corresponding materials are described below:

1. Barrel

Material: Alloy Steel (e.g., AISI 4140 or nitrided steel)

Reason for Selection: Alloy steels such as AISI 4140 offer excellent strength, wear resistance, and heat resistance. Nitriding enhances surface hardness and wear resistance, essential due to the high friction and pressure from the plastic-sand mix.

Reference:

Callister, W.D., & Rethwisch, D.G. (2014).

2. Screw (Auger)

Material: High-carbon steel or tool steel (e.g., H13 tool steel)

Reason for Selection: The screw experiences intense shear and compressive stresses. Tool steel such as H13 is chosen for its hardness, toughness, and resistance to wear and thermal fatigue.

Reference:

Budynas, R.G., & Nisbett, J.K. (2015).

3. Hopper

Material: Mild Steel or Stainless Steel (SS304)

Reason for Selection: Mild steel is cost-effective and suitable for non-corrosive materials. Stainless steel is used when better corrosion resistance and hygiene are required, especially if moisture is present.

Reference:

Smith, W.F., & Hashemi, J. (2011).

4. Die

Material: Stainless Steel or Hardened Tool Steel

Reason for Selection: The die is exposed to high pressure and must retain shape and finish. Stainless steel resists corrosion and has good formability, while hardened tool steel is used for its strength and dimensional stability.

Reference:

Dieter, G.E. (1986).

5. Frame and Support Structure

Material: Mild Steel (Low Carbon Steel)

Reason for Selection: Mild steel provides good weldability, sufficient strength, and is cost-effective for structural applications where high mechanical stress is not present.

Reference:

Ashby, M.F. (2011).

6. Heating Elements

Material: Nickel-Chromium Alloy (e.g., Nichrome)

Reason for Selection: Nichrome offers high electrical resistance and can withstand high operating temperatures, making it ideal for electric heating coils.

Reference:

Callister, W.D., & Rethwisch, D.G. (2014).

3.1.2 Description of components parts of the machine and it making principles

An extruder machine is primarily designed to process materials (e.g., waste plastic mixed with sand) by melting and forcing them through a die to form specific shapes. Below is a detailed description of the major components of the extruder machine along with its operating principles.

1. Component Parts of the Extruder Machine

1.1 Hopper

Function: The hopper is the feeding system of the extruder. It holds and directs the raw plastic-sand mixture into the barrel.

Material: Mild steel or stainless steel.

Design Note: It is usually conical to prevent bridging and facilitate smooth flow.

Reference:

Kalpakjian, S., & Schmid, S.R. (2013).

1.2 Barrel

Function: Houses the rotating screw and provides a heating chamber for plastic melting.

Material: Nitrided alloy steel to resist wear and high temperature.

Reference:

Todd, R.H., Allen, D.K., & Alting, L. (1994).

1.3 Screw (Auger)

Function: The screw conveys, compresses, melts, and mixes the plastic-sand material along the barrel.

Material: Tool steel (e.g., H13), for strength and wear resistance.

Design: Consists of three zones:

Feed zone – moves material forward,

Compression zone – compresses and melts the material,

Metering zone – homogenizes and maintains constant flow.

Reference:

Rosato, D.V., & Rosato, D.V. (2004).

1.4 Heating Elements

Function: Provide the thermal energy required to melt the plastic content in the composite mix.

Material: Nichrome wire or cartridge heaters.

Control: Temperature is regulated using thermocouples and controllers.

Reference:

Rao, P.N. (2013).

1.5 Die

Function: Shapes the molten composite into the desired final product profile (e.g., bricks, tiles).

Material: Hardened steel or stainless steel.

Design: The geometry of the die defines the final product shape and flow characteristics.

Reference:

Brydson, J.A. (1999).

1.6 Frame/Support Structure

Function: Provides mechanical support and rigidity for all machine components.

Material: Mild steel.

Reference:

Ashby, M.F. (2011).

1.7 Motor and Gearbox

Function: Supplies rotational motion to the screw. The gearbox reduces motor speed and increases torque.

Material: Steel casing, hardened steel gears.

Reference:

Shigley, J.E., & Mischke, C.R. (2001).

2. Working Principle of the Extruder Machine

The extruder operates on the principle of thermomechanical processing, which involves converting solid raw materials into a homogenized molten mixture and forcing it through a shaping die. The process consists of the following steps:

1. Feeding: The plastic-sand mixture is poured into the hopper.
2. Conveying: The rotating screw moves the material forward through the barrel.
3. Melting: As the material travels, it is heated by the barrel heaters and compressed by the screw, causing the plastic to melt.
4. Mixing: The rotating screw also ensures thorough mixing of the plastic and sand.

5. Extrusion: The homogeneous molten mixture is forced through the die, which shapes the final product (e.g., bricks or beams).
6. Cooling and Cutting (if applicable): The extruded material is cooled and cut into desired lengths.

Reference for Principle:

Strong, A.B. (2006).

3.1.3 Design considerations

1. Design Considerations

Before construction, key design factors must be addressed:

a. Type of Extruder

Single Screw Extruder is commonly used for plastic-sand composites due to its simplicity, low cost, and ease of maintenance.

Reference:

Rosato, D.V., & Rosato, D.V. (2004).

b. Material Properties

The machine must handle abrasive and semi-solid plastic-sand mixtures.

Components must resist wear, thermal expansion, and corrosion.

c. Thermal Designs

Adequate heating zones and insulation are necessary to maintain a consistent melting temperature (approx. 180–250°C for thermoplastics).

d. Throughput

The screw geometry, motor speed, and die design must align with the desired production rate (kg/hour).

2. Key Components and Their Construction

1. Frame/Base Structure

Material: Mild steel (angle iron or square pipes).

Construction: Welded rectangular frame to hold motor, barrel, gearbox, and hopper.

Design Tip: Ensure strong, level base to reduce vibration.

Reference:

Ashby, M.F. (2011).

2. Hoppe

Design: Conical or pyramidal shape.

Material: Mild steel or stainless steel (if corrosion resistance is required).

Fabrication: Welded sheet metal with a gate valve or feed control mechanism.

3. Barrel

Material: Nitrided alloy steel or high-carbon steel pipe.

Design: Cylindrical tube (length-to-diameter ratio typically 20:1).

Heating System: External electric heaters (band or cartridge type) placed in zones.

Insulation: Glass wool or ceramic fiber to reduce heat loss.

4. Screw (Auger)

Material: Hardened tool steel (e.g., H13).

Construction: Machined from solid steel, with varying pitch zones:

Feed zone

Compression zone

Metering zone

Mounting: Connected to the shaft via key joint or coupling.

Reference:

Todd, R.H., Allen, D.K., & Alting, L. (1994).

5. Motor and Gearbox

Motor: AC induction motor (1–5 HP depending on capacity).

Gearbox: Reduction gearbox to convert high-speed motor rotation into high torque.

Coupling: Flexible coupling to connect the motor shaft to the screw shaft.

Reference:

Shigley, J.E., & Mischke, C.R. (2001).

6. Die Head

Material: Stainless steel or hardened steel.

Design: Interchangeable die plates for different product shapes.

Construction: Bolted or clamped to the barrel outlet.

Cooling System: Water or air cooling near the die exit (optional depending on product).

Reference:

Brydson, J.A. (1999).

7. Control Panel

Includes:

Temperature controllers (PID or thermostat-based)

Emergency stop switch

Motor ON/OFF and speed control

Safety Features: Fuses, relays, and indicators for operational monitoring.

3. Fabrication Process Steps

1. Cutting and Welding: Frame and support structures.
2. Machining: Screw and barrel (turning, threading, drilling).
3. Assembly: Mounting of barrel, screw, die, gearbox, and motor.
4. Electrical Setup: Heater wiring, control panel connections.
5. Testing: Dry run to check rotation, temperature control, and material flow.

4. Safety and Maintenance

Guards over moving parts.

