UNIVERSITY OF NAIROBI

INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY

Design and Fabrication of an Injection Moulding Machine

by

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2015

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this work to my children, my parents, my siblings and my husband. God bless you all.

ACKNOWLEDGEMENT

I am grateful to the Almighty God, for His Mercy, Love and Grace, without which I would never have been able to get the scholarship and great opportunity to join INST and carry out this research.

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Finally, I acknowledge the assistance from my husband who shared his experience and ideas throughout my research.

ABSTRACT

Plastic waste remains an environmental menace around the world but more so in Sub-Saharan Africa. In Kenya, recycling of plastics has been adopted notably for making fencing posts, and this has been an object for job creation. However there is still a lot that needs to be done, bearing in mind that a lot of plastic waste still litters the environment. A table top Injection moulding machine was designed and fabricated to complement already existing efforts towards recycling. In addition to the sound environmental management option this provides, it is hoped that the machine could assist in job creation and more so at local individual levels where idle youths can find an economic activity to engage in. Tensile specimens made from Virgin High Density Polyethylene (HDPE) using the machine, were tested for Ultimate Tensile Strength (UTS) which was found to have a value of 13 MPa and Modulus of Elasticity (E) which was found to have a value of 0.9 GPa and the results are comparable to documented values which were 15 MPa and 0.8 GPa respectively. Recycled plastic was then added to the virgin plastic at various contents to obtain an optimum processing point for the machine. These samples at varying contents of recycled plastic were also subjected to tensile and three point bending test. The general observation was that addition of recycled plastic to the virgin plastic improved tensile and shear strength but declined the tensile modulus of elasticity. Addition of steel wires to the plastic at 60% recycled plastic content, improved tensile strength and modulus of elasticity. Compared to other studies, it was observed that the material obtained could be suited for low strength car bumpers. There is still room for further improvement work on this manually operated machine but results obtained so far are promising as the machine can be used to produce small plastic items such as pegs, complete toys or toy parts, beads and other small plastic items.

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LIST OF ABBREVIATION

ASTM	American Society for Testing and Materials
CWC	Clean Washington Center
GIZ	Deutsche Gessellschaft fur Internationale Zusammenbeit
GOK	Government Of Kenya
HDPE	High Density Polyethylene
IAPD	International Association of Plastics Distribution
ILSS	InterLaminar Shear Strength
INST	Institute of Nuclear Science and Technology
ISP	International Science Programme
KNCPC	Kenya National Cleaner Production Center
KNEB	Kenya Nuclear Electricity Board
MDG	Millennium Development Goal
NACOSTI	National Commission of Science, Technology and Innovations
PE	Polyethylene
PHS	Plastic Historical Society
PP	Polypropylene
PWMI	Plastic Waste Management Institute

RMA	Rubber Manufacturers Association
SEM	Scanning Electron Microscopy (Microscope)
UTS	Ultimate Tensile Strength
VOC	Volatile Organic Compounds

CHAPTER 1

INTRODUCTION

1.1 Background

The long-term strategic plan for Kenya, Vision 2030 (G.O.K, 2007), and the Millennium Development Goals (MDG) all seek to eradicate poverty by ensuring that society is engaged in economic activities that are sustainable. Sustainability involves interconnection of ecology, economics, politics and culture. Therefore in order to attain the visions spelt out in the above development blue prints there is need to consider the effect of a potential economic activity on the environment and ensure that it is politically and culturally acceptable.

For example, the plastic manufacturing industry in Kenya offers employment to many in the population. This is due to the high number of applications that plastics have in our everyday life. However, at the end of their usefulness most of this plastics are dumped haphazardly making this business ecologically unsuitable. This situation can however be changed since most of this waste plastics are High Density Polyethylene (HDPE), which is used for packaging in most supermarkets and shopping stores. HDPE is a thermoplastic and therefore recyclable. If Kenya embraces recycling of plastics in her culture, this would mean creation of employment and in a way that is friendly to the environment. Recycling efforts have been seen where plastic wastes are turned into fencing posts. However the machines used here are bulky, consume large amounts of electricity, and will need high capital to venture into. There is therefore need to downscale recycling to complement the efforts already in place while also addressing the unemployment issue.

Dumping of waste tyres is another issue of concern in Kenya. Tyres are made mostly from rubber, with steel wires, fibers and other miscellaneous constituents. Old tyres in Kenya will be retreaded by local artisans (in Jua Kali cottage industries), a situation that could be responsible for some of the road accidents in Kenya. Tyres that are can no longer be retreaded are dumped carelessly, or end up being burnt down, a situation that pollutes the environment. The steel wires so generated are left to rust away, resulting in more pollution, or they are sold to scrap metal dealers. This research explores use of this steel wires with recycled plastics as a potential material that could be useful and hence mitigate the waste dumping problem.

1.2 Problem statement

Plastic waste remains a serious environmental menace in most parts of Sub Saharan Africa (Bashir, 2013), although in Kenya there have been efforts geared towards recycling, where plastic wastes are recycled into fencing posts there is still a lot of plastics littering the environment. Engaging in plastics recycling remains the preserve of individuals who can afford the high initial capital required to buy the big recycling machines, which will also require large room and use of large quantities of electricity making the overall running cost too high for many. And keeping in mind that most of the unemployed people in Kenya are the youth, there is a felt need to come up with innovations that provide an avenue for self-employment, that do not require a high initial capital investment and overall running cost. According to Kenyan government figures the youth account for over 61% of the unemployed (G. O. K, 2015). Most of this youth are wasting away in drug and alcohol abuse. There is therefore need to provide employment for the youth. The objective of this study is to design a moulding machine that can be used to produce useful products from plastic wastes.

The study goes further and investigates potential inclusion of steel wires from old tyres in recycled plastics, as a potential material for various applications. This is motivated by the fact that old tyres are also dumped in ways that lead to environmental pollution and destruction of aesthetics in the dump site. Some old tyres are also retreaded at the Jua kali sector posing a serious risk of accidents on the roads. Burning of old tyres is known to produce pollutants to air soil and water. Hence, the study explores an application of the steel wires from old tyres that is not detrimental to the environment.

1.3 Justification

The advent of plastics for various packaging uses has only served to aggravate what was already a serious waste management crisis in Sub Saharan Africa. Plastic wastes are an environmental menace because they are not biodegradable and it takes many years for these wastes to wear out (Verma, 2009). This research sort to design a machine for plastic recycling made from locally available materials, one that would consume less room and power compared to already existing industrial machines. This would ensure that the machine is affordable to the average Kenyan, and this would create an avenue for employment creation and income generation.

1.4 Scope

The work in this study involves design and fabrication of a plastic injection moulding machine for plastic recycling. To test use of the machine, samples will be made from plastic and later the plastic will be reinforced with steel wires from old tyres. This samples will be subjected to mechanical testing to gauge the strength of the products.

1.5 Objectives

Overall objective

The overall objective of this research was to develop a versatile injection moulding machine from locally available materials for plastic recycling.

Specific objectives

The specific objectives are;

1. Design and fabricate a table top injection moulding machine.
2. To compare tensile properties of samples made from virgin HDPE using the machine with other documented values.
3. To assess the effect of addition of recycled plastic to the mechanical properties of the virgin plastic
4. To develop a composite material from the highest recycled plastic content and steel wires from old tires.
5. To characterize the mechanical properties of the composite, and asses possible applications for the composite.

CHAPTER 2

LITERATURE REVIEW

2.1 Plastics

2.1.1 Background

The word plastic is derived from the Greek word “plasticos” which means to be moulded or shaped by heat (PHS., 2014, BTRN, 2014). Modern plastics are mainly derived from natural materials such as oil, coal and natural gas but crude oil is the main raw material. From the distillation of crude oil, Naphtha is obtained and this provides the chemical building blocks for making of plastics. Plastics can broadly be classified as thermoplastics and thermosetting plastics. Thermoplastics undergo strong molecular motion when heated which causes them to soften, they will harden when cooled but repeated heating and cooling allows them to be moulded into a variety of shapes (PWMI, 2009). Thermosetting plastics on the other hand soften on heating and can be moulded when soft, but on cooling they settle into the moulded shape. Subsequent heating will not soften them and it is therefore not possible to recycle them.

An important advantage of thermoplastic over thermoset composites is recyclability (Chu and Sullivan, 1996). They also have a near infinite shelf life, are four times tougher than comparable thermosets and are insensitive to chemical attack (IAPD, 2010). In addition, whereas thermoplastics are heated, moulded and cooled rapidly, thermosets have to be held at a certain temperature for a period of time, and therefore thermoplastics have a significant savings on process energy costs. But most importantly thermoplastics are a green solution since they can be fully recycled and little or no Volatile Organic Compounds (VOC) are released in the process (IAPD, 2010). Johnson (2014) points out one disadvantage of thermoplastics: the resin is normally in solid state and much more difficult to impregnate with fibers. Heating of thermoplastics makes them molten and in most cases highly viscous, a situation that makes it quite difficult to mix the plastic with fibers. Table 2.1 shows some common thermoplastics and their symbols.

Table 2.1: Plastic recycling symbols

RECYCLING CODE	ABBREVIATION AND NAME
1 PETE	Polyethylene terapthalate
2 HDPE	High Density Polyethylene
3 V	Polyvinyl Chloride
4 LDPE	Low Density Polyethylene
5 PP	Polypropylene
6 PS	Polystyrene
07 O	Normally a combination of some of the above plastics (Other)

2.2 Processing of plastics

A variety of forming techniques are used in the processing of plastic materials, but the choice of method is dependent on several factors. Callister (2007) and Crawford (1998) cite the following factors:

i) Whether the material is a thermoplastic or a thermosetting plastic;

ii) If thermoplastic, the temperature at which it softens;

iii) The atmospheric stability of the material being formed; and

iv) The geometry and size of the finished product.

Processing of the thermoset polymer involves curing of the liquid polymer by heating and allowing cooling, or by addition of a catalyst to enhance the curing process. The product may then be removed from the mould.

In general, the choice of a processing technique is dictated by the way the part is designed, choice of material, production requirements and cost-performance considerations (Ebewele, 2000). There are many polymer processing techniques such as; extrusion, injection moulding, blow moulding, vacuum forming, extrusion blow moulding, rotational moulding calendaring, foaming and compression moulding. This study focuses on Injection moulding. By definition, injection moulding is the shaping of rubber or plastic articles by injecting heated material into a mould.

Crawford (1998) describes a brief history of injection moulding. The first injection moulding machine was patented in the United States in 1872, but it was in the 1920's that renewed interest in the process was awakened in Germany, with the making of manually operated machines. The first injection machines similar to modern ones were made in the 1950's. Injection moulding is one of the most common plastic processing techniques, the polymer in granule form is heated and fused and then forced into a closed mould. Figure 2.3 gives an overview of the important parts of the injection-moulding machine where a rotating screw pushes the plastic pellets through the heated barrel of the injection machine and at the nozzle forces the molten plastic into the mould.

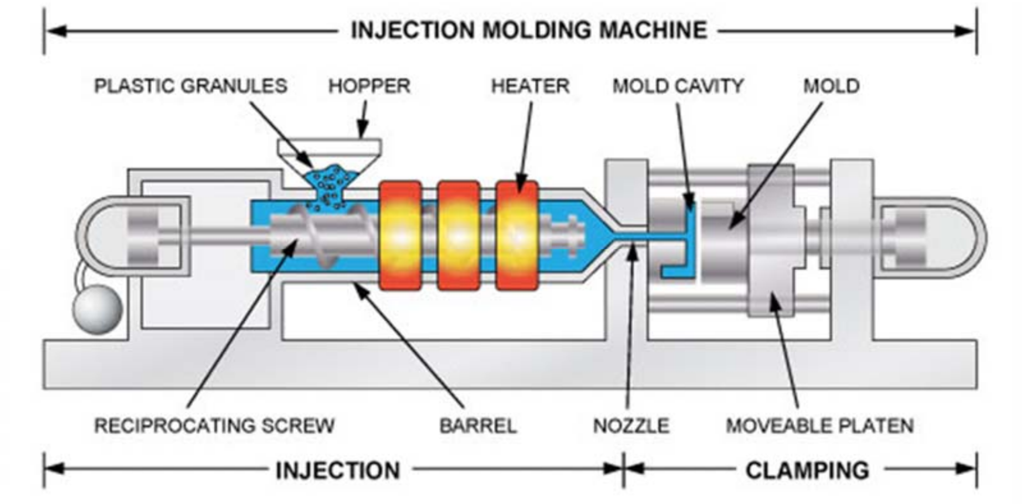

Figure 2.1: Injection moulding process components (Google, 2014)

2.3 Recycling of plastics

Statistics indicate that the amount of plastics in the world in 2008 alone was 245 million metric tons (Statista, 2014). Comparison of consumption figures between 1990 and 2005 indicate that annual metal consumption duplicates once in every nine years while that of plastics duplicates once in every four years (Meran et al., 2007). This increased use of plastics is attributable to the fact that plastics, though derived from non-renewable sources, have lightweight, low cost, are chemically inert and have good strength properties. These many advantages are however overshadowed by the limited amount of reused plastics (Richard et al., 2011). Plastics are not biodegradable and therefore nature cannot absorb them, consequently most of the waste plastic is accumulated, buried or incinerated in legal or illegal landfills, these results in wastage of this resource and impacts negatively on the environment. Combustion of wastes in dumps has the advantage of prolonging the life of the dump, while controlling pests and disease vectors, but this produces toxic gases with carcinogenic effects (Gaggino, 2012).

In developing countries and Kenya in particular, plastic bags are a serious environmental menace. They are difficult and costly to dispose, and they take around 300 years to photo degrade and break down into tiny toxic particles that contaminate the soil and water bodies and find their way into the food chain (Verma, 2009).

In view of the above statistics, and bearing in mind the obvious consequences of poor management of plastic waste, the world is now turning its attention towards recycling of plastics as one of the ways of embracing sound environmental management. Picuno et al. (2012), aware of the amount of plastic waste generated from the agricultural industry in Europe, endeavored to investigate the possibility of regenerating films for reuse from the generated wastes and found that by combining the wastes in certain ratios, reusable material could be obtained that has reasonable mechanical properties. Okuwaki (2004), analysed the feed stock recycling system in Japan and pointed out ways in which the cost could be lowered by involving participation of all stake holders in the plastic industry right from producers, collectors of the waste, legislators and consumers of plastics. Zhang et al (2007), studied the situation of plastics recycling in China and in particular the economics and technology of pyrolysis and pyrolysis upgrade, a process used to convert plastics to oil. They made various recommendations for upgrade of the pyrolisis process to effectively and economically contribute to plastic waste management.

In Kenya, efforts at recycling plastics have been seen extensively where plastic waste has been converted into fencing posts. However, according to a report by Kenya National Cleaner Production Center (KNCPC, 2006), Nairobi alone still produces plastic waste at a rate that outpaces its capacity of collection and disposal. The report further proposes an action plan that involves Reduce, Reuse and Recycle of plastics.

2.4 Steel wires from old tyres

Most tyres will contain steel wires of between 15 to 20 % (Agnihotri and Rani, 2014; RMA, 2005), the other components will include natural and synthetic rubber, carbon black and other miscellaneous constituents. In countries where recycling of this steel wires is adopted for commercial purposes, magnets are used to separate the wires from the rubber (CalRecycle 2013; Agnihotri and Rani, 2014), In most developing countries these tyres will be disposed without much regard to the environment.

According to a Deutsche Genessellschaft fur Internationale Zusammenarbeit (GIZ) report (GIZ, 2014), 34,000 tons of waste tyres were haphazardly disposed in Kenya in 2010 alone, a situation that results in pollution of water, soil and air. Most disposal involves burning of these tyres and in some instances the steel obtained is sold to scrap dealers, while in some instances these steel wires are left to rust away leading to destruction of the aesthetics of the area, while polluting water and soil. This research incorporated steel wires from old tyres into recycled plastic, to produce a composite, whose mechanical properties were gauged and used to suggest a possible use of the composite material.

2.5 Scanning Electron Microscopy (SEM)

SEM is used where surface or near surface information is required of a specimen. It is a powerful tool used in examination of materials, in virtually every field of science and technology including metallurgy, biology, geology, medicine etc. Its principle of operation is that a beam of electrons generated by a suitable source is accelerated through a high potential field and at the same time focused to pass through a system of apertures and electromagnetic lenses to produce a thin beam of electrons. The beam is moved to scan the surface of the specimen by scanning coils and the secondary electrons and/or backscattered electrons from the specimen are collected by a detector/detectors, which converts their kinetic energy to an electronic signal. The signal carries the information of the surface structure and it is amplified, digitized and stored in computer memory prior to displaying on a television screen or computer monitor.

SEM has been used extensively in material science research, mostly to study surface morphology and to analyze the interface between reinforcement fibers and the matrix material. Huda et al (2012) made a composite from Polyactide and poultry fibers and they used SEM to study the effect of treating the feathers with coupling agents on fiber matrix adhesion. The micrographs obtained gave weight to findings of mechanical tests carried out, that adding the coupling agents improved the adhesion. Mordike and Lukac (2001) used SEM and electrical measurements of acoustic emissions to prove that the properties of composites depend on the interfacial bond between the matrix and reinforcement. Reddy and Yang (2010) used kenaf fibers and milkweed fibers to reinforce Polypropylene and they used SEM to compare the structure of the fibers and the interfacial bond between the matrix and the two different types of reinforcement. They concluded that the milkweed was a better reinforcement as its fibers were hollow, hence lighter and therefore more fibers could be used for reinforcement without increasing the density of the composite, making it a suitable composite for automotive applications. A natural fiber hybrid composite was developed by Adekunle et al. (2012) for use in technical applications. In addition to carrying out mechanical tests, they used SEM to study the microstructure of the composite. Using injection moulding process, Vivekanandhan et al. (2012) made a composite from Polytrimethylene terephthalate and carbon fibers and studied the effect of the reinforcement on the thermal, mechanical and dynamic mechanical properties of the composite. Using SEM they were able to study the microscopic properties of the composite.

