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Project Report

Designing and Manufacturing of a hand operated plastic injection moulding machine envisioned for the mesoscale range.

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Table of Contents

LIST OF FIGURES 3
LIST OF TABLES 3
ABSTRACT 4
1.0 INTRODUCTION 5
2.0 JUSTIFICATION 6
3.0 OBJECTIVES 8
4.0 BACKGROUND 9
4.1 TYPES OF INJECTION MOULDING MACHINES: 9
4.2 PARTS OF AN INJECTION MOULDING MACHINE: 11
4.2.1 Powder Injection Moulding (PIM) 12
4.3 DESIGN FACTORS THAT AFFECT PLASTIC INJECTION MOULDING 13
4.3.1 Resin: 13
4.3.2 Machine: 13
4.4 Mould: 14
4.5 MATERIAL CONSIDERATIONS 16
4.6 ERGONOMICS, SAFETY CONSIDERATIONS AND STANDARDS 17
5.0 DESIGN METHODOLOGY 19
5.1 INITIATION 19
5.2 DESIGN PROCESS 22
5.2.1 Development Design Concept 2.0: 22
5.2.2 Development Design 2.1: 24
5.2.3 Development Design 2.2 (Final Version): 25
5.3 Calculations and Discussion Final Version 2.2. 26
6.0 PROTOTYPING & FUTURE WORK 29
7.0 CONCLUSIONS. 30
REFERENCES 31
Glossary 32
Abbreviations list 32
STUDENT DECLARATION 33
APPENDIX 34
Appendix 1. Some thermoplastics' characteristics 34
Appendix 2 Properties AISI SS316 35
Appendix 2 Properties AISI4340 35
Appendix 2 Properties HDPE 35
Appendix 3. Gant Chart 36
Appendix 4. Concept Selection. 37
Appendix 5. Heating Devices 42
Appendix 6. Calculations Model V2.0 42
..... 46
APPENDIX 7. Engineering Drawings 49
APPPENDIX 8. Calculations for version 2.2 59

APPPENDIX 9. FEA RESULTS. 65
Appendix 10. Prototype Construction 67

LIST OF FIGURES

FIGURE 1. TYPES OF PLASTIC INJECTION MOULDING.. 9
FIGURE 2. TWO STAGE PLUNGER INJECTION SYSTEM. 10
FIGURE 3. VERTICAL INSERT INJECTION MOULDING MACHINE SOURCE 10
FIGURE 4. PARTS OF AN INJECTION MOULDING MACHINE 11
FIGURE 5. TYPICAL PIM PROCESS CHAIN. 12
FIGURE 6. WALL THICKNESS CONSIDERATION 15
FIGURE 7. SUMMARY OF THE DUTY'S DESIGNERS OF MACHINERY. 18
FIGURE 8. CONCEPT 2 20
FIGURE 9. METHODOLOGY FLOWCHART. 21
FIGURE 10. 3D MODEL OF CONCEPT 2. V2.0 23
FIGURE 11. 3D MODEL OF CONCEPT 2. V2.1 24
FIGURE 12. LENGTH CONFIGURATIONS 24
FIGURE 13. EXISTING ARBOR PRESS AT WINTEC'S 25
FIGURE 14. 3D MODEL FINAL VERSION 2.2. 26
FIGURE 15..UNDER THE LOADING CONTITIONS 27

LIST OF TABLES

TABLE 1. WALL THICKNESS RECOMMENDED FOR SOME POLYMERS SOURCE (BAYER, 2012) 15
TABLE 2. DRAFT ANGLES FOR DIFFERENT SITUATIONS. SOURCE BAYER,(2012) 15
TABLE 3. GENERAL RECOMMENDATIONS FOR SAFETY FACTORS. SOURCE (ENGINEERING TOOLBOX, 2010) 16
TABLE 4. RECOMMENDED UPPER FORCE LIMITS FOR VERTICAL PUSHING AND PULLING (GOVERMENT OF CANADA, 2018) 17
TABLE 5. IDENTIFIED DESIGN PARAMETERS 19
TABLE 6. WEIGHTED DECISION MATRIX DESIGN PROJECT PLASTIC INJECTION MOULDING MACHINE 20
TABLE 7. FACTOR OF SAFETY. V2.0. 22
TABLE 8. FACTORS OF SAFETY. V 2.2 26