Emergency stop buttons within reach.

Routine checks on wear, heater function, and screw alignment.

3.1.4 Design analysis

Design analysis is a crucial phase in the development of an extruder machine, ensuring the system performs efficiently, safely, and economically. The process involves evaluating mechanical, thermal, structural, and power requirements based on the intended function of the machine — in this case, processing waste plastic-sand composites.

1. Functional Requirements of the Extruder

Melt and homogenize plastic-sand mixture.

Withstand high temperature (~180–250°C).

Generate sufficient torque and pressure to extrude viscous material.

Maintain structural stability during continuous operation.

Ensure material flow rate meets production demands.

Reference:

Rosato, D.V., & Rosato, D.V. (2004).

2. Design Analysis Components

2.1 Screw Design Analysis

Objective: Calculate screw diameter, length, pitch, and compression ratio to ensure proper conveying, melting, and mixing.

Length-to-Diameter Ratio (L/D): Typically between 20:1 and 30:1 for plastic-sand applications.

Compression Ratio: Usually between 2:1 and 3:1 for better compaction and pressure build-up.

Material: Tool steel (e.g., H13) for wear resistance.

Reference:

Brydson, J.A. (1999).

2.2 Barrel Thermal Analysis

Objective: Maintain uniform temperature along the barrel.

Zones: Divided into heating zones with independent control.

Heat Transfer Requirement: Calculated based on:

Thermal conductivity of barrel material,

Melting point of plastics (~120–250°C),

Power rating of heaters.

Heat Energy (Q) Required:

$Q = mc\Delta T$

c = specific heat capacity of plastic (≈ 2 kJ/kg·K)

ΔT = temperature rise

Reference:

Kalpakjian, S., & Schmid, S.R. (2013).

2.3 Torque and Power Requirement

Objective: Estimate motor power and torque needed to rotate the screw under load.

Power (P):

$P = \frac{2\pi NT}{60}$

N = speed of screw (rpm),

T = torque (Nm),

P = power (Watts)

Estimated Motor Power: 1.5 – 5 HP, depending on throughput.

Reference:

Shigley, J.E., & Mischke, C.R. (2001).

2.4 Structural Analysis of Frame

Objective: Ensure the base and frame can withstand machine weight, vibrations, and dynamic load.

Analysis Method: Static and dynamic stress analysis using:

Bending stress calculation for supports.

Finite Element Analysis (FEA) for complex loads (if software is available).

Material: Mild steel (Yield strength ~250 MPa)

Factor of Safety (FOS): 2–3 recommended.

> Reference:

Gere, J.M., & Goodno, B.J. (2012).

2.5 Die Design and Flow Analysis

Objective: Ensure uniform material flow, avoid clogging and dead zones.

Die Pressure Drop (ΔP): Analyzed to match the motor power and material viscosity.

Flow Simulation: Computational Fluid Dynamics (CFD) tools can be used to simulate plastic flow behavior.

Design Tip: Smooth internal contours and streamlined shape minimize pressure loss.

Reference:

Strong, A.B. (2006).

3. Conclusion

Design analysis ensures that each part of the extruder machine — from the screw to the frame is optimized for durability, efficiency, and cost-effectiveness. Accurate thermal, mechanical, and structural calculations are critical to the reliable performance of the machine in recycling and processing waste plastic-sand composites.

3.2 Methods of Fabrication

S/N	Componen t	Link Component	Tools used
1	Hopper	The hopper's construction involves sheet metal or other materials out and formed to the desired shape	Tools used include cutting tools, welding equipment and bending machines
2	Screw	The screw is constructed by machining a metal rod, typically using a lathe or milling machine to create screw slights	Tools include lathers, milling machines and various measuring instruments
3	Barrel	The barrel is constructed from a metal tube and the interior is precisely machined	Tools used include boring machines horing tools and potentially heat treatment equipment
4	Heating elements	Heating elements are often constructed using resistance wires encased in ceramic or metal	Tools used include wire cutters, crimping tools and potentially soldering equipment
5	Die	A die is constructed from hardened steel, precisely machined to shape the desired form	Tools used include milling machines, grinders and EDM (Electrical Discharge Machining) equipment
6	Drive system	A drive system is constructed using a motor, gearbox and belts or chains	Tools used include wrenches, alignment tools and welding equipment

3.2.1. Assembly

- Mount the motor and gearbox on the base frame
- Install the barrel and align it with the gearbox
- Insert and align the screw into the barrel
- Mount heaters, sensors and thermocouples around the barrel
- Connect the hopper to the reed throat
- Attach the die at the extrusion end
- Install electrical panel and control systems (PID controllers, switchers, relays)
- Wire the motor, sensors and heaters

3.2.2. Electrical and controls setup

- Install PLC or Microcontroller (optional)
- Program temperature and motor control logic
- Test all electrical connections and safety interlocks

3.2.3. Testing and commissioning

- Perform dry-run (without material) to test screw rotation, motor function and heating
- Check for vibration, misalignment or noise
- Load material and test extrusion performance
- Adjust temperature profiles, screw, speed and output flow

- Measure final product dimension and quality

3.2.4. Safety precautions

During the fabrication of an extruder machine, several safety precautions must be taken to protect workers from hazaeds like sharp tools, heavy lifting, welding fumes, electrical shocks and more

Here’s a categorized and detailed list of safety Precautions Specifically for the Fabrication Phase:

- Personal protective equipment (PPE)
- Machining operations safety
- Welding and cutting safety
- Electrical safety
- Material handling and lifting
- General workshop safety

3.2.5. Maintenance

Maintenance of an extruder machine is critical for ensuring reliable performance, long service life and consistent product quality

Types of Maintenance

Type	Description	Examples
Preventive	Scheduled tasks to prevent failures	Cleaning, lubrication, temperature calibration
Predictive	Based on data and sensor feedback	Vibration monitoring, screw wear analysis
Corrective	Fixing breakdowns or issues	Replacing a damaged screw or heater
Condition based	Performed when performance drops	Replacing worn barrel, realigning shaft

3.2.6 Estimation for the materials

The feasibility of any project is dependent on the total cost required in the process of the project and the cost of materials due to the instability of the price of materials nowadays in the market, consideration must be given to the following:

- Increase in transport fare
- Increase in material costs
- Improvement in quality of such material
- Cost of labour

Estimation of Project Cost

1. Capital cost (initial setup)

S/N	**Item**	**Description**	**Estimated cost (N)**

1.	Extruder machine fabrication	Mild steel body, barrel, screw, frame, gearbox, etc.	800,000
2.	Heating system	Electric heaters or gas burners with controls	150,000
3.	Motor and Gearbox	3-5 HP electric motor with reduction gearbox	200,000
4.	Molds/Die Design	For shaping composite bricks/tiles	50,000
5.	Control panel	Electrical wiring, switches, relays	50,000
6.	Frame and assembly	Welding, painting, mounting	100,000
7.	Tools and equipment	Measuring tools, safety gear, hand tools	50,000
	Sub Total		**N1,400,000**

2. Raw Materials (Per Batch or Month)

S/N	**Material**	**Description**	**Estimated cost (N)**
1.	Waste plastic	Collected PET, HDPE, LDPE	20,000
2.	River sand or Quarry Dust	Sieved and dried	15,000
3.	Additives (optional)	Colorants, bonding agents, etc.	10,000
	Sub Total		**N45,000**

3. Operating Costs (Monthly)

S/N	Item	Description	Estimated cost (N)
1.	Electricity or fuel	For heating and motor operation	30,000
2.	Labour	2-3 workers	60,000
3.	Maintenance and repair	Lubricants, part replacements	10,000
	Sub Total		**N100,000**

4. Miscellaneous Costs

S/N	Item	Description	Estimated cost (N)
1.	Transportation	Moving raw materials and products	20,000
2.	Packaging materials	For storing composite bricks/tiles	10,000
3.	Testing and Quality control	Lab testing for strength / durability	15,000
	Sub Total		**N45,000**

Summary of Estimated Project Costs

Category	Estimated cost (N)
Capital cost	N1,400,000
Raw materials (Monthly)	N45,000
Operating cost (Monthly)	N100,000

Miscellaneous (Monthly)	N45,000

Initial Total Setup Cost

(One-time): N1.4 million

Monthly Running Cost: N190,000

3.2.7 Economic justification

Due to the economic situation of the country the prices of the selected materials are relatively expensive within our limited capacity and the grand total cost is estimated above, which is very economical when considering the qualities of the materials used and the economic situation of things now in our beloved country.