CHAPTER 3

DESIGN AND FABRICATION OF PLASTIC INJECTION MOULDING MACHINE

3.1 Fabricated Injection Machine

A screw-type plastic injection machine was fabricated and has two main units, heating unit and injection unit (Figure 3.1), where the heating unit consists of the heating elements and the barrel, while the injection unit is the screw and the nozzle. Due to the size of the mould and cost implications, the machine is hand-operated but could be incorporated with a prime mover for large-scale production of sample.

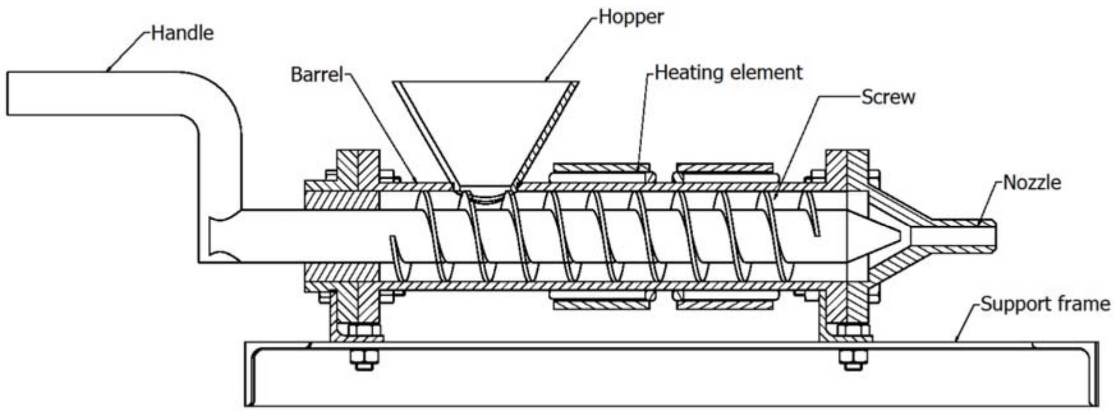

Figure 3.1: Main components of the fabricated hand operated plastic injection machine

3.2: Design Considerations

Barrel Capacity

When designing the barrel for the plastic injection machine, a single stage plasticizing machine was chosen. Single stage means that the melting and injection takes place simultaneously, such that when the screw is turned the melting of the plastic is taking place and what is molten is at that very time being injected into a mould. This ensures melt homogeneity (SABIC, 2008). The barrel capacity depends on the maximum volume of the plastic component to be formed. The barrel dimensions were selected in a way that 40-70% of the barrel was utilized. The selection is particularly useful when positioning the hopper. The main design parameters of the barrel included the internal diameter, the length and the wall thickness and the following factors:

1) The number of samples to process per operation. This would determine the internal volume of the barrel. In this case, 1 sample per operation was required. The design was based on the bending test samples, which had the larger volume of 37,200 mm^3, this would then be the internal volume of the barrel since only one sample was to be produced per operation (see Figure 3.2).

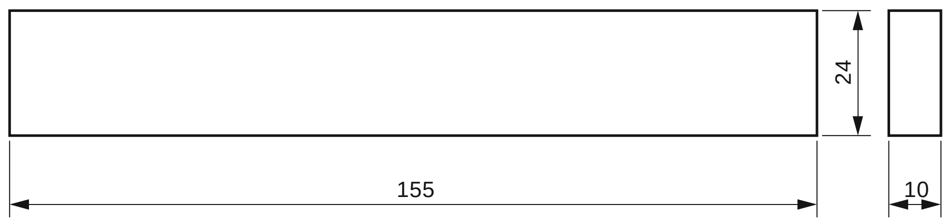

Figure 3.2: Sample used to determine volume of the barrel.

2) The root diameter of the injection screw, was selected as 25 mm, based on available materials and design recommendations from SABIC (2008).

For specimen volume, V_s, a utilization factor u_f = 60%, and accounting for material losses such as sprues, runners and gates in the mould, the required barrel capacity, V_c,, is given by:

$$V_c = \frac{V_s}{u_f} \text{...} 3.1$$

The volume of the Cylinder technically referred to as the barrel is given by equation 3.2;

$$V_c = \pi r_i^2 L \text{..} 3.2$$

where r_i is the internal radius of the chosen barrel, L is the length of the barrel (to be calculated);

Using the above equations therefore, where the required volume of the barrel is calculated using the first equation, and a hollow mild steel barrel of internal diameter of 43 mm had already been acquired, the barrel length was calculated to be 250 mm. This gave a length to diameter ratio (L/D) of 6:1. These considerations were the basis of fabricating a barrel with an internal diameter of 43 mm and length 250 mm. The external diameter of the barrel was 51mm, and therefore the thickness of the barrel wall was 4 mm. With this thickness and using the heaters, it was possible to attain the set temperature on the controller within 30 minutes. Barrel thickness is important, since the band heaters are placed on the barrel, and therefore it was important to consider this when choosing the barrel.

Screw Design

The dimensions for a typical screw for injection moulding are shown in figure 3.2 as proposed by BASF (2006) who also describe the functions of the screw in the plastic injection moulding process to be: (1) conveying the material through the barrel; (2) mixing the material to proper molten state; (3) compressing the material to proper density; (4) forcing the material into the mould.

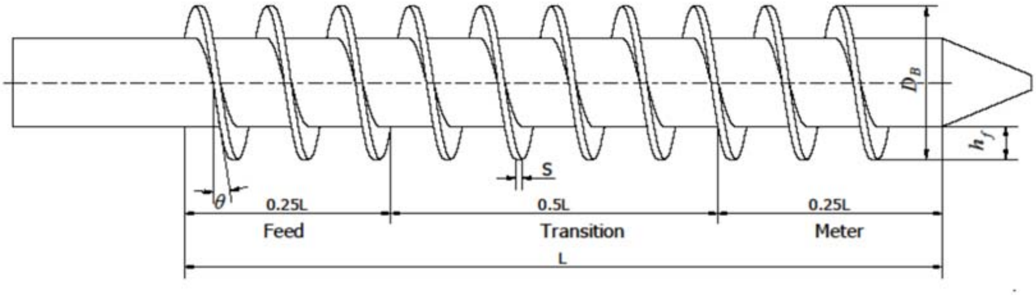

Figure 3.2: Design dimensions of the screw.

In fabricating the designed screw, a minimum ratio L/D of 6/1 was used based on dimensions used in section 3.2 on barrel capacity. A square pitch screw with a slightly varying diameter between the feed section and metering section was fabricated and a compression ratio of 1.5:1. The recommended compression ratio for plastic materials is 3.0:1 (SABIC, 2008), but this could not be achieved due manufacturing limitations. The dimensions of the screw that was developed and used are; an outer diameter of 43 mm, an inner diameter of 25 mm, a flank(S) of 2mm and a helix angle of 20^0.

The injection screw should be constructed of materials that provide a good balance of abrasion and corrosion resistance. Table 3.2 shows the recommended barrel and screw materials for plastic moulding and also for reinforced plastics. However, due to availability of materials and costs, mild steel was selected for the fabrication of the screw.

Design of the nozzle

According to SABIC (2008) nozzles should be as short as possible in order to provide unrestricted flow of the molten plastic and there are two commonly used nozzle designs: (1) Open channel (2) Tapered channel. Open channel design is recommended by TempRite (2009) for processing plastics since it reduces pressure loss and shear heat to the material they further recommend that nozzles be provided with a separately controlled heater band. It was not possible to provide a separate heater for the nozzle in the current design due to the nozzle size, location and cost implications. An open channel nozzle was used, since there was no separate heater element for the nozzle and to avoid clogging at the nozzle, a mild steel nozzle 35mm in length and 10mm internal diameter was fabricated (a short nozzle). Bozelli (2011), points out thermocouple placement as a major issue for nozzle temperature control, as this has effect on the melt temperature to avoid such defects as sink marks. Due to budgetary limitations, a compromise was reached where the thermocouple was placed at the flange between the nozzle and the barrel.

Table 3.1: Barrel and screw recommendations for plastic materials (BASF, 2006).

Ultramid Material Type	**Wear Environment**	**Base Material**	**Screw Flight O.D.**	**Root**	**Barrel Liner**
Homopolymers and unfilled polymers	Standard	ANSI 4140 or Nitrided Steel	Nickel Alloy	Chrome plated	Bimetalic A
Filled Material <20% loading	Abrasive	Nitrided Steel	Tugsten Carbide +Nickel alloy	Nitrited Steel	Bimetalic B
Highly filled material >20% loading	Highly Abrasive	Bimetallic Screw	Tungsten Carbide composites	Tungsten Carbide composites	Bimetalic B
Bimetalic A Chromium-modified boron-iron alloy containing 5 to 7% nickel Bimetalic B Tungsten Carbide Composite					

Hopper Positioning

The hopper loads raw plastic to the heating chamber within the barrel. In order to utilize a large section of the barrel (40-70%), the location of the hopper is important (TempRite, 2009). Therefore the hopper was placed as close as possible to the inlet end of the barrel, and this allowed room (up to 70% of the barrel) for heating of the plastic.

Clamp Selection

The clamping force must be adequate enough to overcome the high injection pressure required to fill the mould cavity. The commonly used clamping types include: (1) Hydraulic clamps; (2) Toggle clamps; (3) Screw operated clamps. The selection of clamping mechanism depends on the size and application of the injection moulding machine, and the size of the mould. Large machines are normally equipped with a hydraulic clamp since it is able to develop large clamping forces. On the other hand small injection machines are normally fitted with screw type clamping devices. In our research, the table top injection moulding machine is small and therefore a screw type clamping device was used (an ordinary G-clamp).

The minimum clamping force (F_c) required can be calculated from:

$$F_c = A_c \times P_c \quad \text{......3.3}$$

Where A_c is the projected area of the mould cavity and P_c estimated pressure which is 31 – 47 Mpa for unreinforced polymers and 47 -78 Mpa for reinforced polymers.

Selection of the Band Heaters

Heaters surrounding the barrel provide the heating energy to melt the material in the screw channel. Commonly used sources of heat include electric, hot oil or steam. Additional heat is provided by the shearing of the material and friction between the moving parts of the machine. Electric heating source is the most commonly used source due to ease of integration and control of temperature and heaters are referred to as band heaters. Their selection and sizing depend on the barrel capacity, length and the required heating period. BASF (2006) recommends a minimum of three band heaters corresponding to the three functional zones of the screw (Figure 3.2). However, the barrel length of the current fabrication allowed only two band heaters, which were rated at 250 W and 500 W. A K-type (immersion type) thermocouple was chosen (it operates over a wide range of temperatures) was used for the measurement of the molten plastic temperature at the injection point.

CHAPTER 4

MATERIAL AND METHODS

4.1 Materials

4.1.1 Plastics and Injection Machine

Waste HDPE plastic bag flimsies were procured from a local recycler. To ease processing, some virgin HDPE was also added to the recycled plastic to ease processing.

The injection machine barrel, nozzle, shaft and screw/worm were locally made from mild steel. The heating coils were covered with aluminium sheets and the machine was insulated using asbestos. A K-type Chromel (Nickel-Chromium), Alumel (Nickel-Aluminium) thermocouple was used for sensing the temperature of the molten plastic.

4.1.2 Specimen moulds

The specimen moulds were made of aluminium using casting process. Aluminium was chosen mainly due to its availability and ease of casting, in addition to the fact that it would retain some heat once heated, and therefore ease flow of the molten plastic during sample preparation. Plastic samples with 60% recycled plastics content were reinforced using steel wires.

4.2 Methods

4.2.2 The injection machine

The object of this research was to design an injection moulding machine and fabricate it from locally available materials to make it low cost. The machine was meant to be versatile and consume power as is available in Kenyan homes as opposed to the large industrial systems that consume large amounts of power. The motivation was a glue gun, which uses polymer glue sticks. After getting a suitable barrel, the initial idea was to use a plunger to push the molten plastic out of the machine. This however proved inefficient, as some of the plastic pellets came out of the machine in solid form. A screw/worm was introduced to push the pellets through the barrel, while stirring them, hence ensuring a uniform melt was obtained at the outlet (Figure 4.1).

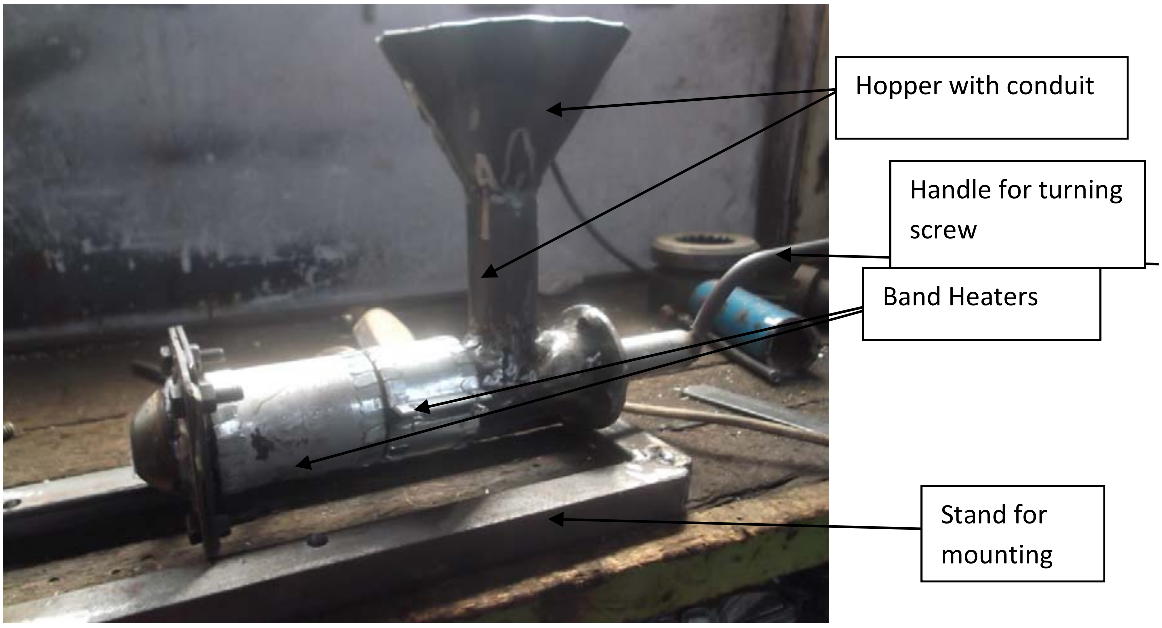

Figure 4.1: The injection moulding machine initially.

Later modification included addition of a nozzle at the outlet to ease coupling of moulds to the injection machine, and removal of the conduit from the hopper to the barrel, as this was viewed as a bottleneck that resulted in pellets melting and clogging before entry to the barrel, resulting in wastage of material. Moreover, a thermostat was added to the electrical connections, as a means of temperature control (Figure 4.2) and was calibrated using a multimeter.

Figure 4.2: The modified injection machine with a nozzle at the outlet, the hopper directly lying on the barrel and with a thermostat for temperature control.

Further modifications involved the upgrade of the temperature control system, from the use of the thermostat to use of a K-type thermocouple and temperature controller, which closely resembled systems used in industry. The thermocouple was a better temperature gauge, as it went right into the molten plastic, unlike the thermostat that gave an approximate melt temperature, as it was anchored underneath the heaters. The thermocouple was inserted at the flange near the nozzle, and it therefore gave the final temperature of the melt before it exited the injection machine. An additional modification was the insulation of the machine with asbestos to retain most of the heat energy in melting the plastic to the right viscosity (Figure 4.3).

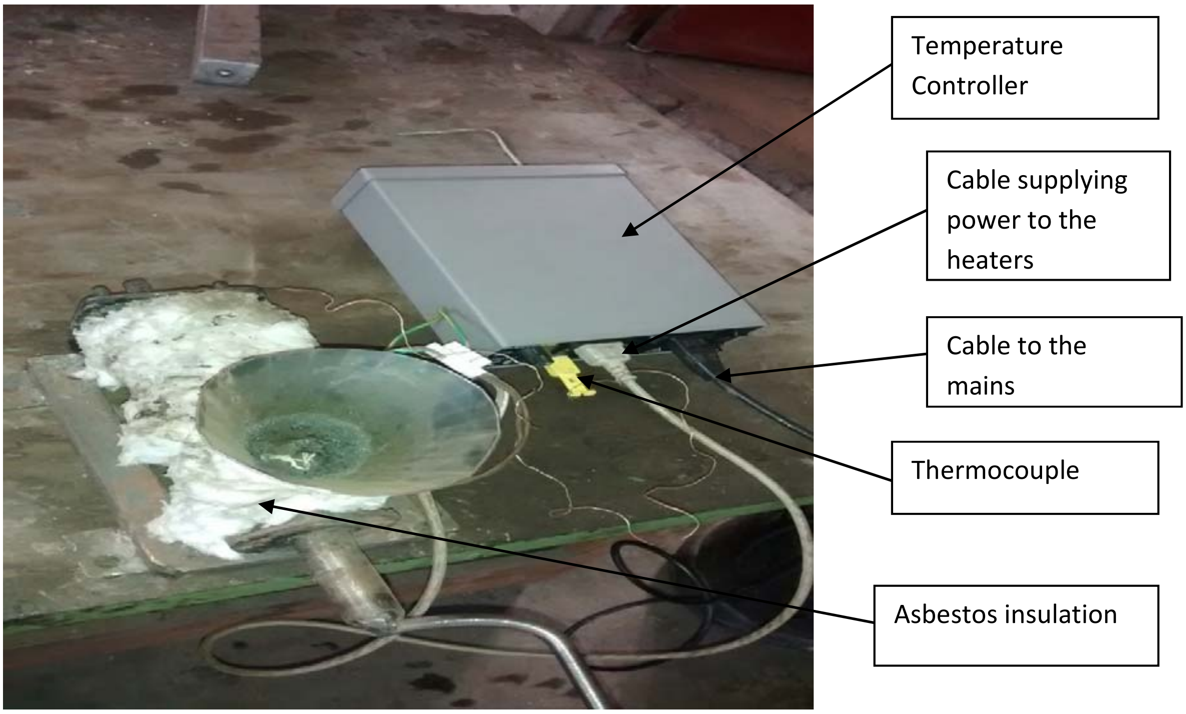

Figure 4.3: The injection machine with the asbestos insulation covering the heaters, with a K-type thermocouple inserted at the flange near the nozzle and connected to the temperature controller on the right side.