ABSTRACT

This project entitles the design of a simple hand operated plastic injection moulding machine capable of processing up to 4 cm^3 of thermoplastic material. The apparatus is designed so it can be used for processing polymer and powder injection moulding, as well as, to be adapted in the future to be used with a different medium of compression. The machine in question is intended to be used for further research in the mesoscale injection moulding process and to reinforce the knowledge gained in the lessons imparted at Wintec.

A literature review identifying present technologies and to identify design parameters was done. Based in this information three different concepts were considered and after receiving input from the client and collaborators the preferred concept was subject to further study. Three iterations brought changes to the preferred concept until a final design was obtained.

The final design parts were designed observing factors of safety and its assemblies were analysed with the use a three-dimensional software and the use of FEA (Finite Element Analysis). The final design conforms to the design parameters identified in the literature review. Prototyping of the unit was initiated but due to constraints could not be finished. Further work to complete the prototyping is advised. The project can be taken from this stage onward to test physically the machine and validate the predicted values obtained in the calculations.

1.0 INTRODUCTION

The following document report presents the design of a small-scale hand operated injection moulding machine. The moulding machine is to be able to process $4cm^3$ or less of thermoplastic material. The design makes use of a perforated barrel which is to be heated up to process temperature using band heaters. The heated material is then to be forced into a mould cavity by action of a piston.

This machine, however intended for thermoplastics, might be used for the processing of PIM "Powder Injection Moulding". Also, the apparatus is designed, so if required, it can be easily adapted to be used or incorporated to another medium of compression as a bigger press or tensile testing machine. The adaption, however, is out of the scope of this work. The heat required for processing the polymer was part of this work however the client was to provide the mean of controlling the heating elements. Also, not part of this work is the design of inserts/mould tools which would fall into the possibility of future project research. The machine was designed seeking to attain injection pressures similar to the pressure machines present in the market since no information on the pressure required to fill the insert was given. Injection pressures above 100 Mpa are typical however machines with 30 Mpa of pressure injection can be found in the market.

The project document outlines the processes carry out to achieve the project objectives. It starts by identifying the reason or need for such a machine. Once this is established, the objectives which have been identified in order to achieve the project are documented. Afterwards a literature review identifying available technologies in the market is carried out, in this segment also, planification process is observed. Following this step, the methodology used is explained. Finally, the document closes with discussions of the findings and recommendation for future work.

2.0 JUSTIFICATION

There is no question about the importance of polymers in our society. Since their practical discovery in the 1800's[1], polymers have been developed in such a manner that have become part of our daily life. They are virtually present in the millions of products that make our life gracious and easier yet, they pose a problem due to the part they play in pollution.

Many industrial processes have been developed to process polymers however, injection moulding it is one of the most used since it is a versatile process. According to Strong (1996), injection moulding allows the production of intricate discrete parts with variable cross sections, as well as, surface texture which allows the production of a wide variety of parts with the same equipment. This characteristic makes injection moulding one of the most used process to produce plastics parts.

Moreover, with the recent advance of industries such as biotechnology, medicine and electronics which requires miniaturisation (Alting L, 2003), there have been an increased in the need for processes that allow the production of parts in the scales pertinent to the miniature and the meso-scale range. One of these processes that have been able to adapt to the challenges that miniaturisation brings is plastic injection moulding (Fassi, 2017) .

Locally, New Zealand has a strong plastics industry. In the Waikato region we have companies like Millennium Plastics and Elite Plastics, among others, that use plastic injection moulding however, these companies mainly focus in the macro scale injection moulding.

Also, New Zealand's Industry have managed to gain an important presence in the global market of electronics, space and healthcare products with innovative companies like Rocket lab and Fisher & Paykel Healthcare.