3.2.8 The Single Screw Extruder Anatomy

In the extrusion of plastics, the raw compound material is commonly in the form of nurdles (small beads, often called resin) or pellet are gravity fed from a top mounted hopper into the barrel of the extruder. Additives such as colourants and UV inhibitors {in either liquid or pellet form) are often used and can be mixed into the resin or pellet prior to arriving at the hopper. The plastic enters through the feed throat (an opening near the rear of the barrel) and comes in contact with the screw. The single screw (normally turning at up to 563 rpm) conveys the material (plastic) forward into the barrel. In this process, a heating profile is set for the barrel in which the controlled heating element gradually increases the temperature of the barrel and screw from the rear (where the plastic enters) to the front. This allows the material to melt gradually as they are pushed through the barrel and lowers the risk of overheating which may cause degradation in material. At the front of the barrel, the molten plastic leaves the screw and travels through the die (small opening). The die is what gives the final product its profile and must be designed so that the molten plastic evenly flows from cylindrical profile to the product's profile shape. Uneven flow at this stage can produce a product with unwanted residual stresses at certain points in the profile which can cause warping upon cooling. Almost any shape imaginable can be created so long it is a continuous profile. The product may be cooled or allowed to cool before any further processing.

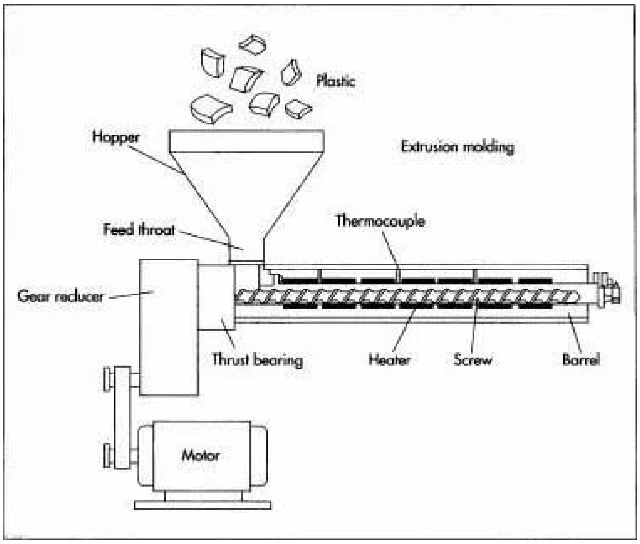

Figure 1: Single screw extruder machine

3.3 Research Methodology

The chapter entails the determination/calculations of the various parts/components of the machine adopted in this research.

3.3.1 Design Calculation

i. The Capacity of the Single Screw Extruder

The single screw extruder machine was designed to have a capacity of extruding $1000 cm^3$ of polymers in 16 minutes.

ii. Rotational Speed of Screw

The single screw extruder machine was designed to rotate at a speed of 563 rpm for effective mixing and extruding.

iii. **Minimum Pressure to Mix Polymer**

A polymer variety requiring 2GPa pressure to mix the polymer was assumed.

3.3.2 Design for Volume of the Hopper (V_h)

The hopper has a base radius (r) of 190mm, a top radius (R) of 72.5mm, and a height of 155 mm and the shape of a truncated cone.

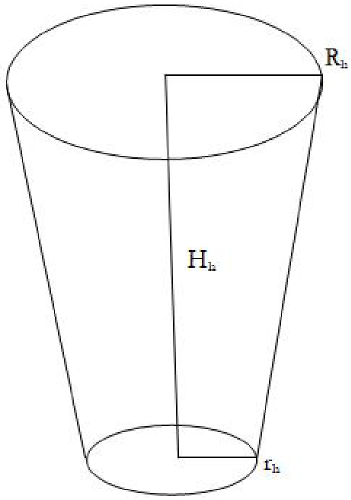

Figure 2: Truncated Cone

Using the truncated cone equation to calculate for the volume of the hopper, according to Ojo 2021.

Volume of hopper (V_h)

$$= \frac{1}{3} \times \pi \times H_h \left(R_h^2 + r_h^2 + R_h \times r_h\right) \qquad (3.3.2)$$

Where,

H_h = Height of the hopper = 160mm = 15.5cm

R_h = Radius of the top of hopper = 72.5mm = 7.25cm

r_h = Radius of the base of hopper = 19mm = 1.9cm

V_n = Volume of the hopper

Therefore,

$$\left(V_h\right) = \frac{1}{3} \times \pi \times H_h \left(R_h^2 + r_h^2 + R_h \times r_h\right)$$

$$\left(V_h\right) = \frac{1}{3} \times 3.142 \times 15.5\left(7.25^2 + 1.9^2 + 7.25 \times 1.9\right)$$

$$\left(V_h\right) = \frac{48.701}{3} (52.5625 + 3.61 + 13.775)$$

$$\left(V_h\right) = \frac{48.701}{3} (69.9475)$$

$$\left(V_h\right) = 16.2337(69.9475)$$

$$\left(V_h\right) = 1135.506731$$

$$\left(V_h\right) = 1136cm^3$$

Therefore,

If 88% of the hopper is being utilized and 12% is allowed for the free space, so as to prevent deformation of barrel and too much load standing in the hopper, therefore, the final volume of the hopper $\left(V_{fh}\right)$ will be,

$$\left(V_{fh}\right) = Calculated\ volume \times \%\ being\ utilized \quad (3.3.2.1)$$

$$\%\ being\ utilized = 88\% = \frac{88}{100} = 0.88$$

$$V_{fh} = 1136 \times 0.88$$

$$V_{fh} = 1000cm^3$$

Therefore, the hopper has a total volume of 1136cm^3 with a utilized volume of 1000cm^3 and a free volume of 136cm^3.

3.3.3 Calculating for the Volume of Spare Hopper (V_{SH})

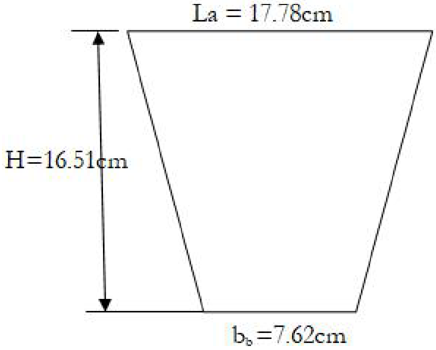

Fig.2a: Front view of hopper

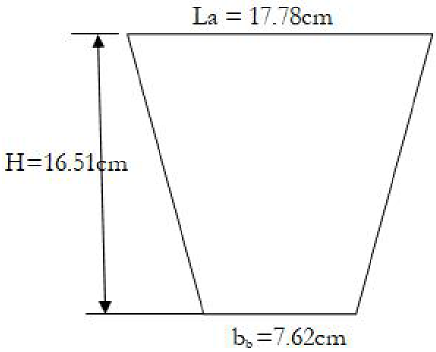

Fig.2b: Side view of hopper

The hopper has a square base of 7.62cm x 7.62cm and rectangular top of 17.78cm x 16.51cm and has the shape of the frustum of a pyramid (truncated).