4.2.3 Fabrication of the moulds

The moulds used to make the tensile and three point bend test specimens were made by casting aluminium. Using specimen specifications from the respective standards, a sketch was made of the required shape, with 1.3% increase in dimensions for shrinkage allowance, this was done since aluminium tends to shrink by 1.3% once poured as it cools and may therefore not meet the standard specifications, therefore to meet the required dimensions, this adjustment is necessary. The mould was to be made in two halves, and therefore a piece of wood was planed to half the thickness of the desired specimen and another piece to make up the other half. Using the prepared sketch, the required design was reproduced on the two pieces of wood, which were then cut to produce a cavity with a shape of an exact replica of the desired specimen shape. And to these thin pieces backing pieces of wood were joined, such that the resultant pattern would be a cavity in a block of wood, as shown in figure 4.4. A dowel is put on one half of the pattern while a hole is sunk on the other half to make it possible to match the two halves. Sand paper was used to smoothen out rough parts on the wooden pattern. Some graphite was applied on the wooden patterns before putting them in casting sand, in preparation for casting (Figure 4.4).

Figure 4.4: The wooden patterns sprinkled with graphite.

Reused sand was mixed with bentonite and water for the aluminium casting. These constituents were mixed to ensure there were no lumps in the sand. The wooden pattern was then positioned upside down on the floor, a drag was positioned around it and sand was sieved in to cover the pattern. The sand was rammed around the pattern after more sand was added until the mould slightly protruded at the bottom of the drag. After scrapping off the excess sand the drag was turned right way up. Parting sand was then sprinkled on the mould surface after ensuring the edges of the pattern were completely covered by sand. The cope was then located accurately to interlock the drag, and the locating dowels were used to locate the other half of the pattern. Runner and riser pipes were located in place, and the same procedure of sieving sand and ramming was repeated. Vent holes were made on the mound carried in the cope. Eventually the wooden patterns were removed from the sand and any loose sand was blown off using air bellows.

The patterns were now ready for casting and aluminium scraps were heated in a crucible. When the scraps attained a putty condition, Coverall II was added to prevent oxidation and improve fluidity. The temperature was then raised to the required 750 ^{0}C, and the surface flux cover was pushed to one side, and Degasser 190 tablets were plunged to the bottom of the melt to help in degassing the molten metal. Nucleant II tablet, was used for grain refinement and the molten metal was poured into the sand prepared previously to obtain the desired patterns. Figure 4.5 shows the resultant mould, which is rough and required finishing work. The rough edges were removed by grinding and since the dowels for the male parts of the mould were worn out during finishing work holes were drilled on the female half and pins with similar external diameters were put on the male half. This was to ensure the mould closed well during injection moulding and aligned to the pattern to ensure the product had the desired size and shape.

Figure 4.6 shows a pictorial appearance of the three point bending-test mould after finishing. On the same figure drilled holes are seen at one end of the mould for easing coupling to the injection machine, while at the other end the holes were provided for venting air thus preventing the produced plastic specimens from having voids. Subsequent modifications in the moulds were made during addition of the reinforcement to the plastic. This involved additional pins being added to the moulds to be used for anchoring the reinforcement wires and to ensure that the required reinforcement of unidirectional lamina was achieved (Figures 4.7).

Figure 4.5: The mould after casting showing rough edges.

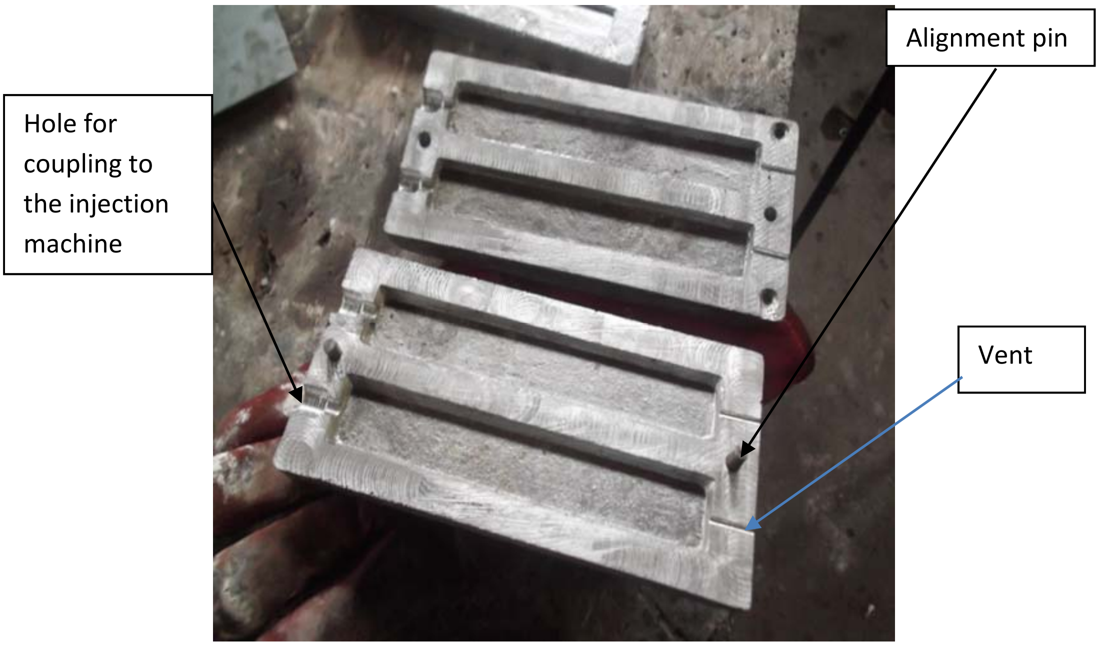

Figure 4.6: The three-point bend-test mould after the finishing work.

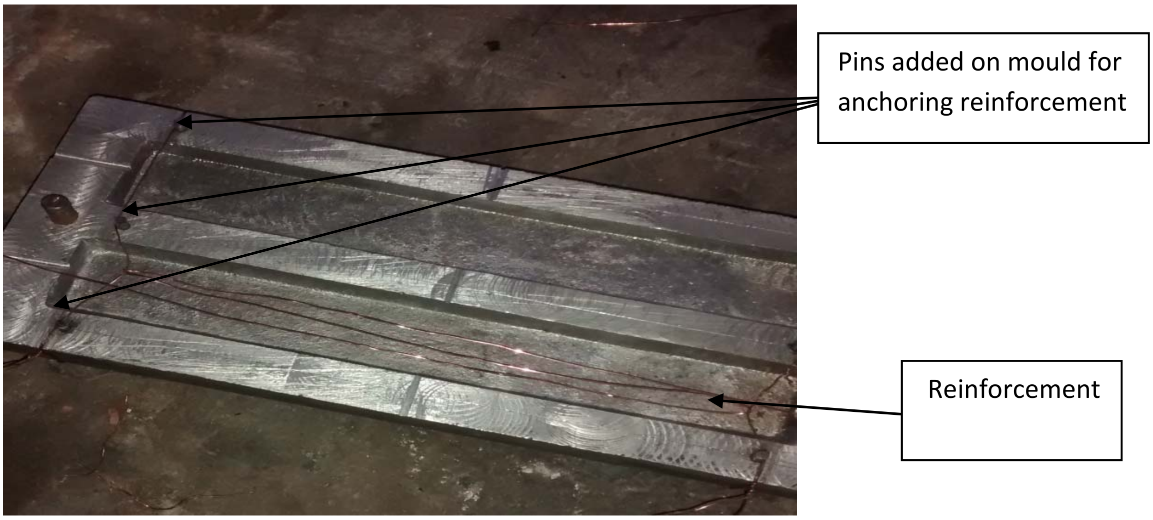

Figure 4.7: Moulds for the three-point bending-test show added reinforcement anchoring pins.

4.2.4 Specimens production

Injection moulding of recycled plastic material alone resulted in a molten form with poor flow into mould cavities and products with a large number of voids. Virgin plastic was added to the recycled and was observed to improve the properties of molten form thus easing the process of the mould production. Specimens for tensile and three-point bending tests were prepared from virgin HDPE plastic followed by others HDPE with a content of 20%, 40% and 60% recycled plastic. It was observed that beyond 60% content, it was not possible to produce samples due to increased viscosity. During the sample production process the machine was allowed to heat for 30 minutes to the set temperature on the controller. Table 4.1 shows the temperature used to prepare specimens at various recycled contents. This temperature was varied to improve melt flow as the amount of recycled plastic was increased.

Table 4.1: Variation of process temperature with increased recycled plastic content.

Description	**Processing temperature ^{o}C**
Virgin plastic	210
20% Recycled content	225
40% Recycled content	240
60% Recycled content	260
Steel Reinforced	260

Since the machine used is manually operated, there was a limitation as to the speed with which the machine could be operated therefore to compensate for the high viscosity at higher plastic content that resulted in poor flow into the moulds, the melt temperature was increased at higher recycled plastic contents. But even to the temperature increase, there was a limit since temperatures higher than 260 were seen to result in specimens that could easily be broken by hand, suggesting that high temperatures destroyed the structure of the plastic, hence poor samples. Figure 4.8 shows the setup for sample production.

The process involved pouring the plastic pellets at the hopper, and turning the screw to mix the pellets to facilitate a uniform melt. The two halves of the mould were clamped together using a G-clamp. Once the samples were removed from the mould some finishing work had to be done. This involved removing the excess plastic, that took the shape of the entry to the mould and the vents once the mould cavity was filled with plastic, and smoothening the long edges of the three-point bending-test specimens, to testing-machine fit.

Figure 4.8: Sample preparation process.

4.2.6 Mechanical testing

Two mechanical tests were done on samples produced: tensile test and three point bending test. The Hounsfield tensometer (Type W from the Tensometer Ltd) was used for both tests.

4.2.6.1 Tensile test

This test was conducted in accordance with ASTM D3039/ D3039M - 08 (ASTM, 2008) and the dimensions of the test specimen is shown in Figure 4.10. The tensometer used for the test, had crosshead speeds of 0.03 m h^{-1}(5mm/min). Thirteen samples for each plastic mixture of virgin plus and a percentage of recycled plastic: 0%, 20%, 40% and 60% were tested. 60% recycled plastic content was used to make reinforced specimens with specimens of 14.4% steel reinforcement.

Figure 4.9: Test specimens: On top left are samples for compression test, samples for tensile test on top right and for the three-point bending test at the bottom of the picture.

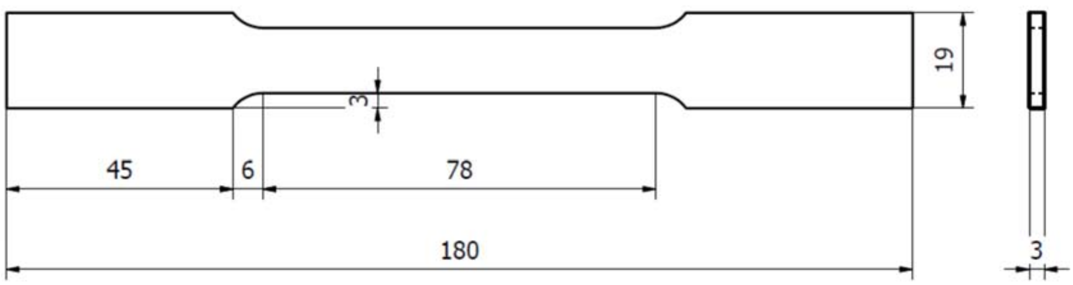

Figure 4.10: Dimensions of the tensile test specimen in Millimeters (mm).

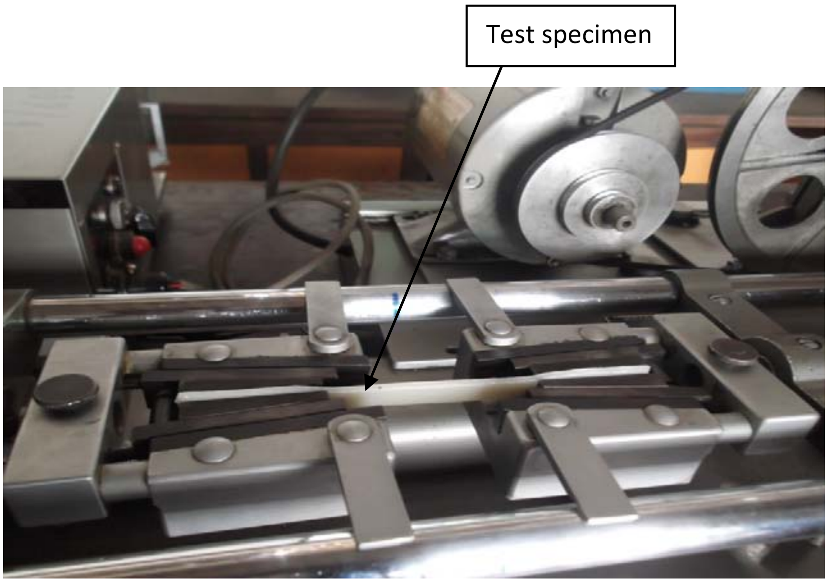

Figure 4.11: Tensile test setup showing a plastic sample under test

From the results derived from this test the Ultimate Tensile Strength (*UTS*), tensile strain (ε) and tensile modulus of elasticity (*E*) were calculated as follows:

$$UTS = \frac{\max(F)}{A} \quad \ldots\ldots 4.1$$

Where *F* is the applied load and *A* is the cross sectional area of the specimen.

$$\varepsilon = \frac{\Delta l}{l} \quad \ldots\ldots 4.2$$

Where *l* is the gauge length of the specimen

$$E = \frac{\sigma}{\varepsilon} \quad \ldots\ldots 4.3$$

Where σ is the applied stress

4.2.6.2 Three point bend test

This test was also carried out on the Hounsfield tensometer and in accordance with ASTM D2344/D2344 – 00 (ASTM, 2006). Figure 4.12 shows the dimensions of the used rectangular-block test specimens.

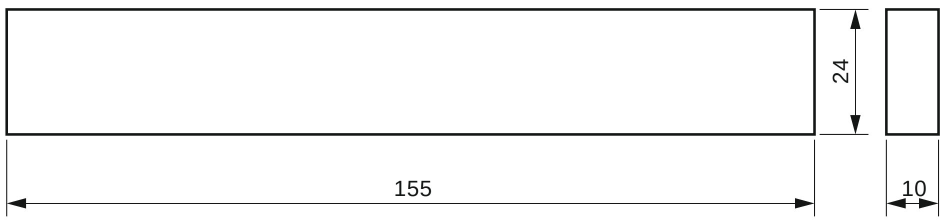

Figure 4.12: Dimensions of the three point bend test specimen in millimeters (mm)

The book of thermoplastics and thermoplastic composites (Biron, 2007) describes the inter-laminar shear strength (ILSS) as the value of shear strength producing delamination between two layers of a composite, along the plane of their interface. Thirteen samples were tested; virgin plastic, 20%, 40% and 60% recycled plastic content respectively. The cross head speed was 0.3 m h^{-1} (5mm/min) and the span was 63.1 mm. Reinforced samples of 14.4% by weight of steel content, were tested. The experimental set up was as shown in Figure 4.13.

The shear strength was calculated as follows;

$$\tau = \frac{3F}{4bh} \qquad \text{......4.4}$$

where,

F is the applied load in kilo Newtons, while b and h are the specimen width and thickness respectively.

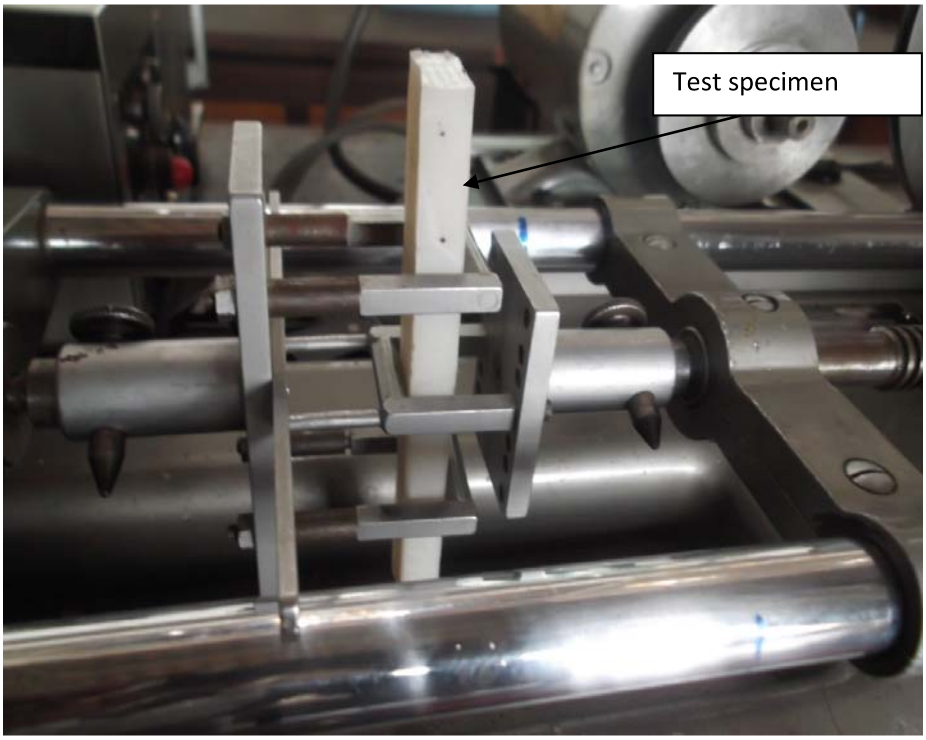

Figure 4.13: Experimental set up for the three point bending test on a virgin plastic specimen.

4.2.7 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (Zeiss 1550 FEG SEM) at Uppsala University in Sweden was used to study the interfacial bond between the plastic matrix and its metal reinforcements. A sample of the 60% recycled plastic was also subjected to SEM to act as a control and also helped to gauge the soundness of the injection process since it would have been possible to identify voids and other faults resulting from the injection process. The pictures of polished samples with reinforcement were also used to investigate any effect of machining on the interfacial bond between the metal and matrix.