The products created in these companies frequently require components with very small dimensions which conventional machining processes are not capable of producing economically. On the other hand, we have that the micro and mesoscale manufacturing of products is an area that has not been well advanced which opens a niche for more research and development. The production on the meso and micro scale has stringent requirements that pose a challenge for conventional plastic injection moulding. Knights, (2001) explains that 75% or more of the melt shot are lost to the sprue and runner system if conventional machines are used thus, lots of energy is wasted. Also, higher injections speeds and pressures are required to push the melt through tinier nozzles and flow channels and conventional machinery poorly control such small shot sizes. Resident time also plays a big factor if conventional machines are used. Large volumes of melt sitting in the barrel being heated as it waits to be injected propense the material to go through thermal degradation.

[1] Natural polymers were used by meso and south American aborigines likes Mayas and Caribes many centuries before polymers started to be developed by western civilisation in the 1800's

For all the above-mentioned reasons it is only logical that a professional educational institution that is preparing professionals that might work in the plastic industry to have equipment that would help students to understand and gain the adequate knowledge that would put them in the industry's vanguard.

With this in mind, this project seeks to provide WINTEC'S Centre for Engineering and Industrial Design with a simple device which is going to allow further research in the mesoscale injection moulding process and that will help to reinforce the knowledge gained in the lessons imparted in the institution by allowing practice labs.

3.0 OBJECTIVES

The main Objective of this project is to **Design and Manufacture a manually operated meso-scale injection unit capable processing thermoplastic material in volumes less than 4 cm^3.** In order to achieve this goal other sub-objectives have been identified and these are:

- Investigate Plastic Injection Moulding Process.
- Investigate current Injection machine technology available in the market.
- Design an economical Plastic injection Moulding machine.

4.0 BACKGROUND

In order to grasp and understand the existing injection moulding technologies a literature review is to be performed. This literature review not only will allow to see existing technologies to but also will help to identify what engineering considerations are to be taken.

4.1 TYPES OF INJECTION MOULDING MACHINES:

In general, there are two types of plastics injection moulding machines based on the type of ramming system used, see figure 1. We have the injection mould plunger type and the reciprocating rotating screw (Serope & Shimid, 2014).

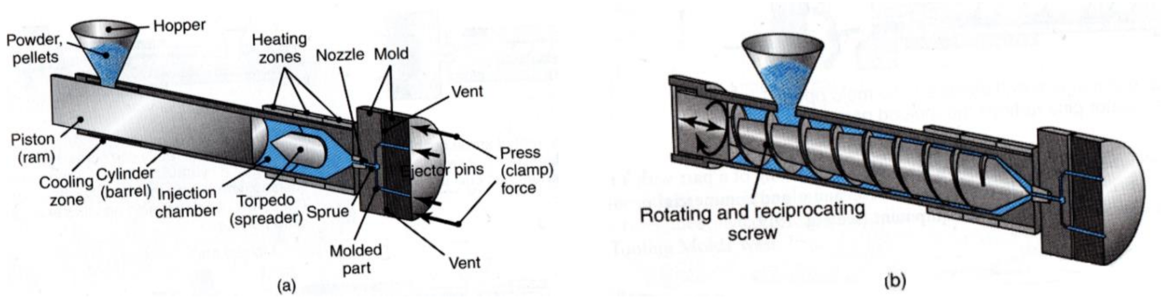


Figure 1. Types of plastic injection moulding. On the left a plunger type machine. On the right a rotating screw type. Source:(Serope & Shimid, 2014, p. 503).

Both systems have a plasticising cylinder which is surrounded by heaters elements. The difference lies in that in the plunger machine type a piston is rammed through the cylinder forcing the molten polymer through the nozzle. On the other hand, the reciprocating rotating screw machine has a rotating Archimedes screw type plunger which forces the molten polymer forward by rotation, then, when enough material is plasticized, this Archimedes screw is hydraulically rammed forward forcing the molten polymer through the nozzle and into the mould cavity.