Using the frustum of a pyramid (truncated equation) to calculate for the volume of the hopper, we have,

Volume of spare hopper $\left(V_{sh}\right)$

$$= \frac{H}{3}\left(A_a + A_b + \sqrt{A_a A_b}\right) \qquad (3.3.2.2)$$

Where,

$H_{sh} = Height\ of\ the\ spare\ hopper = 16.51cm$

A_a = Area of the top of spare hopper

= $L_a \times b_a = 17.78 \times 16.51$

$= 293.55cm\ cm^2$

A_b = Area of the base of spare hopper

$= b_b \times b_b = bb^2 = (7.62)^2$

$= 58.06cm^2$

V_{sh} = Volume of spare hopper

Therefore,

$$\left(V_{sh}\right) = \frac{H}{3}\left(A_a + b_b^2 + \sqrt{A_a b_b^2}\right)$$

$$\left(V_{sh}\right) = \frac{H_{sh}}{3}\left(A_a + b_b^2 + b_b\sqrt{A_a}\right)$$

$$\left(V_{sh}\right) = \frac{16.51}{3}\left(293.55 + 58.06 + 7.62\sqrt{293.55}\right)$$

$$\left(V_{sh}\right) = 5.5(293.55 + 58.06 + (7.62 \times 17.13))$$

$$\left(V_{sh}\right) = 5.5\ (293.55 + 58.06 + 130.53)$$

$$\left(V_{sh}\right) = 5.5(482.14)$$

$\left(V_{sh}\right) = 2651.77cm^3$

If 76% of the hopper is being utilized and 24% is allowed for the free so as to prevent deformation of barrel due to load standing in the hopper before the volume of the hopper will be

$$V_{sh} = Calculated\ volume \times \%\ being\ utilized \qquad (3.3.2.1)$$

$$\%\ being\ utilized\ = 76\% = \frac{76}{100} = 0.76$$

$$V_{sh} = 2651.77 \times 0.76$$

$$V_{sh} = 2015.3452cm^3 = 2015cm^3$$

Therefore, the spare hopper has a total volume of $2651.77cm^3$ with a free space of $636cm^3$ and a utilized space of $2015cm^3$

3.3.4 Design for Volume of the Barrel $\left(V_B\right)$

$$\left(V_b\right) = n \times r^2 \times L \qquad (3.3.4)$$

Where,

r_b = inner radius of the barrel

= 35.1mm = 3.51cm

L_b = length of the barrel

= 457mm = 45.7cm

$$V_b = 3.142 \times (3.51)^2 \times 45.72$$

$V_b = 3.142 \times 12.3201 \times 45.72$

$V_b = 1769.8 cm^3$

3.3.5 Calculating the Volume Occupied by the Screw Shaft (V_{SS})

Where,

Radius of screw shaft $(r_{ss}) = 19mm - 1.9cm$

Length of the screw shaft $(L_{ss}) = 457mm = 45.7cm$

$$V_{ss} = \pi \times r_{ss}^2 \times L_{ss} \quad (3.3.4)$$

$V_{ss} = 3.142 \times (1.9)^2 \times 45.7$

$V_{ss} = 3.142 \times 3.61 \times 45.72$

$V_{ss} = 518.58 cm^3$

3.3.6 Calculating for Volume Occupied by the Screw Flight (V_{SF})

Where Number of screw ribs $(n_{sf}) = 7 = 3.5\, rev$

Length of 1 screw rib $(L_{sf}) = 20mm = 2cm$

Length of 3.5 screw rib $(L_{sf}) = 2 \times 3.5 = 7cm$

Radius of the screw rib $(r_{sf}) = 35 - 19 = 16mm = 1.6cm$

$V_{sf} = \pi \times r_{sf} \times L_{sf}$

(3.3.6)

$V_{sf} = 3.142 \times (1.6)^2 \times 7$

$V_{sf} - 3.142 \times 2.56 \times 7$

$V_{sf} = 56.3cm$

3.3.7 Calculating for Volume Occupied by the Screw $\left(V_S\right)$

$$V_s = V_{ss} + V_{sr} \quad (3.3.7)$$

$V_s = 518.58 + 56.3$

$V_s = 574.88cm^3$

3.3.8 Calculating for Final Volume of the Barrel $\left(V_{FS}\right)$

$$V_{fb} = V_b - V_s \quad (3.3.8)$$

$V_{fb} = 1769.8 - 574.88$

$V_{fb} = 1194.92 = 1195cm^3$

If 95% of the barrel is being utilized and 5% is allowed for the free space so as to prevent improper melting and mixing of polymer and also to prevent too much load in the barrel, therefore the new final volume of the barrel will be,

$$V_{fb} = Calculated\ volume \times \%\ being\ utilized \quad (3.3.2.1)$$

% being utilized $= 95\% = \frac{95}{100} = 0.95$

$V_{fb} = 1195 \times 0.95$

$V_{fb} = 1135.25cm^3 - 1135cm^3$

3.3.9 Power Requirement

Power can be expressed as

Power (P) = Torque resistance × Angular Speed

$P = T\omega$ (3.3.9)

But $\omega = \frac{2nN_1}{60}$

Where T = Torsional Stress

ω = Angular Speed

N_1 = Speed in revolution per minute (1425 r.p.m)

Substituting the value of N into equation (11)

We have,

$$\omega = \frac{2nN}{60}$$

$$\omega = \frac{2 \times 1.42 \times 1425}{60} = \frac{4047}{60} = 67.45 rad/sec$$

The angular speed is 67.45 rad/sec

For the electric motor

1h.p = 746 watts

$$3\ h.p = 3 \times 746\ watts = 2238\ watts$$

$$P = 2238\ watts$$

Calculating the torgue transmitted

From equation (3.2.9)

$$P = T\omega$$

$$T = \frac{P}{\omega}$$

$$T = \frac{2238}{67.45} = 33.18N/M$$

3.4 DESIGN OF SCREW

3.4.1 Calculating for Screw Geometry

$$tan = \frac{Pitch}{\pi D_2} \qquad (3.4.1)$$

Where,

Helix angle (ϕ) = ? (unknown)

Screw diameter (D_2) = 70mm

Screw pitch (p) = 48mm

$$tan = \frac{48}{3.142 \times 70}$$

$$tan = \frac{48}{219.94}$$

$$tan = 0.2182$$

$$= tan^{-1}(0.2182)$$

$$= 12.3 = 12^0$$

3.4.2 Calculation for Compression Ratio

$$CR = \frac{Channel\ depth\ in\ feed\ section}{Channel\ depth\ in\ metering\ section} \qquad (3.4.2)$$

Where

Channel depth in feed section = 16mm

Channel depth in metering section = 16mm

$$CR = \frac{16}{16}$$

$$CR = 1:1$$

3.4.3 Calculation For Length/Diameter (L/D) Ratio

$$\frac{L}{D} = \frac{Screw\ flighted\ length}{Screw\ outside\ diameter} \quad (3.4.3)$$

Where

Screw Flighted length = 419.2mm

Screw Outside diameter = 70mm

$$\frac{L}{D} = \frac{419.2}{70}$$

$$\frac{L}{D} = 6:1$$

3.4.4 Design of Screw Shaft (Parameters)

W = 0.96KN

= 0.96 x 10^3N.

L= 10.5mm.

x = 436.2mm, T = 33.18 N/m = 33180N/mm,

$$d_{ss} = 38mm$$

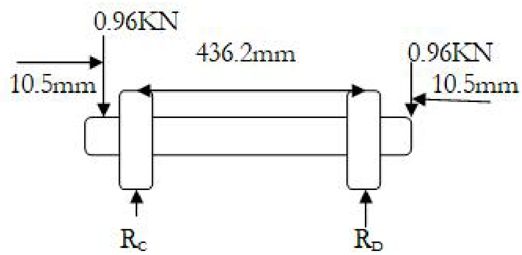

Figure 3: The shaft with bearings

A little consideration will show that the maximum bending moment acts on the shaft at c and D. Therefore maximum bending moment,

$$M = W \times L \qquad (3.4.4)$$

$$M = 0.98 \times 10^3 \times 2.34 \times 10^4$$

$$M = 22464000$$

$$M = 22.46 \times 10^6 N - mm$$

3.4.5 Calculating for Shaft Subjected to Combined Twisting Moment and Bending Moment

Let, T = Shear stress induced due to twisting moment, and

σ_b= Bending stress (tensile or compressive) induced due to bending moment.