4.2.7.1 Sample preparation

Samples were cut from the three point beam test specimens. These samples were cleaned with Isopropanol to remove any body oils and carefully placed in well-sealed and labeled containers. The sample dimensions were 1 cm by 1 cm by 3 mm thick for purposes of fitting into the sample chamber of the Scanning Electron microscope. Most operational SEM instruments require samples to be coated with conductive material however the used SEM at Uppsala University uses charge compensation system, which involves injection of nitrogen gas near the surface of the samples which makes them visible.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Tensile test results

5.1.1 Plastic samples

Virgin HDPE was mixed with the recycled HDPE to counter the high viscosity of the recycled material that made flow into the moulds difficult. The plastic was therefore tested as virgin plastic, 20%, 40% and 60% recycled plastic. A total of 13 samples for each composition were tested in order to see the disparity in the results. Figures 5.1 – 5.3 show the distribution of strain, tensile stress and Young’s modulus of elasticity at various percentages of recycled plastic, respectively. The distribution plots help to show whether there is consistency of properties in the specimens produced and also repeatability of the experiments. The results show that specimens had similar mechanical properties, for example from figure 5.1, and considering the 20% recycled plastic content, it can be seen that strain varied between 0.0285 and 0.0295, and that out of 13 samples 7 had strain of 0.0285. In figure 5.2 and taking the 40% recycled plastic as an example, it is seen that 5 samples had a stress of 15 Mpa, while in figure 5.3 and taking 60% recycled plastic as an example, the thirteen samples had young’s modulus varying between 13.5 and 14.8 MPa. The Standard recommends testing of at least five samples, however more tests on the plastic samples were carried out to gauge disparity of results obtained, which has implications on the soundness of the process of production and hence the machine. This was due to the fact that the moulding machine was still at the development stage.

The ultimate tensile strength and modulus of elasticity for virgin plastic processed using the machine developed in this research were 13 MPa and 0.9 GPa respectively.These results are comparable to documented values which were 15 MPa and 0.8 GPa respectively (TOOLBOX, 2014).

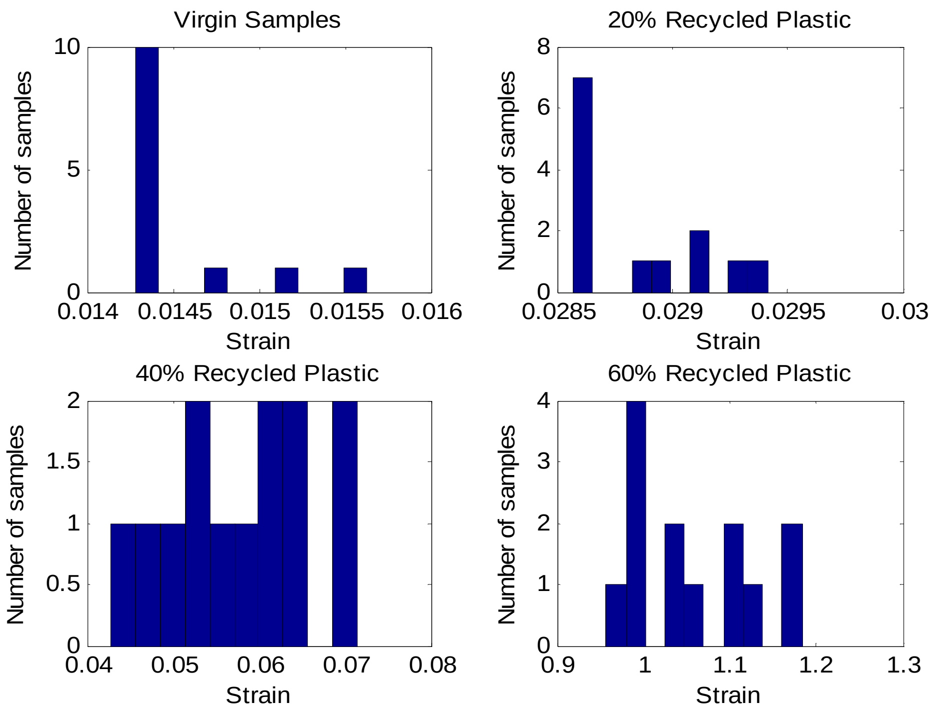

Figure 5.1: Distribution of strain for 13 samples at various percentages of the recycled plastic.

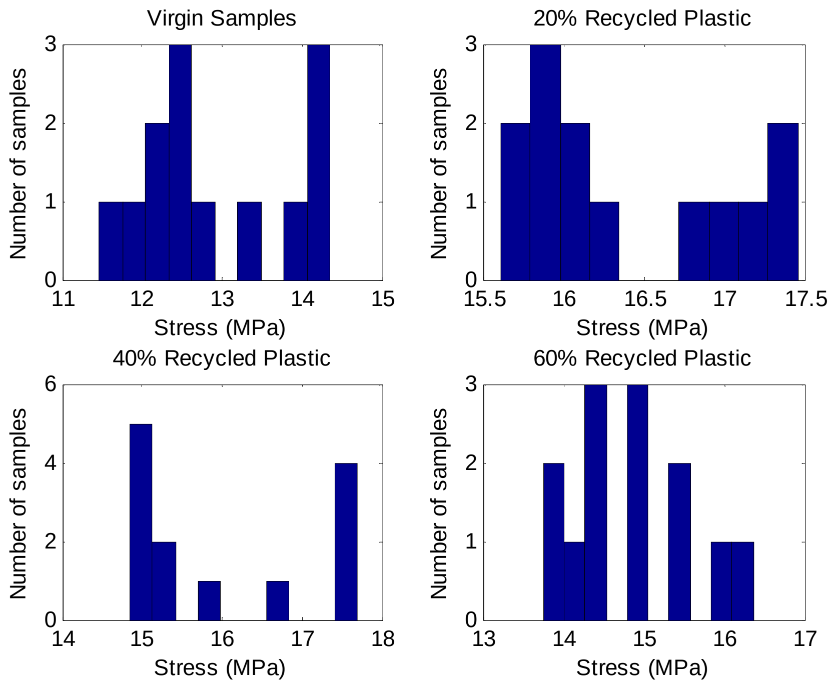

Figure 5.2: Distribution of tensile stress at various percentages of the recycled plastic.

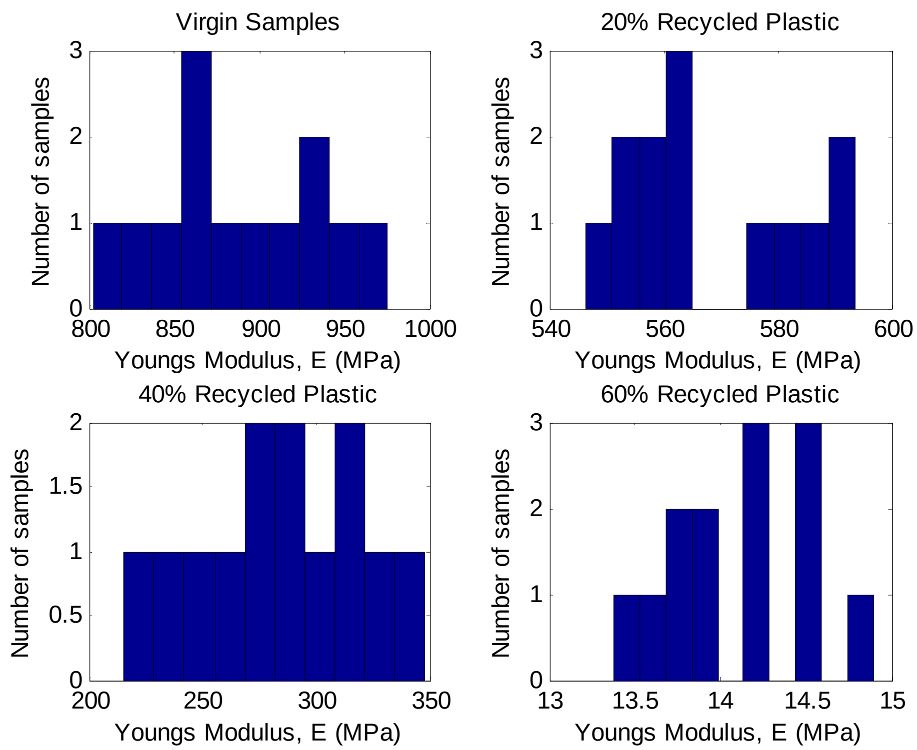

Figure 5.3: Distribution of Young's Modulus (E) at various percentages of the recycled plastic.

It is observed that as the percentage content of the recycled plastic was increased, the engineering strain increased (Figures 5.4). This means that the percentage elongation to failure increased as the content of recycled plastic was increased. However, the trend for the Ultimate Tensile Strength (*UTS*) implied a maximum between a mixture of 20% and 40% recycled plastic, which is able to withstand higher loads to failure. Overall, the change in value of *UTS* between the samples was <2 MPa suggesting similar characteristics in terms of *UTS*. The modulus of elasticity (*E*) exhibited a strong decrease with increasing amount of recycled plastic.

The Engineering dictionary (2008), defines *E* as the ratio of stress to strain, and a measure of stiffness of a material, thus the higher the *E* the greater the stiffness. Comparing figure 5.4 and 5.5, it is seen that there was little variation in *UTS* among the various recycled plastic contents, whereas there was great variation in strain, consequently, it is expected that higher values of strain result in lower *E* since they are inversely proportional. Therefore, the observed trend in *E*, where the plastic sample with 60% recycled plastic had the lowest value of *E*, since it experienced the highest elongation to failure and hence, high strain. It is observed that addition of recycled plastic content had the effect of reducing stiffness and hence the lower *E* values. The drop in stiffness is quite significant since *E* drops from the order of hundreds of MPa to tens of MPa.

In the work Kiaeifar et al. (2011) also observed a decrease in modulus of elasticity with use of recycled plastic. Our results are similar to findings of a report published by CWC (1999) after a test survey of recycled plastic from injection moulding process and products from Calorado's injection moulding companies. The tests included processing trials of virgin and recycled HDPE plastics in an injection-moulding machine and laboratory testing to establish their strength and melt flow characteristics. The observations were increased tensile strength and decreased melt flow as recycled content was increased similar to our results (Figure 5.2) where there was increase in *UTS* initially when recycled plastic was added to the virgin, but in this research further increase in recycled plastic content saw a slight decline in strength.

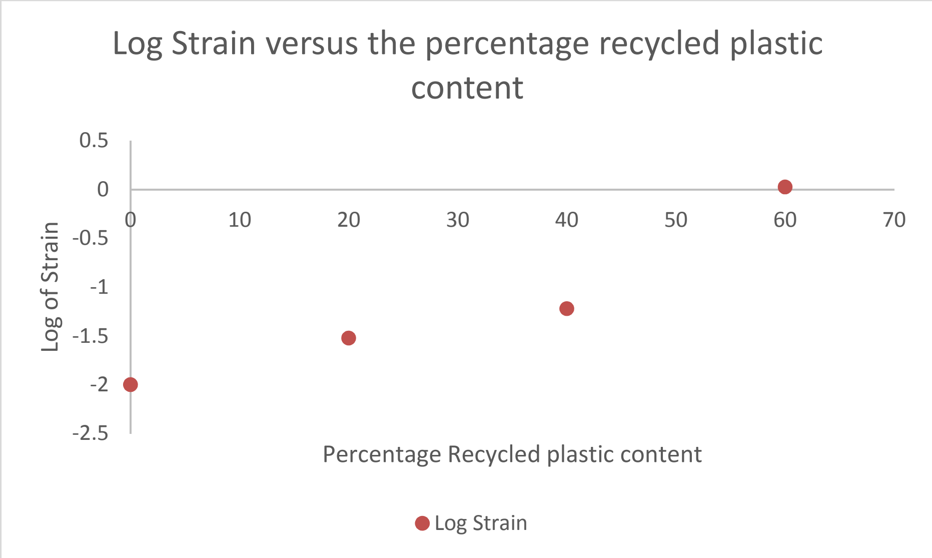

Figure 5.4: Variation of log of tensile strain in % with percentage content of recycled plastic.

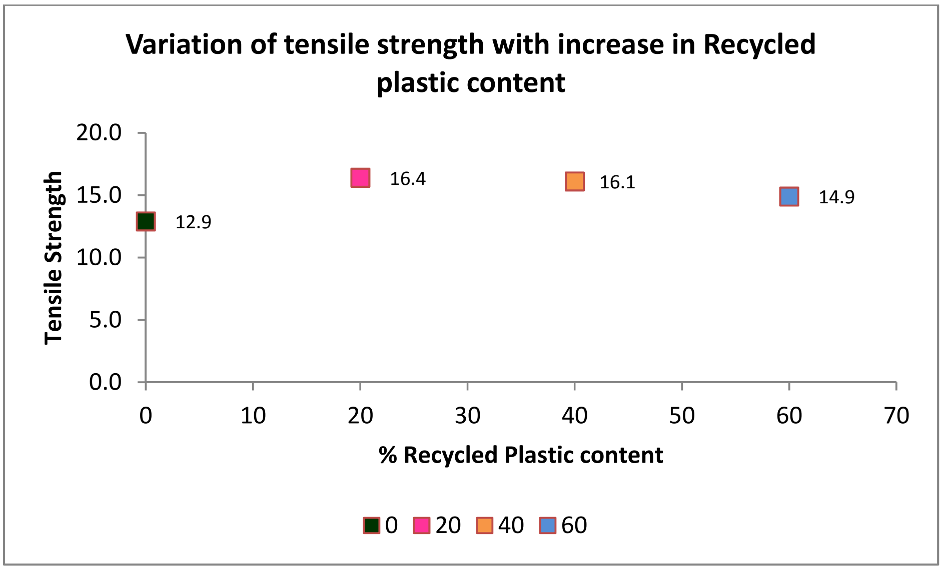

Figure 5.5: Variation of Ultimate Tensile Strength (MPa) with percentage recycled plastic content.

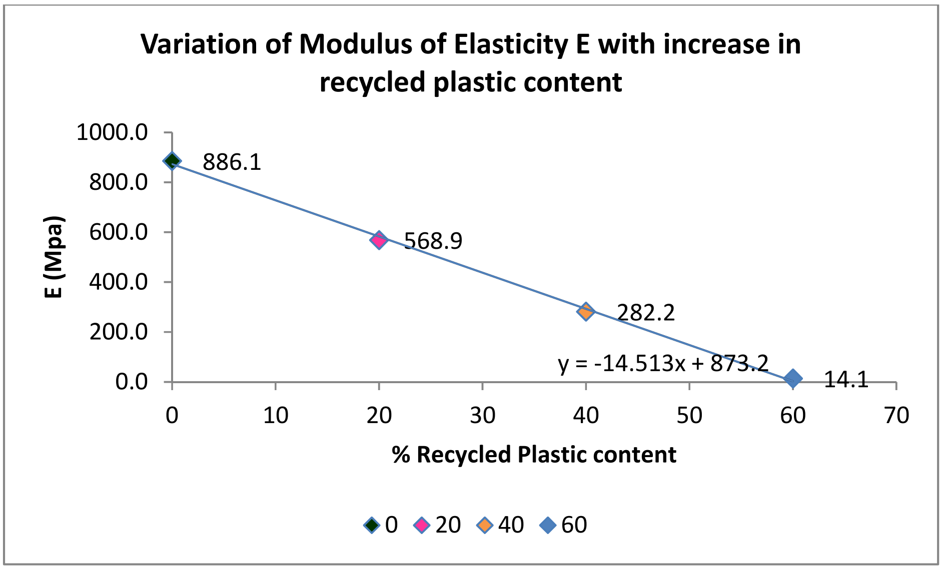

Figure 5.6: Variation of modulus of elasticity with percentage recycled plastic content

5.1.2 Tensile results for reinforced samples

Reinforced samples were made using the 60% recycled plastic content. The temperature used in melting the plastics was 260^0 C. steel at 14% by weight was used for reinforcement. Figure 5.7 shows evidence that the reinforcement had the effect of reducing the engineering strain.

Figure 5.8 shows steel reinforced samples had significantly higher *UTS* than the pure plastic. In our study (figure 5.9), the reinforcements improved the E of the plastic. Assuming a linear inverse proportionality between E and strain the addition of reinforcement increased the stiffness of the sample (as seen from the higher E values in reinforced samples).