In the market today, based on the manufacturing process and the end product, can be found injection moulding machines designed with a combination of the above-mentioned ramming system (Medina, 2017). Once of such a machine can be appreciated in figure 2. These machines have a pre-plasticization unit and a dosification unit. The pre-plasticizing unit has a mixing screw. In this chamber the polymer is heated and mixed by action of the mixing screw helicoidal movement. The polymer is forced into the dosification chamber where the amount of polymer required is measured and then rammed into the mould cavity.

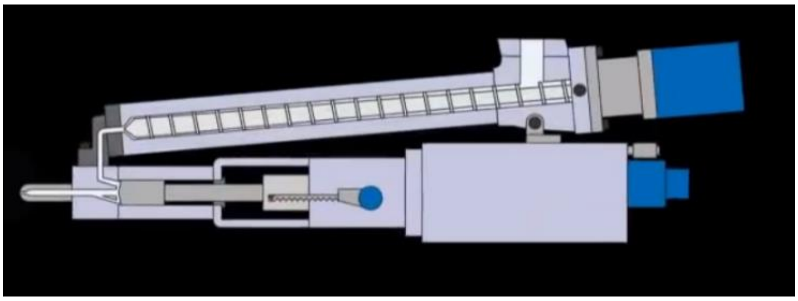


Figure 2. Two stage Plunger Injection System. This system has precise dosing capability. Source (Plustech, (22 Octuber 2013)

Typically, plastic injection moulding machines are horizontal however, there are vertical machines which are usually used for producing small close tolerant parts and/or for insert moulding. (Serope & Shimid, 2014). One of these machines can be appreciated in figure 3. Insert moulding is a process where the polymer is formed around other metallic parts called inserts.

Figure 3. Vertical Insert Injection Moulding Machine Source (Engel, n.d.)

4.2 PARTS OF AN INJECTION MOULDING MACHINE:

Plastic injection moulding machines usually consist of two different parts. The clamping unit and the plasticising unit (Fassi, 2017). See figure 4.

The clamping unit is the unit in charge of holding the moulding tool closed while the molten polymer is injected. In automated systems the clamping unit is in charge of ejecting the formed parts as well. The clamping unit has to be able to withstand the pressure exerted by the ram system which tends to open the moulding too. The mechanical action of this unit could be of mechanical or hydraulics nature. On the other hand, the plasticising unit is in charge of heating and melting the polymer and forcing it into the mould cavity (Groover, 1996) .

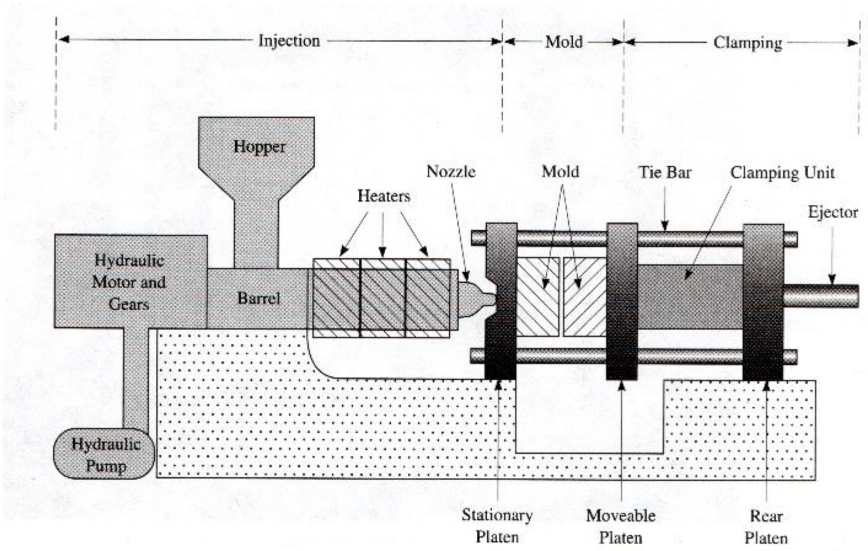


Figure 4. Parts of an injection Moulding machine. Source (Strong, 1996)

The plasticising unit melts the polymer with the use of heating elements however, a lot of the heat generated is due the shear forces when the polymer is being compressed by the ram, on the case of the injection mould plunger, and rotational-translation movement, on the case of the reciprocating rotating screw. For this reason, regular injection moulding machines do not use the heating elements to heat the polymer until its melting point since shear forces assists with the plasticising process (Serope & Shimid, 2014). This needs to be considered when designing a manual operated machine since the pressures and shear forces involved might be insufficient requiring the heating elements to bring the polymers to it processing temperature.