According to maximum shear stress theory, the maximum shear stress in the shaft,

$$\tau_{max} = \frac{1}{2}\sqrt{\left(\sigma_b\right)^2 + 4\tau^2} \quad (3.4.5)$$

Where

$$\tau = \frac{16T}{\pi d^3} \; and \; \sigma_b = \frac{32M}{\pi d^3}$$

Substituting values of τ and σ_b into equation (3.3.5)

$$\tau_{max} = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + \left(\frac{16T}{\pi d^3}\right)^2} = \frac{16}{\pi d^3}\sqrt{M^2 + T^2}$$

$$\frac{\pi}{16} \times \tau_{max} \times d^3\sqrt{M^2 + T^2}$$

Therefore

$$\tau_{max} = \frac{16}{3.142 \times 38^3}\sqrt{\left(22.46 \times 10^6\right)^2 + (33180)^2}$$

$$\tau_{max} = \frac{16}{3.142 \times 54872}\sqrt{5 \times 10^{14} + 11 \times 10^8}$$

$$\tau_{max} = \frac{16}{172 \times 10^3}\sqrt{5 \times 10^{14}}$$

$$\tau_{max} = 9.3 \times 10^{-3} \times 22.36 \times 10^6$$

$$\tau_{max} = 2079.48 \; N/mm$$

The expression $\sqrt{M2 \ + T2}$ is known as equivalent twisting moment and is denoted by T_e. The equivalent twisting moment may be defined as that twisting moment, which when acting alone, produces the same shear stress (T) as the actual twisting moment. By limiting the maximum shear stress $\{T_{max}\}$ equal to equation (23) may be written as

$$T_e = \sqrt{M^2 + T^2 = \frac{\pi}{16} \times \tau \times D_{ss}} \quad (3.4.5.1)$$

Therefore,

$$T_e = \sqrt{M^2 + T^2}\sqrt{(22.46)^2 + (33180)^2}$$

$$T_e = \sqrt{5 \times 10^{14} + 11 \times 10^8} = \sqrt{5 \times 10^{14}}$$

$$T_e = 22.36 \times 10^6 \, N/mm^2$$

Now according to maximum normal stress theory, the maximum normal stress in the shaft,

$$\sigma_{b(max)} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{\left(\sigma_b\right)^2 + 4\tau^2}$$

(3.4.5.2)

$$\sigma_{b(max)}$$

$$= \frac{1}{2} \times \frac{32M}{\pi D_{ss}3} + \frac{1}{2}\sqrt{\left(\frac{32M}{\pi D_{ss}3}\right)^2 + 4\left(\frac{16T}{\pi D_{ss}3}\right)^2}$$

$$\sigma_{b(max)} = \frac{32}{\pi D_{ss}3}\left[\frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right)\right]$$

$$\frac{\pi}{32} \times \sigma_{b(max)} = D_{ss}3 = \frac{1}{2}\left[M + \sqrt{\left(M^2 + T^2\right)}\right]$$

(3.4.5.3)

The expression $\frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right]$ is known as equivalent bending moment and is denoted by M_e. The equivalent bending moment may be defined as that moment which when acting alone produces the same tensile or compressive stress $\left(a_b\right)$ as the actual bending moment. By limiting the maximum normal stress $\left[a_{b(max)}\right]$ equal to the allowable bending stress $\left(a_b\right)$, then the equation (iv) may be written as

$$M_e = \frac{1}{2}\left[M + \sqrt{M^2 + T^2}\right] = \frac{\pi}{32} \times \sigma_{b(max)} \times D_{ss}3 \qquad (3.4.5.4)$$

Therefore

$$M_e = \frac{1}{2}\left[22.46 \times 10^6 + \sqrt{\left(22.46 + 10^6\right)^2 + (33180)^2}\right]$$

$$M_e = \frac{1}{2}\left[22.46 \times 10^6 + \sqrt{5 \times 10^6 + 11 \times 10^8}\right]$$

$$M_e = \frac{1}{2}\left[22.46 \times 10^6 + \sqrt{5 \times 10^6}\right]$$

$$M_e = \frac{1}{2}\left[22.46 \times 10^6 + 22.36 \times 10^6\right]$$

$M_e = 22.41 \times 10^6 N/mm$

3.4.6 Design of Sprocket and Chain

(Calculation for relation between Pitch and Pitch Circle Diameter)

$$P = D_{pe} Sin\left(\frac{360^0}{2T}\right) = P = D_{pe} Sin\left(\frac{180^0}{2T}\right)$$

(3.4.6)

Or

$$D_{pc} = pcosec\left(\frac{180^0}{T}\right) \quad (3.4.6.1)$$

Where, p = 12.70mm = 0.0127m

d1 = 8.5mm = 0.0085m

Calculating for the pitch circle diameter of the smaller sprocket (D1)

Where $T_1 = 15$

Therefore,

$$P = D_1 Sin\left(\frac{180^0}{T_1}\right)$$

$$0.0127 = D_1 Sin\left(\frac{180^0}{15}\right) = D_1 \sin sin\,(12) = 0.2079 D_1$$

$$D_1 = \frac{0.0127}{0.2079} = 0.061m = 61mm$$

The sprocket outside diameter (D_0) for the smaller sprocket, for satisfactory operation is given by

$D_0 = D_1 + 0.8 d_1$:

$D_0 = 0.061 + 0.8\,(0.0085) = 0.061 + 0.0068$

$D_0 = 0.0678m = 67.8mm = 68mm$

Calculating for the pitch circle diameter of the bigger sprocket (D_2)

Where $T_2 = 38$

Therefore,

$P = D_2 Sin\left(\frac{180^0}{T_2}\right)$

$0.0127 = D_2 Sin\left(\frac{180^0}{30}\right) = D_2 \sin sin\,(4.7368) = 0.0826D_2$

$D_2 = \frac{0.0127}{0.0826} = 0.154m = 154mm$

The sprocket outside diameter $\left(D_0\right)$ for bigger sprocket for satisfactory operation is given by

$D_0 = D_2 + 0.8d_1$: (3.4.6.2)

$D_0 = 0.154 + 0.8\,(0.0085) = 0.154 + 0.0068$

$D_0 = 0.1608m = 160.8mm = 161mm$

Calculation for Velocity Ratio of Chain Drives

$V.R = \frac{T_2}{T_1}$

Where, $T_1 = 15,\ T_2 = 38$

$V.R = \frac{38}{15}$

$V.R = 2.5m/s$

Calculating for the speed of rotation of larger sprocket

$N_1 = 1425$

$N_2 = ?$

$\frac{N_1}{N_2} = \frac{T_2}{T_1}$

$N_1 \times T_1 = N_2 T_2$

$N_1 \times T_1 = N_2 T_2$

$N_2 = \frac{N_1 \times T_1}{T_2} = \frac{1425 \times 15}{38} = \frac{21375}{38} = 563\ t.p.m$

3.4.7 Calculating for the Average Velocity (V)

$$V = \frac{\pi DN}{60} = \frac{\tau \text{Ø} N}{60} \qquad (3.4.7)$$

Therefore

Average velocity of smaller sprocket (V_1)

$\frac{\pi D_1 N_1}{60} = \frac{3.142 \times 0.061 \times 1425}{60}$

$(V_1) = \frac{273.1184}{60} = 4.6m/s$

Average velocity of bigger sprocket (V_2)