The findings of E in our research varied with those of Kiaeifar (2013) and Chianelli(2011) perhaps because in these two researches, organic fibers were used. In terms of E, metals are stiffer compared to organic fibers, and hence addition of metal reinforcement improved E. Also organic fibers tend not to bond with the polymer matrix very well, and may need to be treated to improve the bonding (Huda et al., 2012) and a poor bond leads to poor mechanical properties

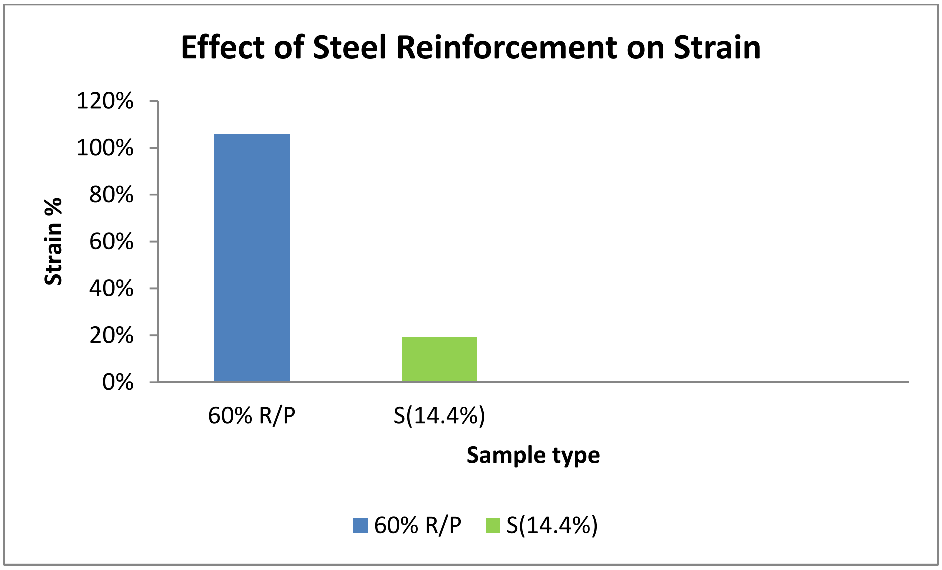

Figure 5.7: Tensile strain percentage comparison for the unreinforced 60% recycled plastic and after addition of steel at 14.4%

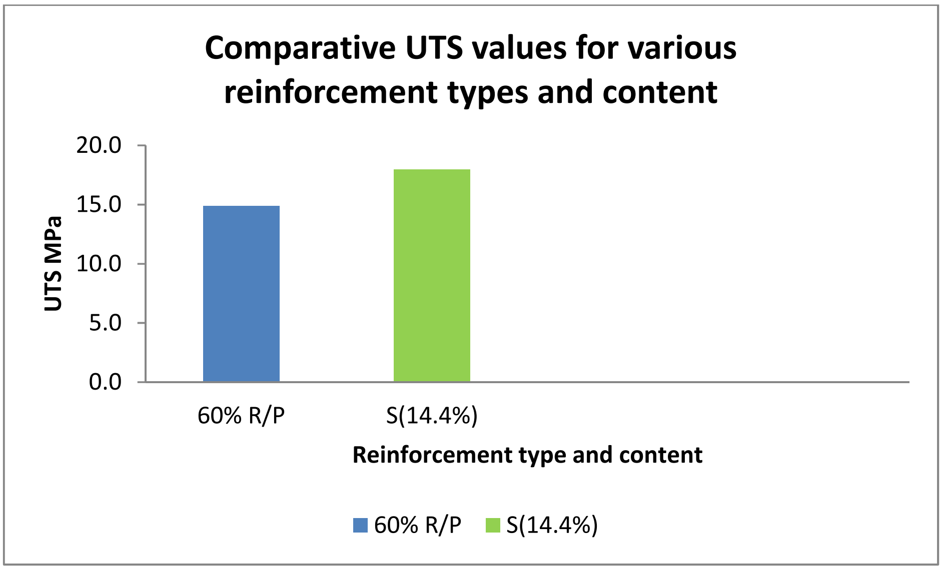

Figure 5.8: Effect of steel Reinforcement on UTS of 60% recycled plastic

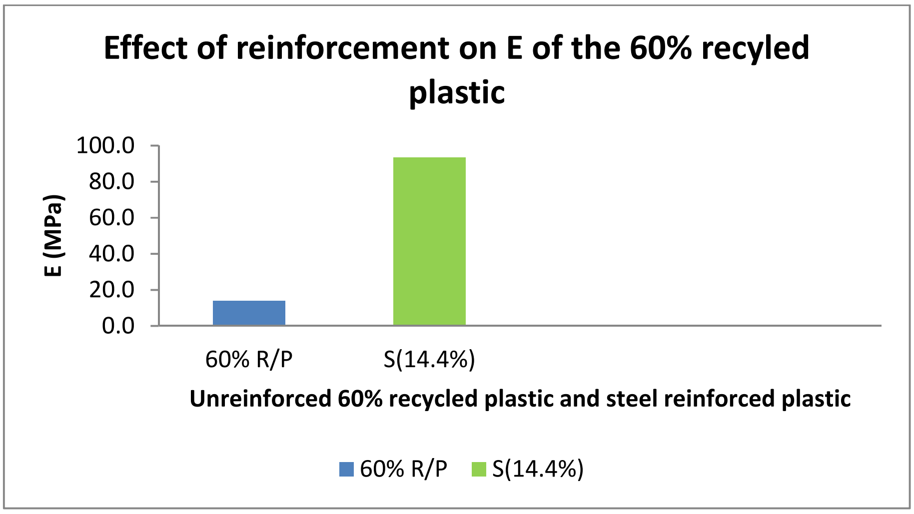

Figure 5.9: Modulus of Elasticity (E) for 60% recycled plastic and steel reinforced samples.

5.3 Three point bending test results

5.3.1 Plastic sample results

Figure 5.10 shows the percentage stress measured on non-reinforced plastics. Recycled plastic had higher shear strength compared to the virgin plastic. There appears to be a maximum shear strength between 15 and 25% recycled plastic content, beyond which the strength settles to a near constant. However between the 20, 40 and 60% recycled plastic content, there is only a variation of 0.1 MPa.

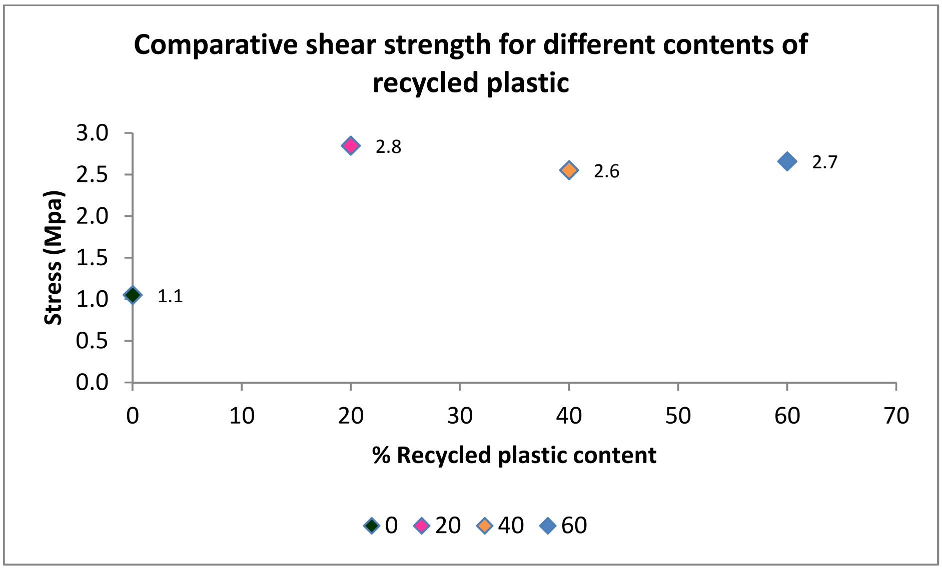

Figure 5.10: Variation of shear strength with increase in recycled plastic content

5.3.2 Reinforced samples results

Figure 5.11 shows the results of inter-laminar shear strength and it shows a decrease in ILSS with addition of steel reinforcement.

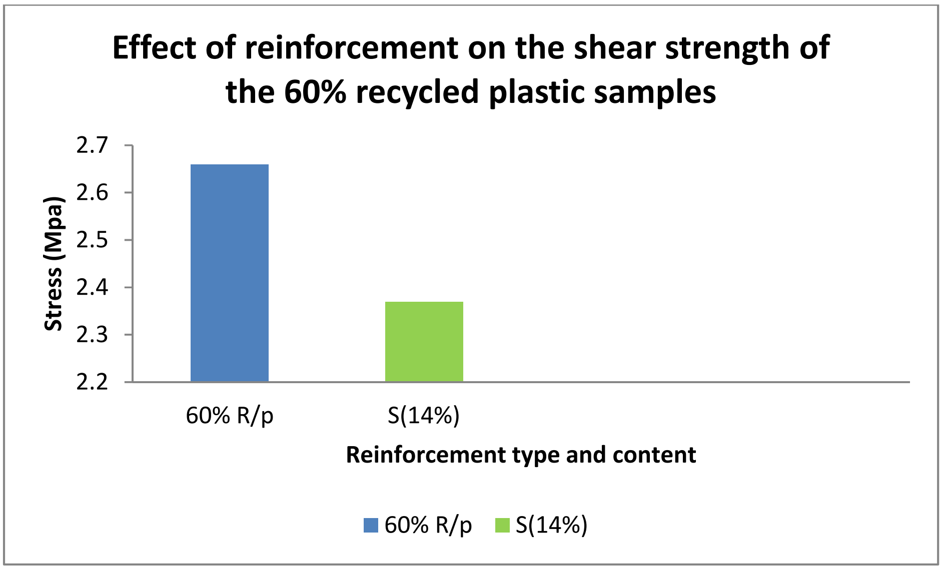

Figure 5.11: Effect of steel reinforcement on the 60% recycled plastic content samples.

5.4 Scanning electron microscopy results

SEM was carried out on samples cut from the three point beam test specimens and also on the sample fracture sites. The reinforced samples were further scanned after polishing to gauge the effect of machining on the interfacial bond between the reinforcement and matrix (Figures 5.12 - 5.16).

Figure 5.12 shows the plastic samples with 60% recycled plastic were devoid of faults such as air pockets and discontinuities that would have resulted from a poor production process. The SEM image qualified the ability of the locally fabricated injection machine in processing plastics. This is of particular importance since production process influences the structure and hence the properties and performance of a material. Figures 5.13, cutting operation had the effect smearing the reinforcement, however, the interfacial bond at this stage was not interfered with. Figure 5.14 shows voids between the plastic and reinforcement, an indication that polishing damaged the bond between the reinforcement and the plastic. In Figures 5.15 and 5.16 fracture sites of the reinforced samples are shown and the information are used to explain how the specimens failed and how strong the interfacial bond was. The two images suggest that the interfacial bond between the plastic and steel wires was poor, as is evidenced by fiber pull out especially seen in Figure 5.16 where some fibers were completely dislodged from the plastic matrix. One reason could be that since the steel wires were from old tyres, obtained through burning of the tyres, they had some burnt rubber still adhering to them. This could have been a coat on the surface of the steel wires which prevented bonding.

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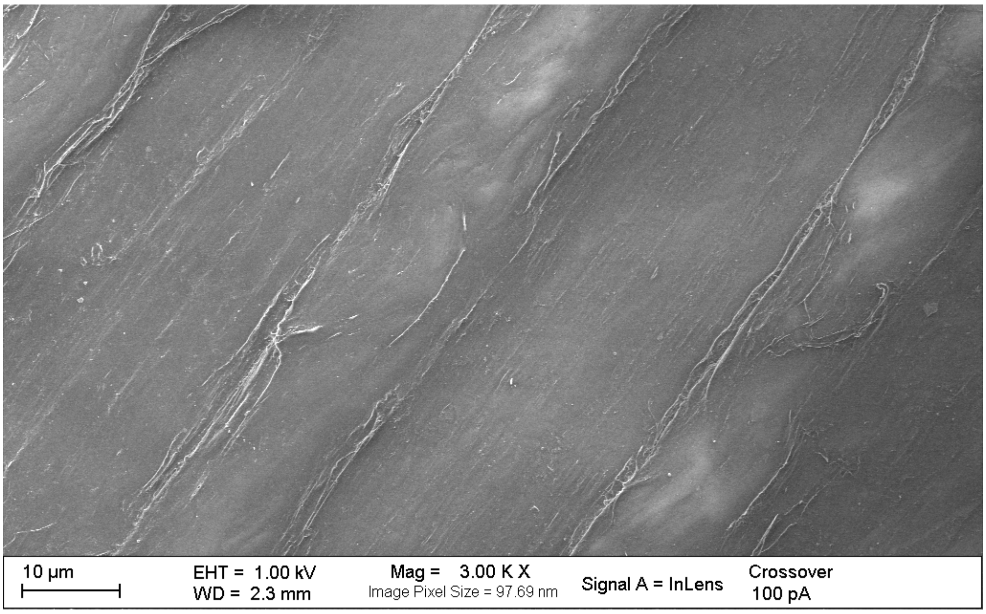

Figure 5.12: SEM image of a plastic sample with 60% recycled plastic content.

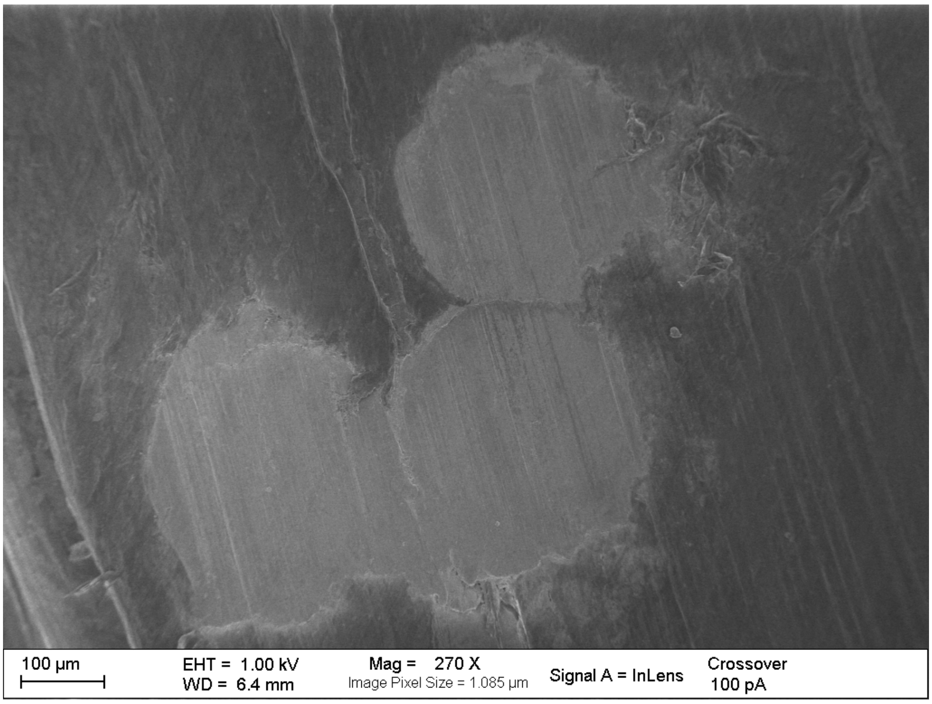

Figure 5.13: SEM image of cut steel reinforced sample.

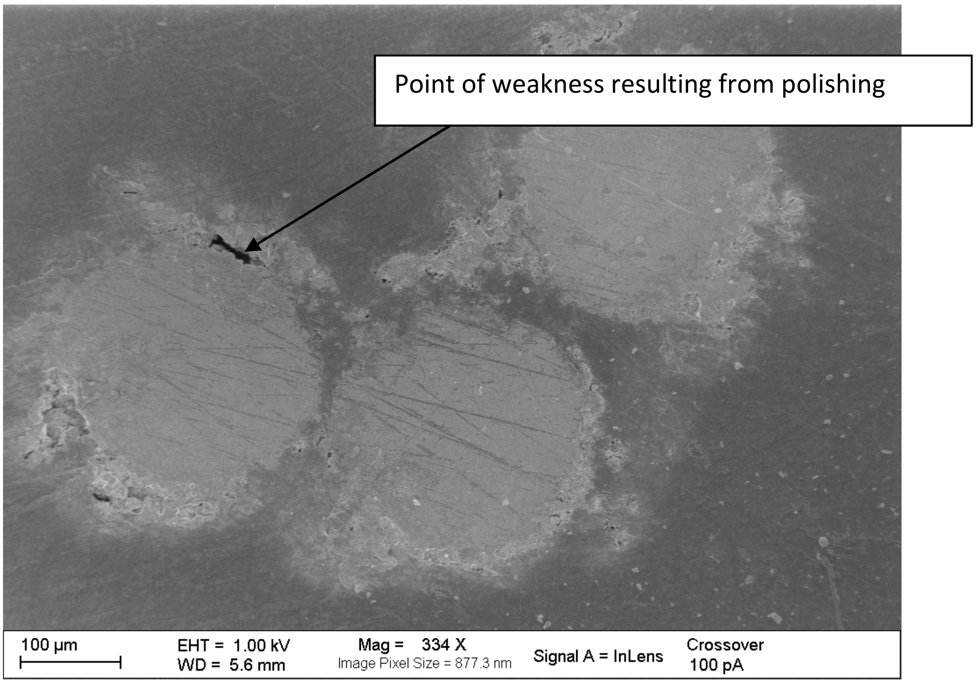

Figure 5.14: SEM image of polished steel reinforced sample

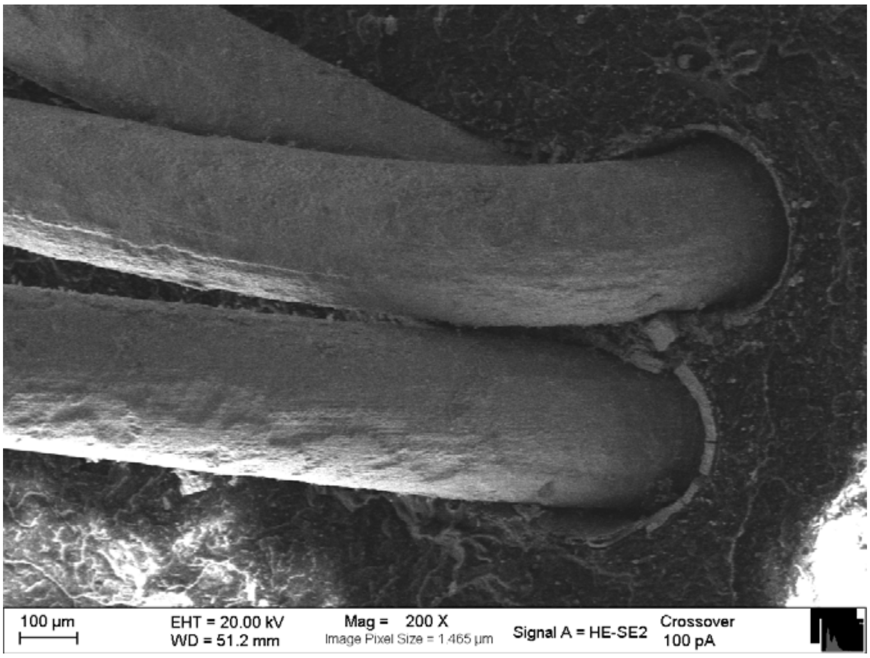

Figure 5.15: Fracture site image of steel reinforced specimen

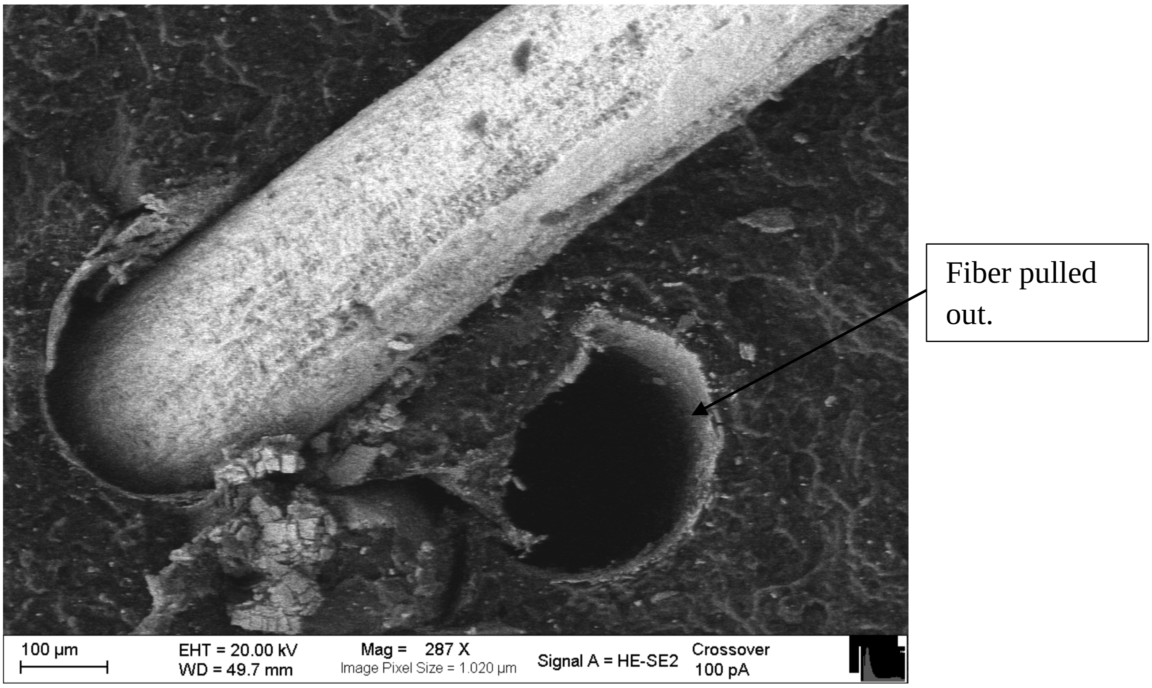

Figure 5.16: Fracture site of steel reinforced sample showing fiber pull out

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

1. An injection moulding machine was designed and fabricated.

2. Comparison of tensile properties of samples made from virgin HDPE using the machine designed in this sample were comparable to documented values.