It is worth noting that the melting temperature of polymers due to their inherent molecular structure can be a range or a specific temperature. In addition, thermoplastics have a processing temperature which is determined by experimentation. According to Strong, (1996) this process temperature is somehow different for different process equipment and process's conditions but there are ranges to work from. Processing temperatures for some polymers can be seen in appendix 1. Strong, (1996) also states that most manufactures rate their equipment based on the most common polymmer which is polyethyline

(PE). Therefore the injection moulding machine object to this work is going to be designed to be able to reach temperature within 170 and 230 degrees Celsius.

4.2.1 Powder Injection Moulding (PIM)

Powder injection moulding as process inherits the low cost and productivity characteristics of plastic injection moulding. The process uses the same equipment and tooling that are used in plastic injection moulding, but the tool cavities are designed 20% larger to account for part shrinkage (SOFINE GIAN PIM TECH, n.d). The parts created with this process are characterised by great homogeneity and high material density (ARBURG, 2016) and according to Éric Baril et all., (2006) the process combines the qualities of injection moulding such as the form complexity and high productivity

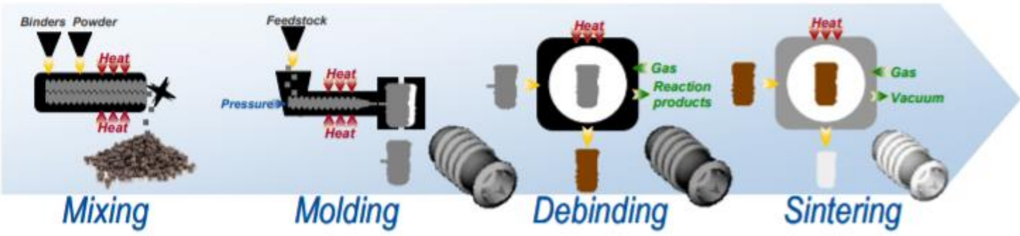


Figure 5. Typical PIM process chain. Source (Éric Baril et all., 2006)

PIM uses polymeric binding agents which are premixed with metal or ceramic powders. The mixture is then heated in an injection barrel and then this mixture is pressure forced into a die cavity by a ramming system. The part obtained then goes into a process call debinding, see figure 5, this process removes the polymeric binding agent from the metal or ceramics. Debinding is done by dissolving the binding agents with catalytic compounds or thermal decomposition. The product finally goes to a process called sintering. In this process the part is heated in a furnace at a specific atmosphere and temperature- time profile. The sintering occurs at a temperature lower but close to the melting point of the metallic ceramic powder material. The final part, which densify from 15 to 25%, is produced by diffusion and/or the formation of liquid phases and grain growth (ARBURG, 2016). The physical, chemical and mechanical properties are comparable to wrought material (Éric Baril, et all., 2006).

4.3 DESIGN FACTORS THAT AFFECT PLASTIC INJECTION MOULDING.

Strong, (1996) states that main elements to achieve successful injection moulding are "... proper machine for good melting and injecting the resin; the proper resin for appropriate part performance; and good mould for part definition and removal …", therefore in this section these three elements are discussed. Similarly, due to the fact the machine being designed is not only going to be used for the processing of thermoplastics but also for the processing of PIM considerations for materials is discussed in this section.