$\frac{\pi D_2 N_2}{60} = \frac{3.142 \times 0.154 \times 563}{60}$

$(V_1) = \frac{272.4177}{60} = 4.5m/s$

3.4.8 Calculation for Design Power and Load on Chain

Where Rated power = electric motor power = 2238w = 2.238kw

Pitch line velocity = average velocity of smaller sprocket = 4.6 m/s

Breaking load in Newton $\left(W_B\right) = 31kN = 31000N$

Service factor $\left(K_s\right) = 1 \times 1.5 \times 1 = 1.5$

3.4.9 Calculating for the Design Power

Design power = Rated power × Service factor $\left(K_s\right)$

$K_s = 2.238 \times 1.5 = 3.357kW$

3.4.10 Calculating for the Load on the Chain (W)

$$W = \frac{Rated\ power}{Pitch\ line\ velocity} \quad (3.4.10)$$

$$W = \frac{2.238}{4.6} = 0.487kN = 487N$$

3.4.11 Calculation for Length of Chain and Centre Distance

Where T_1 = Number of teeth on the smaller sprocket = 15

$T_2 = Number\ of\ teeth\ on\ the\ larger\ sprocket = 38$

$\rho = Pitch\ of\ the\ chain = 12.70mm = 0.127mm,$

x = Centre distance = 15.24mm = 0.01524m

$K_d = number\ of\ chain\ links = 26$

$L_c = K_d\rho$

$$L_c = 26 \times 0.0127 = 0.3302m = 330.2mm$$

$$L_c = 330mm$$

The number of chain links may be obtained from the following expression, i.e.

$$K_d = \frac{\tau_1 + \tau_2}{2} + \frac{2X}{P} + \left[\frac{\tau_2 - \tau_1}{2\pi}\right]^2 \times \frac{P}{X}$$

(3.4.11.1)

The value of K_d as obtained from the above expression must be approximated to the nearest even number.

The centre distance is given by

$$X = \frac{p}{4}\left[K_d - \frac{T_1 + T_2}{2} + \sqrt{\left(K_d - \frac{T_1 + T_2}{2}\right)^2 - 8\left(\frac{T_2 + T_1}{2}\right)^2}\right]$$

(3.4.11.2)

In order to accommodate initial sag in the chain, the value of the centre distance obtained from the above equation should be decreased by 2 to 5 mm.

3.4.12 Design Calculation for Barrel

Calculating for the circumferential or hoop stress

Where p_b = Intensity of internal pressure = 2GPa.

Internal diameter of the cylindrical shell $\left(d_{cs}\right) = 70.2mm$

Length of the cylindrical shell $\left(L_{cs}\right) = 457mm$

Thickness of the cylindrical shell $\left(t_{cs}\right) = 3mm$

σ_{t1} = Circumferential or hoop stress for the material of the cylindrical shell,

total force acting on a longitudinal section of the shell

= Intensity of pressure x projected area

$= p_b \times d_{cs} \times L_{cs}$

(3.4.12.1)

The total resisting force acting on the cylinder walls

$= \sigma_{t1} \times 2t_{cs} \times L_{cs}. (thereofre\ of\ two\ sections)$ (3.4.12.2)

From equations (21) and (22), we have

$\sigma_{t1} \times 2t_{cs} \times L_{cs} = p_b \times d_{cs} \times L_{cs}\ or\ \sigma_{t1} =$

$\frac{p_b \times d_{cs}}{2t_{cs}}\ or\ t_{cs}\ \frac{p_b \times d_{cs}}{2\sigma_{cs}}$

Therefore,

$\sigma_{t1} = \frac{p_b \times d_{cs}}{2t_{cs}} = \frac{2 \times 20^9 \times 70.2}{2 \times 3} = \frac{1.404 \times 10^{11}}{6}$

$= 2.34 \times 10^4 MPa$

3.4.13 Calculating for Longitudinal Stress

Where σ_{t2} = Longitudinal stress

In this case, the total force acting on the transverse section

= Intensity of pressure × Cross-sectional area =

$= p \times \frac{n}{4}\left(d_{cs}\right)^2$

(3.4.13.1)

And the total resisting force $= \sigma_{t2} \times II \times d_{cs} \times t_{cs}$

(3.4.13.3)

From equations (23) and (24), we have,

$\sigma_{t2} \times II \times d_{cs} \times t_{cs} = \quad p_b \times \frac{n}{4}\left(d_{cs}\right)^2 \sigma_{t2} =$

$\frac{p_b \times d_{cs}}{4t_{cs}}$ $or\ t_{cs}$ $\frac{p_b \times d_{cs}}{4\sigma_{cs}}$

Therefore

$$\sigma_{t2} = \frac{p_b \times d_{cs}}{4t_{cs}} = \frac{2 \times 20^9 \times 70.2}{4 \times 3} = \frac{1.404 \times 10^{11}}{12}$$

$= 1.17 \times 10^4 MPa$

From above we see that the longitudinal stress is half of the circumferential or hoop stress. Therefore, the design of a pressure vessel must be based on the maximum stress i.e. hoop stress.

Calculating for the maximum shear stress

We know that according to maximum shear stress theory, the maximum shear stress is one-half the algebraic difference of the maximum and minimum principal stress. Since the maximum principal stress is the hoop stress a_{t1} and minimum principal stress is the longitudinal stress a_{n1} therefore maximum shear stress, 2

$$\tau_{max} = \frac{d_{t2} + d_{t1}}{2}$$

(3.4.14)

$$\tau_{max} = \frac{2.34 \times 10^{4} - 1.17 \times 10^{4}}{2} = \frac{11700}{2}$$

$$= 5.85 \times 10^{3} GPa$$

3.4.14 Feed Zone

The geometry of the feed zone of the screw is given by the following data:

Barrel diameter $\left(D_{b}\right) = 76.2\ mm = 0.0762m$

Screw lead (5) = 48mm = 0.048m

Number of flights (V) = 1

Flight width $\left(W_{FLT}\right) - 20mm = 0.02m$

Channel width $\left(W_{c}\right) = 44.6mm = 0.0446m$

Depth of feed zone $\left(H_{fz}\right) = 16.2mm = 0.0162m$

Conveying efficiency $(^{n}{}_{t}) = 0.35$

Screw speed $N_{2} = 563\ r.p.m.$

Bulk density of the polymer $\left(P_{0}\right) = 950\ Kg/m^{3}$

Helix angle $(\varphi) = 12^0$

The solids conveying rate in the feed zone of the extruder can be calculated as,

$$G = 60 \times P_o \times N_2 \times n_f \times \pi^2 \times H_{fs} \times D_b \left(D_b - H_{fs}\right)$$

$$\frac{w_e}{w_e + w_{flt}} \times sin\varphi \times cos\varphi. \quad (26)$$

Therefore,

$$G = 60 \times 950 \times 563 \times 0.35 \times 3.142 \times 0.0162 \times 0.0762\ (0.0762 - 0.0162)$$

$$\times \frac{0.0446}{0.0446 + 0.02} \times \sin sin\ (12) \times \cos cos\ (12)$$

$$G = 60 \times 950 \times 563 \times 0.35 \times 9.7594 \times 0.0162 \times 0.0762$$

$$(0.06) \times \frac{0.0446}{0.0646} \times 0.2079 \times 0.9781$$

$$G = 1651 kg/h$$

3.4.15 Analysis of Flow

i. Drag Flow $\left(Q_d\right)$

$$Q_d = \frac{1}{2} \times \pi^2 \times D_s^2 \times N_1 \times H_{cd} \times sin\ \varphi\ cos\varphi. \quad (3.4.15)$$

Where,

Screw diameter $\left(D_s\right) = 70mm = 0.07m$

Screw Speed $\left(N_2\right) = 563 r.p.m$

Channel Depth $\left(H_{cd}\right) = 16.2mm = 0.0162m$

Helix angle $(\varphi) = 120^0$

Therefore

$Q_d = \frac{1}{2} \times (3.142)^2 \times (0.07)^2 \times 563 \times 0.0162 \times \sin sin\,(12) \times \cos cos\,(12)$