3. Addition of recycled plastic to the virgin plastic was seen to improve the UTS with very minimal variation in strength when recycled plastic content was increased from 0-60%. However the Young's modulus decreased when recycled plastic content was increased.

4. The addition of steel wires to the highest content of recycled plastic, improved the tensile properties of the plastic.

5. Having studied the mechanical properties of the steel-plastic composite developed in the study and comparing with previous studies, it was seen that the composite could be used for making os low strength car bumpers.

6.2 Recommendations

1. Future research should look into automating the injection machine.

2. Future composites could also include the various recycled plastic contents as outlined in the study to make superior composites.

3. Future studies could also explore use of agricultural by products as reinforcement since this are cheap and locally available.

REFERENCES

Adekunle K., Cho S. W., Ketzscher R., Skrifvars M. (2012). Mechanical Properties of Natural Fiber Hybrid Composites Based on Renewable Thermoset Resins Derived from Soybean Oil, for Use in Technical Applications. *Journal of Applied Polymer Science,* 124**,** 4530-4541.

Agnihotri R. and Rani S., (2014). Recycling of waste tyres. *International journal of materials science and applications*, 3, 164-167.

Agusonye J.O. and Aigbodion V.S. (2013). Bagasse filled recycled polyethylene bio-composites: Morphological and mechanical properties study. *Results in Physics,* 3, 187-194.

ASTM 2006. Standard test method for short beam strength of polymer matrix composite materials and their laminates. USA: ASTM International.

ASTM 2008. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. USA: ASTM international.

BASF, P. 2006. Injection Moulding Process Guide for UltramidPolyamide (Nylon). BASF, The Chemical Company. Europe.

Bashir N.H.H. 2013. Plastic problem in Africa, *Japanese Journal of Veterinary Research*,16, S2 – S11.

Biron, M. 2007. Thermoplastics and thermoplastic composites. first ed. UK: Butterworth-Heinman. United Kingdom

Bozelli, J. 2011. Pay attention to your nozzle body and tip. Plastics Technology. www.ptonline.com/columns/pay-attention-to-your-nozzle-body-tip Visited on 22/1/2015.

BTRN. 2014. Plastics - History, types and processing. Melbourne Australia. Retrieved 4/2/2014 from www.plasticaust.com.au./plasticsOnline/browse/catalog/document/an-Insight-into-plastics.pdf

Callister, W. D. 2007. Material Science and Engineering. *An introduction.* Seventh ed. United States: John Wiley & Sons Inc.

CalRecycle, 2013. Market for wire and fiber from waste tyres. United States: California Department of Resources Recycling and Recovery.

Chianelli, R. J., Reiss J.M.L., J.L.Cardoso & P.F.Castro 2013. Mechanical Characterization of Sisal Fiber-Reinforced Recycled HDPE Composites. *Materials Research,* 6**,** 1393-1397.

Chu, J. and Sullivan, J., L., 1996. Recyclability of a Glass Fiber Poly(Butylene Terephthalate) Composite. *Polymer Composites,* 17, 523-531.

Crawford, R. J. 1998. Plastics Engineering. Third ed. USA: Butterworth-Heinemann.

CWC 1999. Using Recycled Plastics In An Injection Moulding Process. www.cwc.org/plastic/p1992fs.pdf Visited on 23/1/2014

Ebewele, R. O. 2000. Polymer Science and Technology. New York, USA: CRC Press LLC.

Engineering-Dictionary.org 2008. Material Science and Engineering dictionary, www.engineering-dictionary.org/materials-science-and-engineering-dictionary/MODULUS_OF_ELASTICITY_(E) Visited on 19/1/2015

G.O.K 2007 Kenya Vision 2030, www.vision2030.go.ke Visited on 15/8/2015.

G.O.K 2015 Youth Enterprise Fund, www.youthfund.go.ke Visited on 15/8/2015.

Gaggino, R. 2012. Water-resistant panels made from recycled plastics and resin. *Construction and Building Materials,* 35**,** 468-482.

GIZ 2014. Waste Tyre Management. Eschborn. Germany: Deutsche Gessellschaft fur Internationale Zusammenbeit.

GOOGLE, 2014. https://www.google.com/search?q=injection+moulding+process+pictures Visited on 2/2/2014

Huda, M. S., Schmidt, W. F., Misra, M. & Drzal, L. T. 2012. Effect of Fiber Surface Treatment of Poultry Feather Fibers on the Properties of Their Polymer Matrix Composites. *Journal of Applied Polymer Science,* 128**,** 1117-1124.

IAPD 2010. Thermoplastic Composites for Aerospace. *IAPD magazine.* April/May 2010 ed. USA: International Association of Plastics Distribution.

Johnson T. (2014). Thermoplastic vs Thermoset Resins: The Difference in Two Resins Used in FRP Composites http://composite.about.com/od/aboutcompositesplastics/a/Thermoplastic-Vs-Thermoset-Resins.htm visited on 5/1/2014

Kiaeifar, A., Saffari, M., Kord, B. 2011. Comparative investigation on Mechanical Properties of Wood Plastic Composites Made of Virgin and Recycled Plastics. *World Applied Sciences,* 14**,** 735-738.

KNCPC 2006. A Comprehensive Waste Management Strategy For The City of Nairobi. Nairobi: Kenya National Cleaner Production Center.

Meran, C., Ozturk, O. & Yuksel, M. 2007. Examination of the possibility of recycling and utilizing recycled polyethylene and polypropylene. *Materials and Design,* 29**,** 701-705.

Mordike, B. L. and Lukac, P. 2001. Interfaces in Magnesium-based composites. *Surface and Interface Analysis,* 31**,** 682-691.

Okuwaki, A. 2004. Feedstock recycling of plastics in Japan. *Polymer Degradation and Stability,* 85**,** 981-988.

P.H.S. 2014. An Introdution to Plastics. http://www.plastiquarian.com/userfiles/file/plasticbook.pdf. Visited on 22/1/2014

P.W.M.I. 2009. An Introduction to Plastic Recycling. http://www.pwmi.or.jp/ei/plastic_recycling_2009.pdf. Visited on 24/1/2014

Picuno, P., Sica, C., Laviano, R., Dimitrijevic, A. & Mugnozza, G. S. 2012. Experimental tests and technical characteristicsof regenerated films from agricultural plastics. *Polymer Degradation and Stability,* 97**,** 1654-1661.

Reddy, N. & Yang, Y. 2010. Non-traditional lightweight polypropylene composites reinforced with milkweed floss. *Wiley Interscience,* 59**,** 884-890.

Richard, G. M., Mario, M., Javier, T. & Susana, T. 2011. Optimization of the recovery of plastics for recycling by density media separation cyclones. *Resources Conservation & Recycling,* 55**,** 472-482.

Rubber Manufacturers Association, 2005. Considerations for starting a scrp tire company A blue print for planning a business strategy. https://www.rma.org/download/scrap-tires/general/GEN-060-Considerations%20for%20Starting%20a%20Scrap%20Tire%20Company%20A%20Blueprint%20for%20Planning%20a%20Business%20Strategy.pdf visited on 15/8/2015.

SABIC 2008. Injection Molding Processing Guide. Sabic Innovative Plastics. http://www.controlplastics.com/injection_molding/HealthcareEdu/SABIC-PLA-751_Injection_Molding.pdf Visited on 4/2/2014

Statista 2015. Production of plastics world wide. www.statista.com/statistics/282732/global-production-of-plastics-since-1950/ Visited 19/8/2015

TEMPRITE 2009. Industrial Molding Processing Guide. TempRite CPVC Material Solutions https://www.lubrizol.com/CPVC/Documents/Guides/General-Injection-Molding-Guide.pdf Visited on 4/2/2014

TOOLBOX, E. 2014. *Modulus of Elasticity - Young Modulus for some common Materials.* http://www.engineeringtoolbox.com/young-modulus-d_417.html Visited on 10/2/2014

Verma, B. B. 2009. Continuous jute fibre reinforced laminated paper composite and reinforcement-fibre free paper laminate. *Bulleting of Material Science,* 32**,** 589-595.

Vivekanandhan, S., Misra, M. & Mohanty, A. K. 2012. Thermal, Mechanical, and Morphological Investigation of Injection Molded Poly(trimethylene terephthalate)/Carbon Fiber Composites. *Polymer Composites,* 33**,** 1933-1940.

Zhang, G. H., Zhu, J. F. & Okuwaki, A. 2007. Prospects and current status of recycling waste plastics and technology for converting them into oil in China. *Resources Conservation & Recycling,* 50**,** 231-239.

APPENDICES

Plastic injection moulding machine detailed drawings

In this section assembly and detail drawings of the tabletop plastic injection moulding machine are presented.

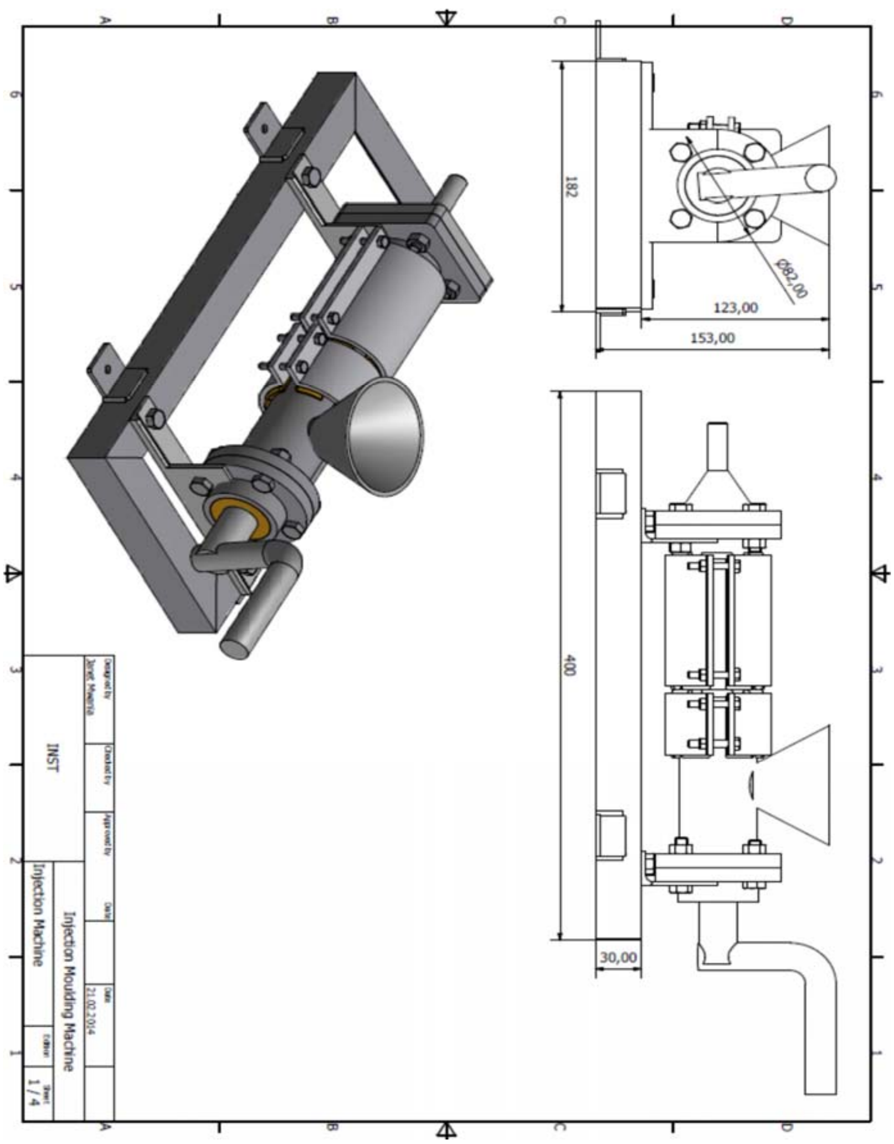

Figure A.1: The Injection Moulding Machine Front and End Elevations with Dimensions (mm) and 3D images.

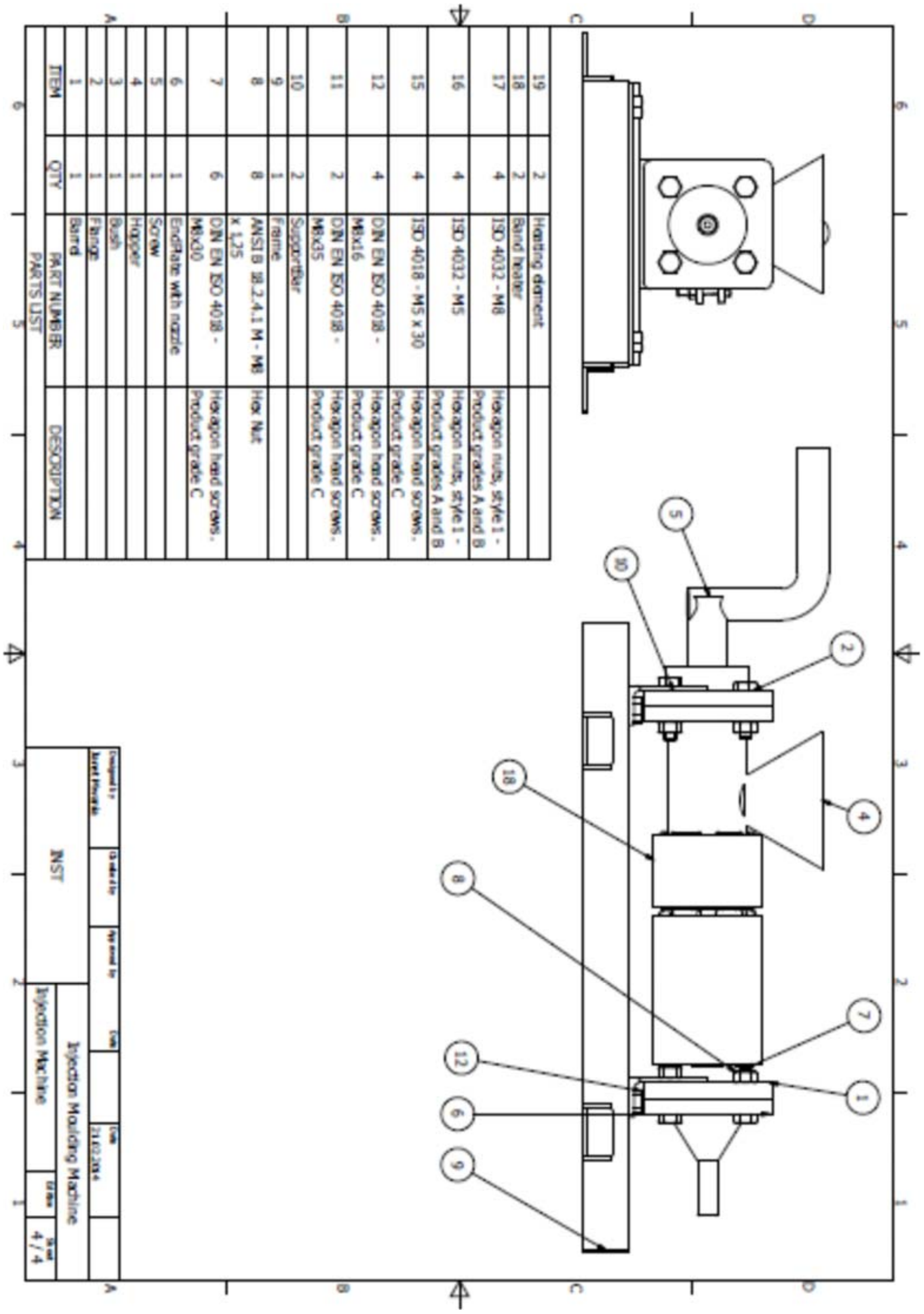

Figure A.2: The Injection Machine Parts List on the End elevation and a front elevation (see table A for parts list).