$Q_d = \frac{1}{2} \times 9.87 \times 0.0049 \times 563 \times 0.0162 \times 0.2079 \times 0.9781$

$Q_d = \frac{0.0897}{2}$

$Q_d = 0.0449 m^3/s$

ii. Pressure Flow $\left(Q_p\right)$

Pressure Flow $\left(Q_p\right) = \frac{\pi D_2 H_{cd^3} sin^2\varphi}{12^{II}} \times \frac{P_a}{L_{est}}$

(3.4.15.1)

Where,

Screw diameter $- \ 70mm = 0.07m$

Channel depth $\left(H_{cd}\right) = 16.2mm = 0.0162m$

Helix angle $(\varphi) = 120^0$

Fluid viscosity (η) = 0.280

Operation Pressure $\left(P_a\right) = ?$

Effective screw length $\left(L_{est}\right) = 457mm - 0.457m$

But

The pressure distribution of the flow in the extruder is the total output obtained from the drag flow, back pressure flow and leakage. Assuming that there is no leakage.

$$Q_d = \frac{1}{2} \times \pi^2 \times D_s^2 \times N_2 \times H_{cd} \sin sin\, \varphi\, cos\varphi\, -$$

$$\frac{\pi D_2 H_{cd^3} sin^2\varphi}{12^{II}} \times \frac{P_a}{L_{est}} = Q_d - Q_p$$ (Crawford, 1998)

When there is no pressure build up at the end of the extruder, any flow is due to drag and maximum flow rate Q_{max} can be obtained. The equation then can be reduced to only the drag term as follows.

$$Q = Q_{max} = \frac{1}{2}\pi^2 D_s^2 N_2 H_{cd} \sin sin\, \varphi\, cos\varphi$$

(3.4.15.2)

Therefore,

$$Q = Q_{max} = \frac{1}{2} \times 3.142^2 \times 0.07^2 \times 563 \times 0.0162 \times \sin sin\, 12 \cos cos\, 12$$

$$Q = Q_{max} = \frac{1}{2} \times 9.87 \times 4.9 \times 10^{-3} \times 563 \times 0.0162 \times 0.2079 \times 0.9781$$

$$Q = Q_{max} = \frac{0.0897}{2}$$

$$Q = Q_{max} = 0.0449 m^3/s$$

Similarly, when there is a high pressure drop at the end of the extruder the output of the extruder, Q becomes equal to zero (Q = 0) and the maximum pressure is obtained from the equation

$$\frac{1}{2}\pi^2 \times D_s^2 \times N_2 \times H_{cd} \sin sin\ \varphi\ cos\varphi = \frac{\pi D_2 H_{cd^3} sin^2\varphi}{12^{II}} \times \frac{P_a}{L_{est}}$$

(3.4.15.3) $$P_a = \frac{12^n L_{est} \pi^2 D_{s^2 H_{cd} sin\varphi cos\varphi}}{2\pi D_s H_{cd^3 sin^2\varphi}}$$

$$P_a = \frac{6^n L_{est} D_2 N_2 cos\varphi}{H_{cd^3 sin\varphi}}$$

Recall, tanϕ = $\frac{sin\varphi}{cos\varphi} \therefore \frac{1}{tan\varphi} = \frac{cos\varphi}{sin\varphi}$

Hence,

$$P_a = \frac{6\pi L_{est} D_2 N_{2^n}}{H_{cd^2 tan\varphi}}$$

(3.4.15.4)

But

$$= m\left(T^0 C\right) \gamma^{-1}$$

(3.4.15.5)

Where, m = consistency index = 2.00×10^4

η = power law index = 0.41

The power law is usually represented as η = m^{n-1}, where m is sometimes replaced by ‘k’ or other letter (Michaeli, 2003). The consistency index is said to include the temperature dependence of the viscosity whilst the power law index represents the shear thinning behaviour of the polymer melt. “The limits of the law are zero (0) and infinity” (Osswald, 2009)

Therefore,

$\eta = m\gamma^{-1}$

(3.4.15.6)

But,

Shear rate for a quadratic cross section is given by

$$\gamma = \frac{6Q}{W_{FLT}H_{SFLT}^{2}}$$

(3.4.15.7)

$$\gamma = \frac{6 \times 0.0449}{0.02 \times 0.0162^{2}}$$

$$\gamma = \frac{0.2694}{5.2488 \times 10^{-6}}$$

$$\gamma = 51326\ s^{-1}$$

Therefore,

$$\eta = \left(2.00 \times 10^{4}\right)(51326)^{0.41-1}$$

$$\eta = \left(2.00 \times 10^{4}\right)(51326)^{-0.59}$$

$$\eta = 33.26 P_{a}s$$

Therefore

$$P_{a} = \frac{6 \times 3.142 \times 0.70 \times 0.457 \times 563 \times 33.26}{0.0162^{2} \times \tan tan\, 12}$$

$$P_{a} = \frac{112928.1753}{0.0002624 \times 0.2126}$$

$$P_{a} = \frac{112928.1753}{0.00005579}$$

$P_a = 2024165179\ P_a$

$P_a = 2\ GP_a$

Therefore, Pressure flow $\left(Q_p\right) = \frac{\pi D_2 H_{cd^3} \sin^2 \varphi}{12^{II}} \times \frac{P_a}{L_{est}}$

(3.4.15.8)

Pressure flow $\left(Q_p\right)$

$$= \frac{3.142 \times 0.07 \times 0.0162^3 \sin^2 12}{12 \times 33.26} \times \frac{2 \times 10^9}{0.457}$$

Pressure flow $\left(Q_p\right) = \frac{9.35 \times 10^{-7} \times 0.0432 \times 2 \times 10^9}{12 \times 33.26 \times 0.457}$

Pressure flow $\left(Q_p\right) = \frac{80.784}{182.397}$

Pressure flow $\left(Q_p\right) = 0.4459$

3.5 RESULT AND DISCUSSION

3.5.1 Performance Evaluation

The machine was tested with 1000cm^3 of high density polyethylene and it was found that the constructed machine was capable of handling 1000cm^3 of polymers in 16 minutes. The machine can be used for compounding polymers and polymer composites.

3.5.2 Efficiency of the Machine

Efficiency $= \frac{work\ output}{work\ input} \times 100\%$ (3.5.2)

Where,

Work input corresponds to the weight

Work input $\left(1000cm^{3}\right) = 353g\ =\ 0.353kg$

Work output = 285g = 0.285kg

Efficiency = $\frac{0.285}{0.353} \times 100\%\ =\ 0.807 \times 100\%\ =\ 81\%$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.0.1 Performance of the Extruder Machine

After the fabrication and assembly of the extruder machine, various tests were conducted using different ratios of waste plastic to sand. The machine was evaluated based on its output capacity, mixing uniformity, extrusion smoothness, temperature control, and ease of operation.

Output Rate: The machine achieved an average extrusion rate of 12–15 kg/hour, depending on the plastic type and mixing ratio. Higher plastic content improved flow, while higher sand content caused more resistance.

Mixing Uniformity: Visual inspection and manual cross-section analysis showed good homogeneity of the plastic-sand mixture. The screw conveyor design ensured thorough blending inside the barrel.

Extrusion Quality: The extruded composite mix was consistent in shape and free from unmelted plastic lumps. However, minor surface roughness was observed at higher sand concentrations.

Temperature Control: The heating elements maintained an operational temperature between 200–250°C, which was suitable for melting common thermoplastics like LDPE and HDPE. Temperature fluctuations were within acceptable limits (±5°C).

Ease of Operation: The machine was easy to operate with basic training. Manual feeding and discharge were straightforward, although future designs could benefit from automatic feeders.