Table A: The parts list as extracted from figure A2

19	2	Heating Element	
18	2	Band Heater	
17	4	ISO 4032 - MS	Hexagonal nuts Style 1 Products grade A and B
16	4	ISO 4032 - MS	Hexagonal nuts Style 1 Products grade A and B
15	4	ISO 4018 - MS x 30	Hexagonal head screws product grade C
12	4	DIN EN ISO 4018 - M8 x 36	Hexagonal head screws product grade C
11	2	DIN EN ISO 4018 - M8 x 36	Hexagonal head screws product grade C
10	2	Support bar	
9	1	Frame	
8	8	ANSI B 18.2.4.1 M - M8 x 1.25	Hex Nut
7	6	DIN EN ISO 4018 - M8 x 30	Hexagonal head screws product grade C
6	1	End plate with nozzle	
5	1	Screw	
4	1	Hopper	
3	1	Bush	
2	1	Flange	
1	1	Barrel	
ITEM	QTY	PART NUMBER	DESCRIPTION

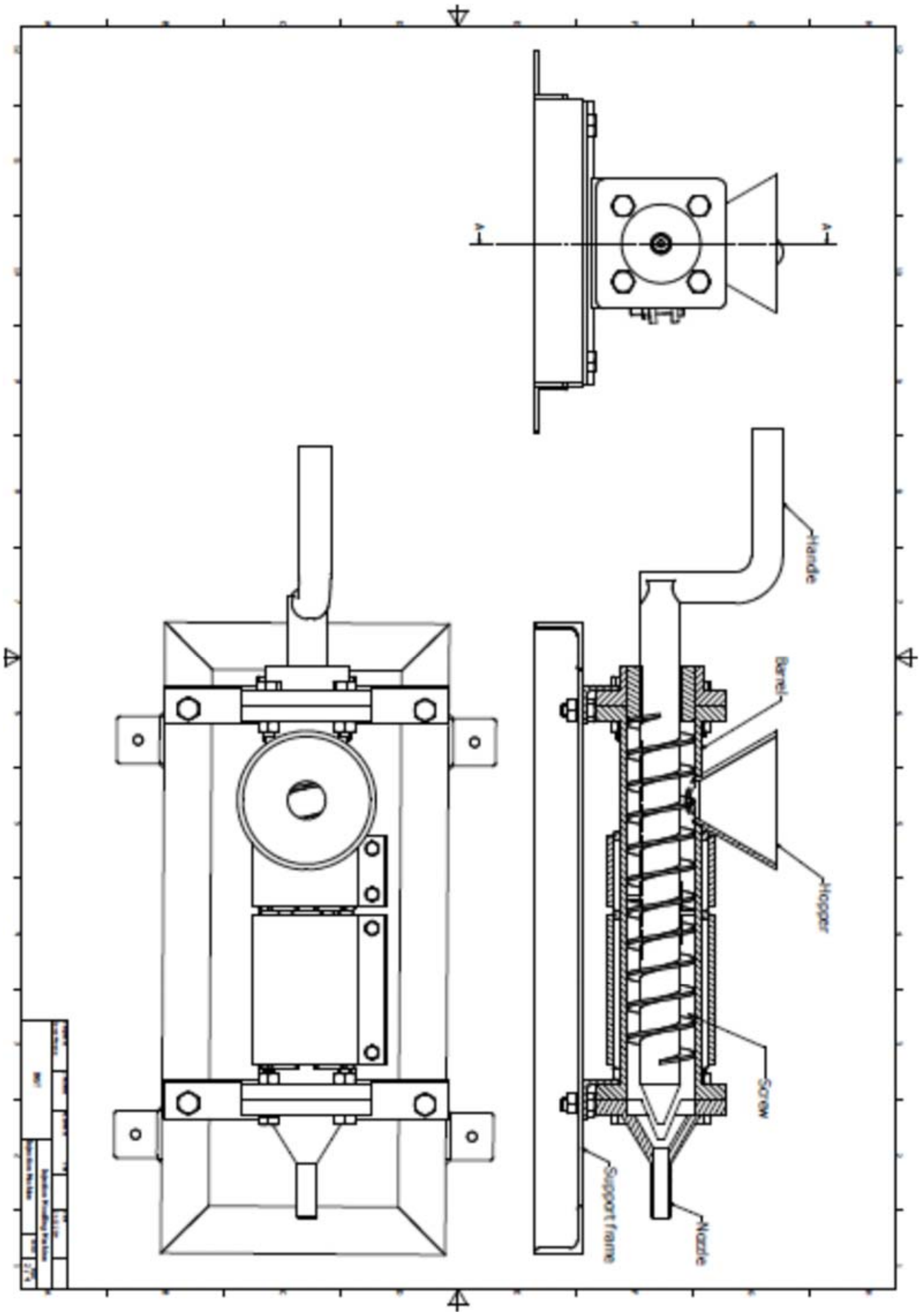

Figure A.3: The Injection Machine Section View with Plan and Front Elevation.

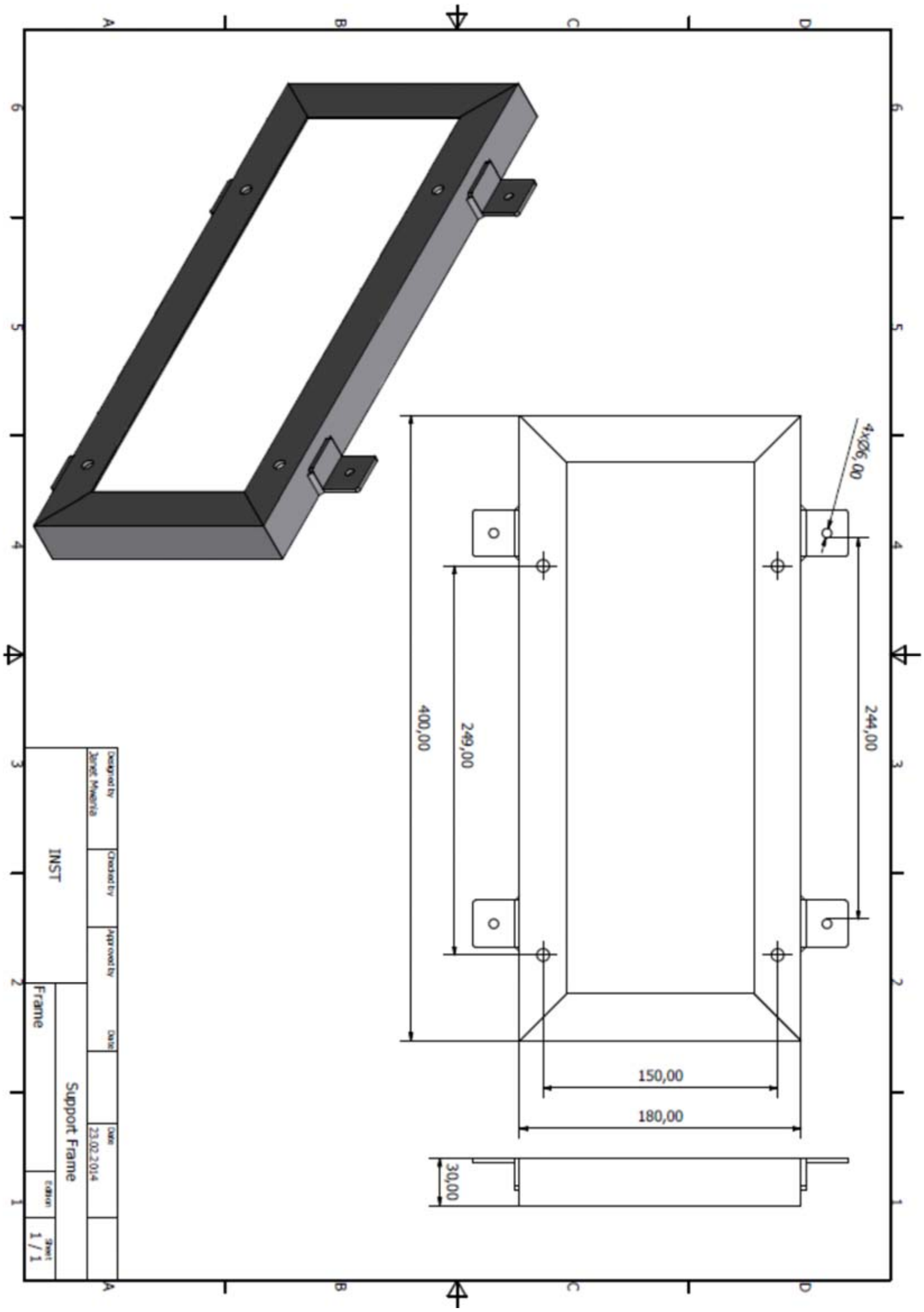

Figure A.4: The Injection Machine Support Frame 3D image and plan elevation showing dimensions

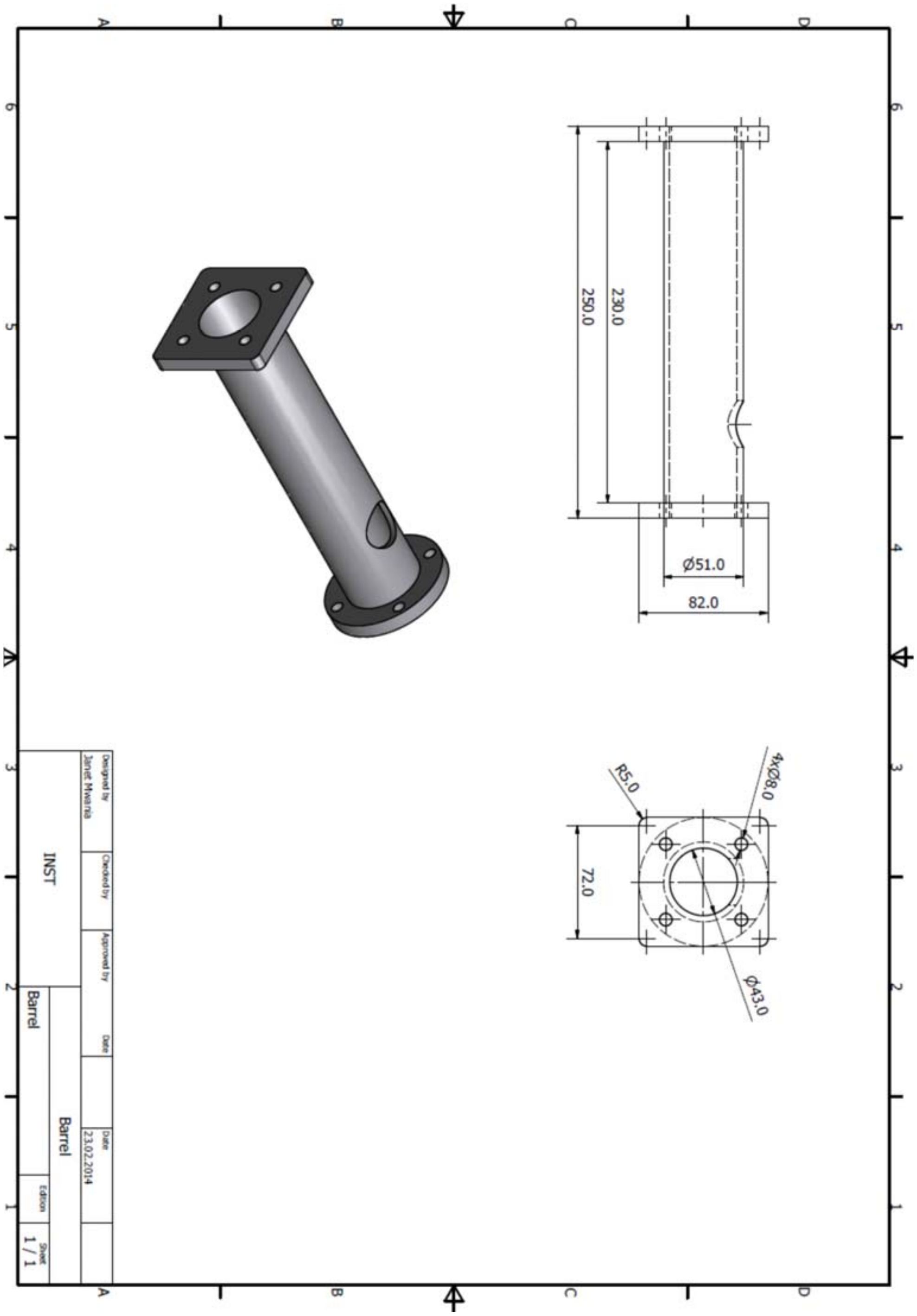

Figure A.5: The 3D image of the Barrel with End and Front elevations showing dimensions

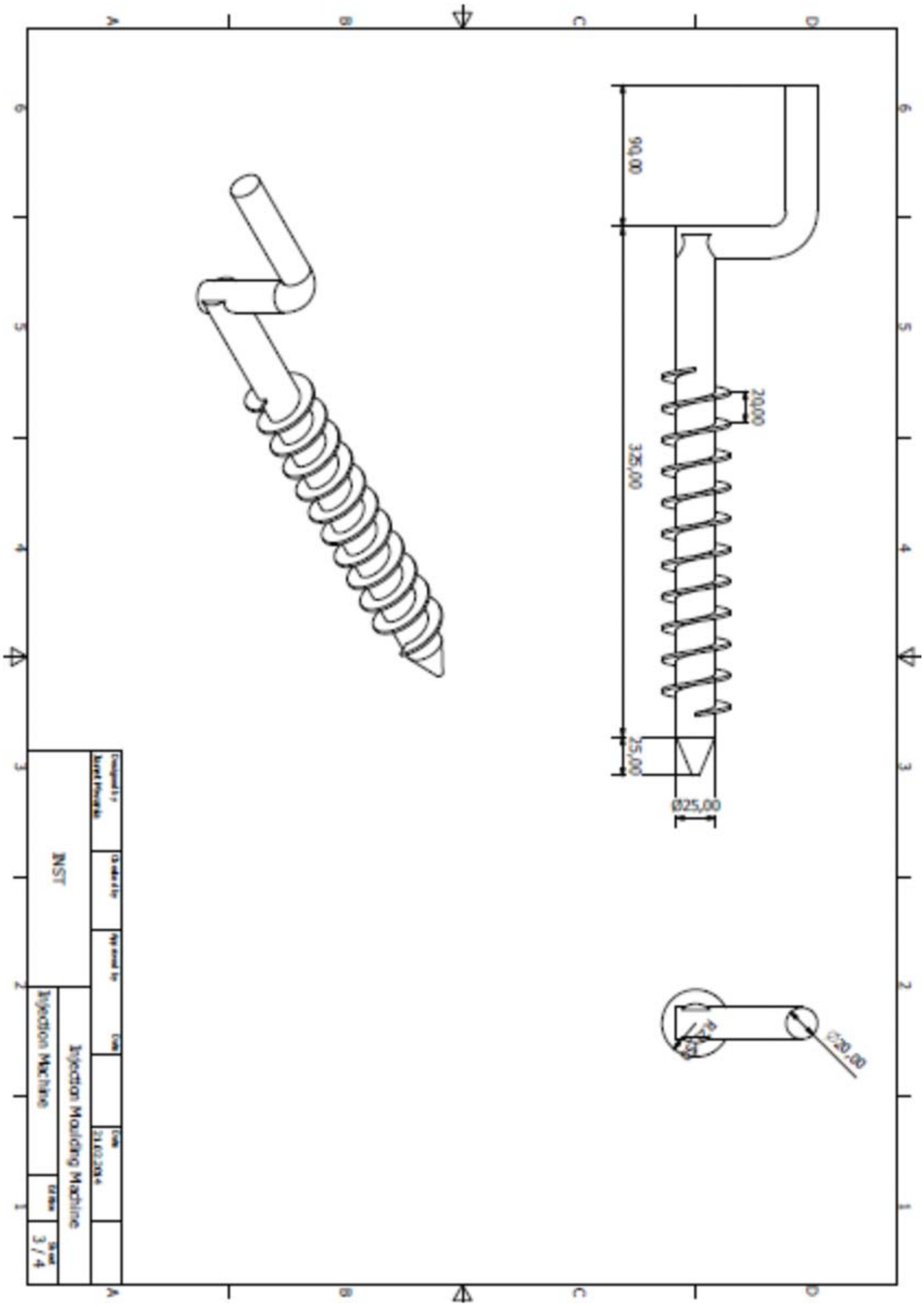

Figure A.6: The Screw in 3D and End and front elevations showing dimensions

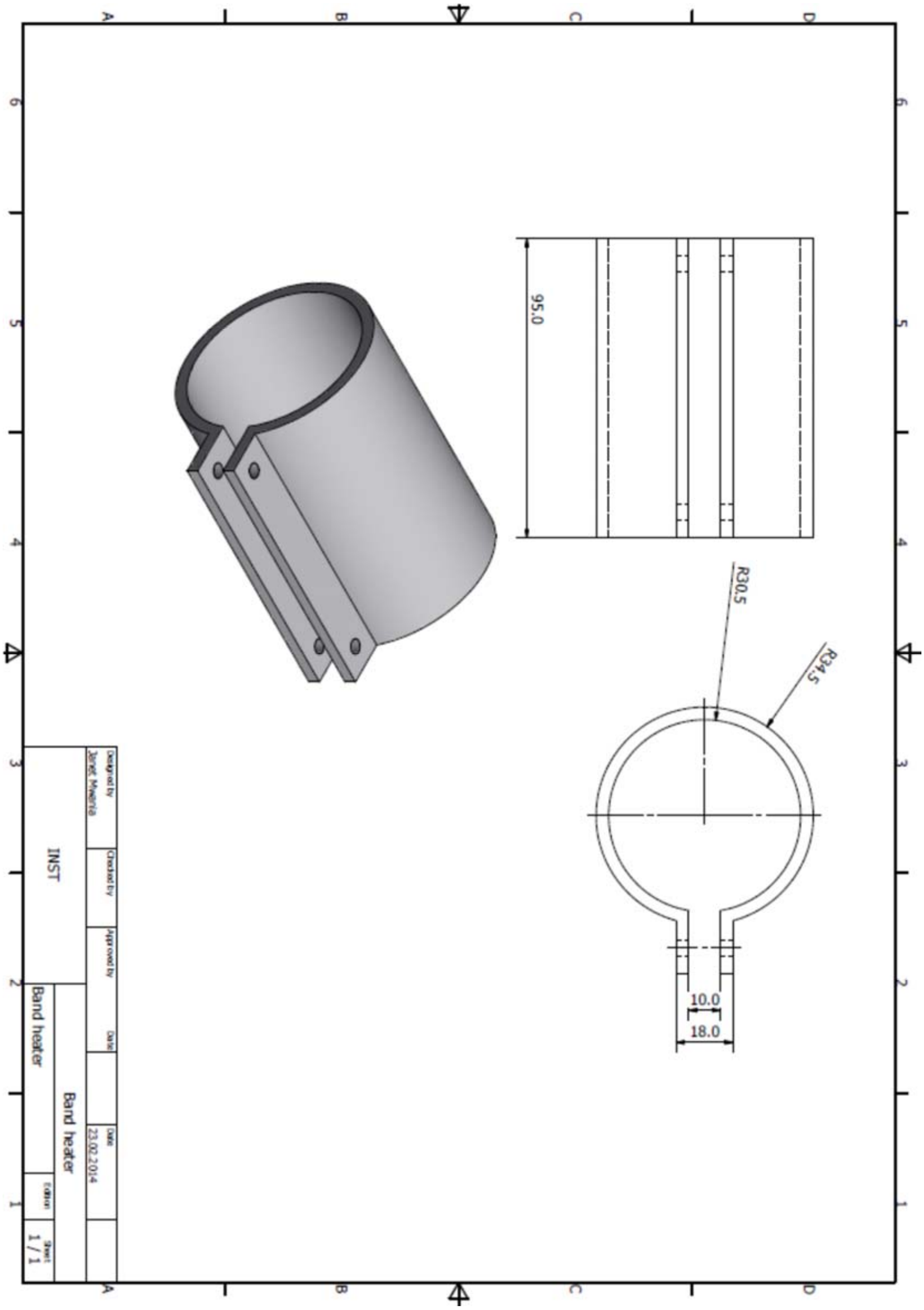

Figure A.7: 3D image of the 500W band heater with End and Front elevations and dimensions(mm)

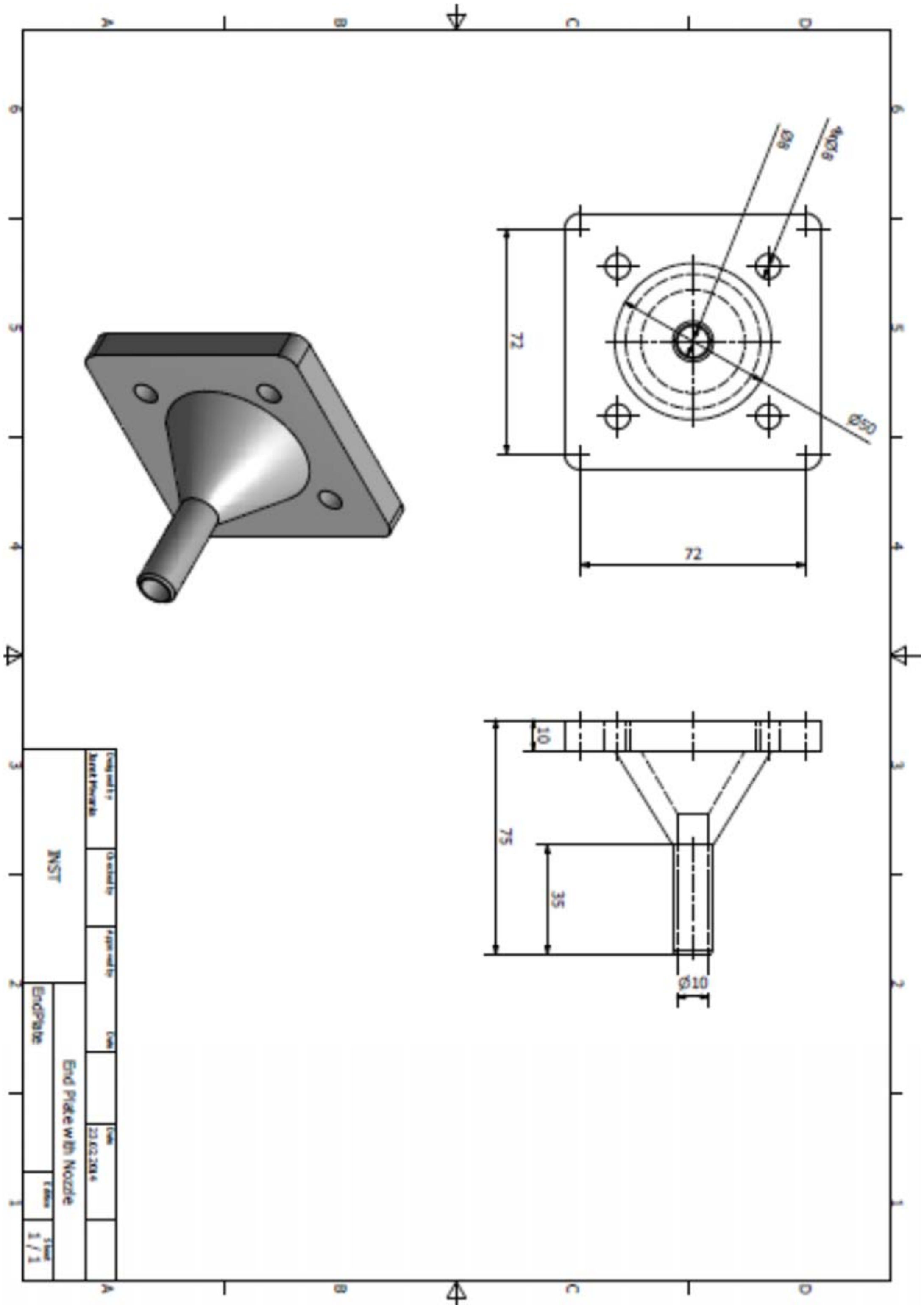

Figure A.8: 3D image of the nozzle and Front and End elevations showing dimensions (mm)

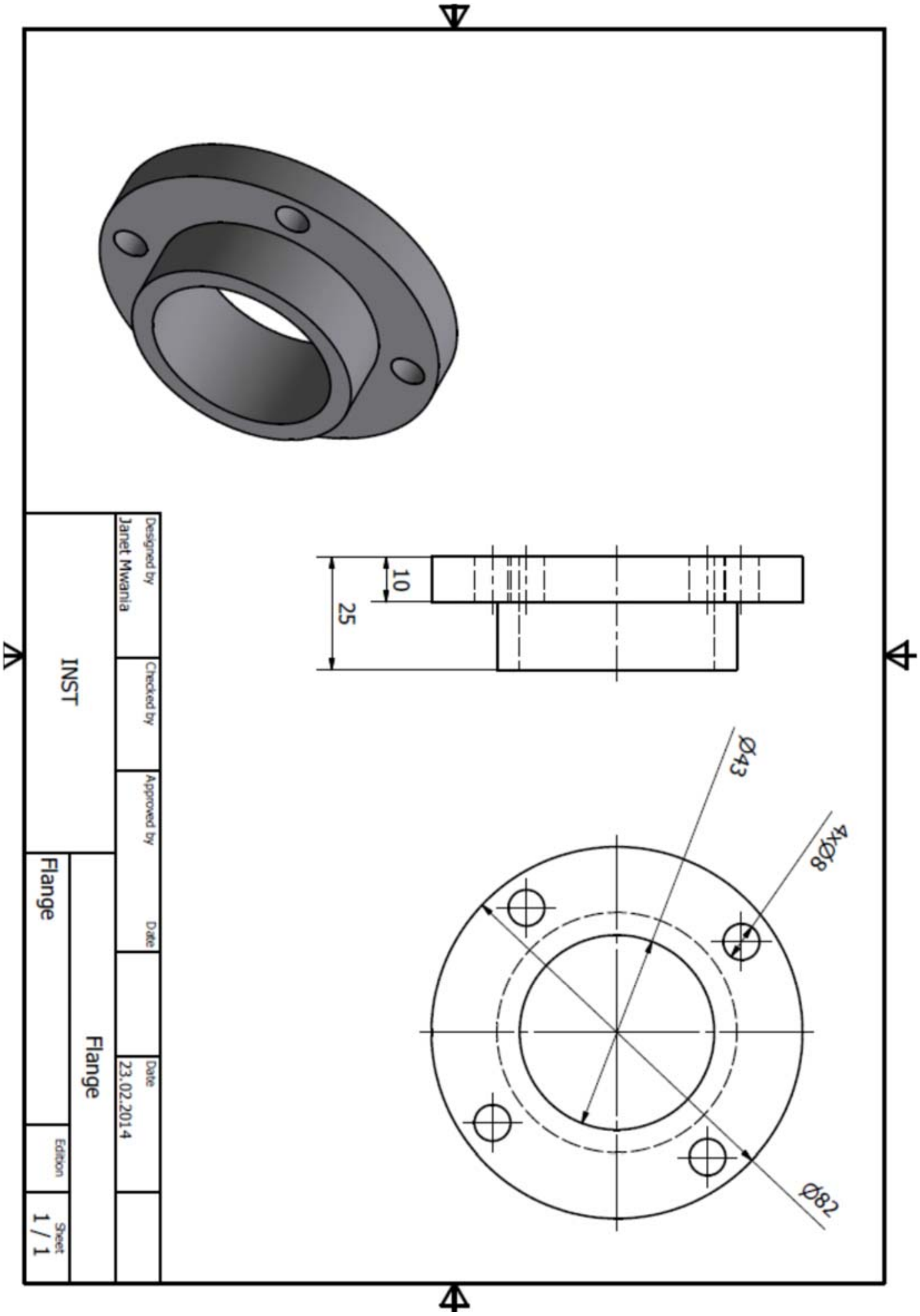

Figure A.9: The Barrel’s rear Flange in 3D with End and Front Elevations detailing dimensions (mm)

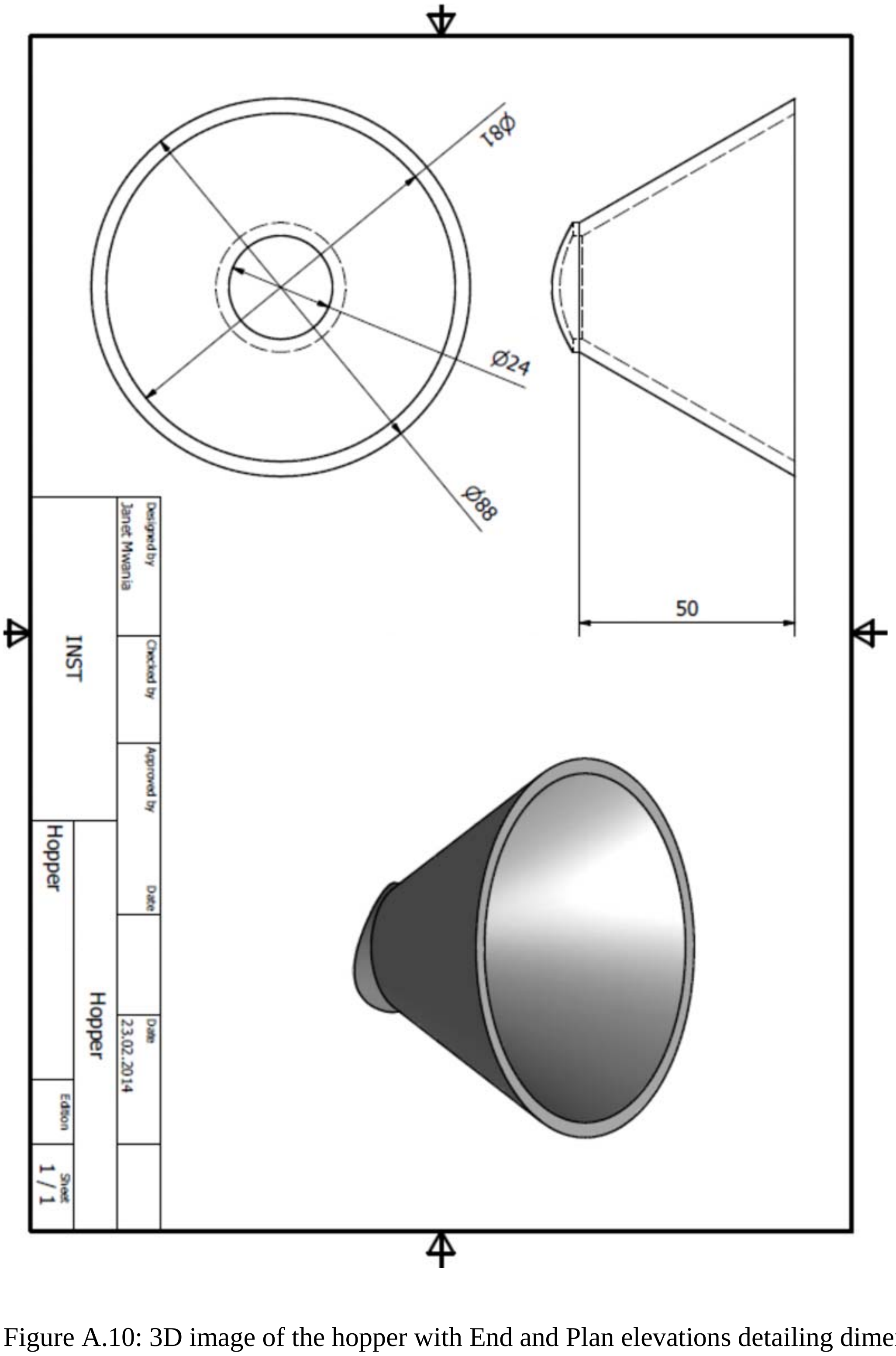

Figure A.10: 3D image of the hopper with End and Plan elevations detailing dimensions

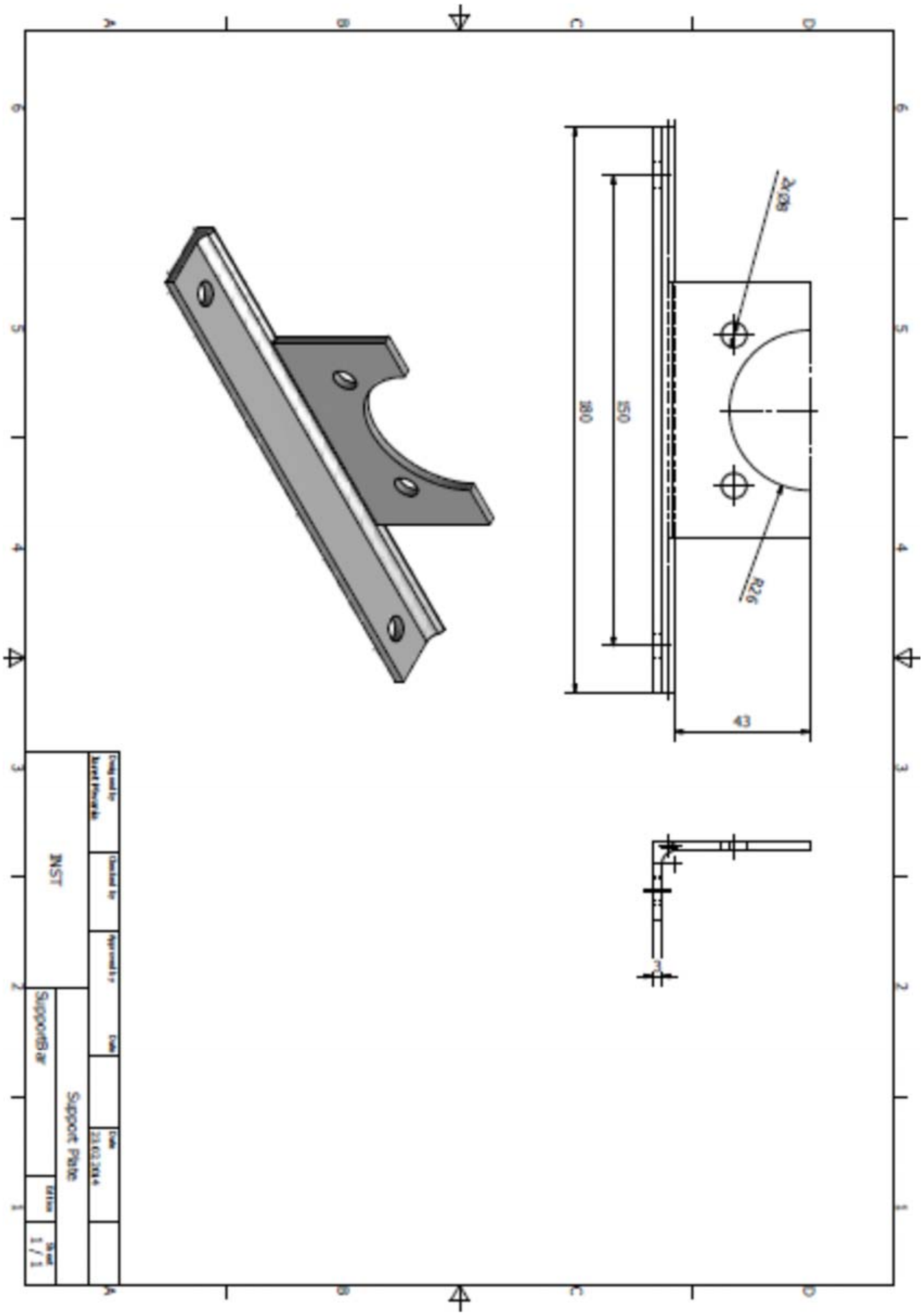

Figure A.11: The Barrel’s front flange in 3D and Front and End elevations showing dimensions