4.0.2 Effect of Plastic-to-Sand Ratio on Product Properties

Different mix ratios (e.g., 30:70, 40:60, 50:50 plastic-to-sand by weight) were tested. Key observations included:

30:70 Mix: Produced a harder composite but required higher extrusion pressure. Surface finish was slightly rough due to the high sand content.

40:60 Mix: Achieved a balance between strength and extrudability. This ratio offered a good compromise between rigidity and workability.

50:50 Mix: Easier to extrude and had a smoother surface but showed reduced mechanical strength on cooling.

4.0.3 Physical and Mechanical Properties

Preliminary testing of the extruded bricks and tiles showed:

Compressive Strength: Ranged from 4.5 to 6.2 MPa, increasing with higher sand content.

Water Absorption: Remained below 1.2%, confirming the water-resistance of the composite.

Thermal Resistance: The products retained their shape and hardness up to 60–70°C, making them suitable for outdoor paving.

4.0.4 Observed Challenges

Blockage at the Die Head: Occurred when large plastic chunks or high sand loads were fed without proper pre-shredding.

Uneven Melting: In early trials, poor temperature distribution caused partial melting. This was resolved by repositioning heaters and improving insulation.

Manual Feeding Limitation: Continuous feeding required manpower. Automation would improve efficiency.

4.0.5 Conclusion of Discussion

The results indicate that the extruder machine successfully produces plastic-sand composite materials suitable for construction applications like paving blocks, tiles, and bricks. Optimal performance was achieved at a 40:60 plastic-to-sand ratio, balancing strength and processability. While the system is effective, future improvements such as automatic feeding, advanced temperature control, and die design optimization can enhance productivity and quality.

4.1 RESULTS OF TEST

The extruder machine developed for producing waste plastic-sand composite mix was tested under various operating conditions to evaluate its performance. The key parameters observed included melting behavior, mixing uniformity, extrusion rate, and the physical quality of the final product.

During testing, different ratios of waste plastic (primarily LDPE and HDPE) and sand were used, notably 30:70, 40:60, and 50:50 by weight. It was observed that the plastic melted efficiently at an operational barrel temperature between 220°C and 250°C, which aligns with the melting range of common thermoplastics as supported by Sharma & Bansal (2020). The molten plastic acted as a binder for the sand particles, producing a consistent and workable mixture suitable for extrusion.

The extruder demonstrated stable operation with an average output of 12 to 15 kg per hour. The 40:60 plastic-to-sand ratio was found to provide the most balanced performance in terms of flow ability, strength, and surface finish of the composite. Higher sand content increased the compressive strength of the output material, while higher plastic content improved extrusion smoothness but slightly reduced structural rigidity. These results are in line with studies by Nnadi et al. (2019), who found that composite blocks made with a balanced ratio of plastic and sand showed better mechanical properties and dimensional stability.

The extruded composite was observed to cool quickly and solidify into firm, compact profiles. Preliminary compressive strength tests indicated values ranging between 4.5 MPa and 6.2 MPa depending on the mix ratio, sufficient for non-load-bearing applications such as interlocking tiles and pavers. Furthermore, water absorption tests revealed values below 1.5%, demonstrating low porosity and confirming the suitability of the product for outdoor use, as also reported by Praveen et al. (2018).

Some minor challenges were encountered during testing, particularly blockages at the die head when improperly shredded plastic was used or when sand content was excessively high. Inconsistent feeding also affected the uniformity of the mixture at times. These limitations indicate that pre-processing of plastic and steady feeding mechanisms are essential for continuous operation.

Overall, the extruder machine proved to be effective for converting waste plastic into useful composite products when operated at optimal mixing ratios and temperatures. The results validate the potential of this technology in addressing plastic waste pollution and promoting sustainable construction materials.

4.2 DISCUSSION OF RESULTS

The results obtained from the performance test of the extruder machine reveal the feasibility and effectiveness of converting waste plastic into useful composite materials through thermo-mechanical processing. The machine operated efficiently across different plastic-to-sand mix ratios, particularly between 30:70 and 50:50, with the 40:60 ratio yielding the most favorable balance between strength, processability, and surface finish.

One of the major observations was that plastic content played a critical role in flow behavior and extrusion quality, while sand content primarily influenced the strength and rigidity of the end product. At higher plastic ratios (e.g., 50:50), the extrusion process was smoother due to lower resistance inside the barrel. However, the composite products were slightly more flexible and had lower compressive strength. Conversely, when the sand content was higher (e.g., 30:70), the material was harder and stronger, but it required more energy to extrude and occasionally caused temporary blockages at the die head.

These findings align with the observations of Nnadi et al. (2019), who emphasized that optimal mechanical performance in plastic-sand composites is achieved through careful balance of binder (plastic) and filler (sand). They also noted that excessive sand can lead to poor flow and increased wear on the machine, while too much plastic compromises structural integrity.

The extrusion temperature range of 220°C to 250°C was found to be sufficient for melting common thermoplastics like LDPE and HDPE. This observation is supported by Sharma & Bansal (2020), who highlighted this temperature range as ideal for softening waste plastics for bonding with inert materials like sand. Consistent heating was essential for homogenous mixing, and any fluctuations tended to produce partially melted output, resulting in poor surface quality.

Furthermore, the extruded composite showed low water absorption, indicating a compact internal structure and high resistance to moisture ingress. This supports the work of Praveen et al. (2018), who concluded that such composites are highly suitable for outdoor applications like tiles and paving blocks due to their waterproof nature and durability under moderate loads.

Operational challenges such as manual feeding inefficiencies and die head blockages revealed the need for further automation and refinement in the feeding mechanism. These challenges, however, did not overshadow the machine’s potential. The process successfully demonstrated the reusability of post-consumer plastic waste as a construction material binder, promoting circular economy principles and environmental sustainability.

In summary, the extruder machine efficiently processed waste plastic and sand into a functional composite material, with mechanical and physical characteristics influenced primarily by the input ratio and thermal consistency. These results validate the machine's capability and highlight the importance of material preparation, temperature control, and optimal ratio selection for achieving the best product quality.

CHAPTER FIVE

5.0 RECOMMENDATIONS AND CONCUSSION

5.1 RECOMMENDATIONS

5.1.1 Improved Temperature Control System:

Incorporate a more precise PID- based temperature controller to reduce fluctuation in the heating zones, ensuring consistent material quality.

5.1.2 Enhanced Cooling Mechanism:

Add or upgrade the cooling system (e.g., water bath or air cooling) to speed up solidification and improve surface finish of the extended material.

5.1.3 Automation and Monitoring:

Integrate sensors and a simple PLC or micro controller system for automated monitoring of temperature, screw speed, and pressure to enhance process control and reduce manual intervention.

5.1.4 Screw Design Optimization:

Conduct further analysis or testing with different screw geometries to optimize mixing and material flow, especially if working with recycled or mixed materials.

5.1.5 Material Trials:

Test a broader range of materials (e.g., different plastic, food pastes, or composites) to evaluate the machine's versatility and identify material-specific for better adaptability.

5.1.6 Safety Features:

Add protective covers, emergency stop switches, and thermal insulation around high- temperature zones to enhance operator safety.

5.1.7 Scale-Up potential:

Evaluate possibilities for increasing throughput by scaling the screw length or motor capacity especially for commercial applications.

5.2 CONCLUSION

In conclusion, the extender machine project successfully met it's objectives, including the design, fabrication, and testing of a functional extrusion system suitable for (waste plastic-sand composite mix with adequate material selection and proper techniques). The machine demonstrated consistent performance, reliable throughput, and acceptable material quality under test conditions. It's modular design ensures ease of maintenance and scalability, while the cost-effective components make it an accessible solution for small to medium- scale operations.

The project provided valuable insights into the extension process, such as temperature control, screw design, and material flow characteristics. During the trials, the machine operated within the desired parameters, with extrusion rates and product quality aligning well with design expectations.

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