4.3.1 Resin:

Polymers (Thermoplastics): Thermoplastics are polymers that when heated melt and flow, once they cool, they solidify. They have for characteristic that when they are reheated they can go to a fluid state and they can be reshaped. When thermoplastics solidify, they can take one of two molecular structures; Amorphous and Sem- crystalline (Goodship, 2017). Semi-crystalline thermoplastics have crystalline regions in their molecular structure. These thermoplastics tend to have a sharp melting points versus amorphous plastics which soften within certain temperature range. A table with the most commonly used thermoplastics and their characteristics can be seen in appendix 1.

The characteristics of polymers that influence the quality of plastic moulding are according to (Bolur, 2011):

- *Melt flow index* — Measure of the how ease melt of polymer flows. (mass of polymer in grams flowing *in* 10 min).
- *Heat thermal stability* — Ability of polymers to avoid molecular scission at processes temperatures.
- *PVT Characteristic:* — Volume shrinkage is affected by pressure. The pressure and temperature affect specific volume.
- *Shrinkage:* — Thermoplastics present substantial shrinkage when cooling due to their high thermal expansion. Some thermoplastics experience up to 15% volumetrically shrinkage and crystalline polymers contract more than amorphous.
- Shear thinning: — Tendency of polymers to thing out under shear stress.
- *Hygroscopicity* — Some polymers are hygroscopic. When exposed to process temperatures moisture could turn to steam and cause splay in case of ABS and Hydrolysis in polymers like Nylon and PET

4.3.2 Machine:

As stated before, the typical injection moulding machine consist of two parts. The clamping unit and the plasticizing unit. Both working in accordance are specified to meet the requirements of the mould and the plastic end products. The parameters used to determine the configuration injection moulding machine are as follow.

4.3.2.1 Shot capacity: Also known as shot size is the maximum amount of material that the plasticising unit can inject into the mould per cycle and it is rated in cm^3 This parameter is usually given as standard in machine datasheets as shot capacity for polystyrene (Goodship, 2017).

4.3.2.2 Plasticisation capacity: It is the rate at which the polymer is plasticised, and it is given in terms of Kg/hr.

4.3.2.3 Maximum injection pressure: When the polymer travels through the mould cavity it experiences a resistance to flow. The injection Moulding machine (plasticising unit) is required to overcome this resistance so all cavities in the mould are filled. The maximum injection pressure is the maximum that the plasticising unit can exert, and it depends on the melt viscosity, flow ration and mould temperature. Typical injecttion pressures are from 28 MPa to 110MPa (Douglas M, 1997)

4.3.2.4 Clamping force: It is the force applied to the mould tool to keep it close. The mould tends to open due to the forces exerted by the plasticising unit pushing the melt in to the mould. The clamping force is used as a rating method for injection moulding machines (Strong, 1996).

4.4 Mould:

The mould is the tooling where the polymer is injected into and which give form. It is custom designed and fabricated for a given part to be produced (Groover, 1996). Usually moulds are two plated type and each half is attached to platens in the injection machine clamping unit.

Goodship,(2017) states that the mould tool has two mayor purposes. The first purpose is to act as a cavity into which the polymer is injected to and the second purpose is to act as heat exchanger where the surface of the tool absorbs heat from the part as solidifies.

Some of the engineering parameters to consider when designing a mould tool are described by (Bayer, 2012) these are:

4.4.1 Consideration of the delivery system: The delivery system consists of the channels that direct the melt into the product cavity. It comprises of the sprue, runners and gate. The delivery system should be designed to assure proper flow of the resin. Runners should be as short as possible and preferable of round cross section and should be large enough to minimize pressure loss.

4.4.2 Wall thickness and transitions considerations: Wall thickness is dictated by the structural and strength requirements of the part being produced and it is also dependant of the type of polymer being used. Walls should be design aiming to uniformity but when this is not achievable wall transitions should be smooth. The wall thickness recommended for some polymers can be seen in table 1 and examples of wall designs in figure 5

TABLE 1. ***Wall thickness recommended for some Polymers*** *Source (Bayer, 2012)*

Material	**Wall Thickness (mm)**
ABS	1.143 – 3.556
Polypropylene	0.635 – 3.81
Polyethylene	0.762 – 5.08
Nylon	0.762-2.921

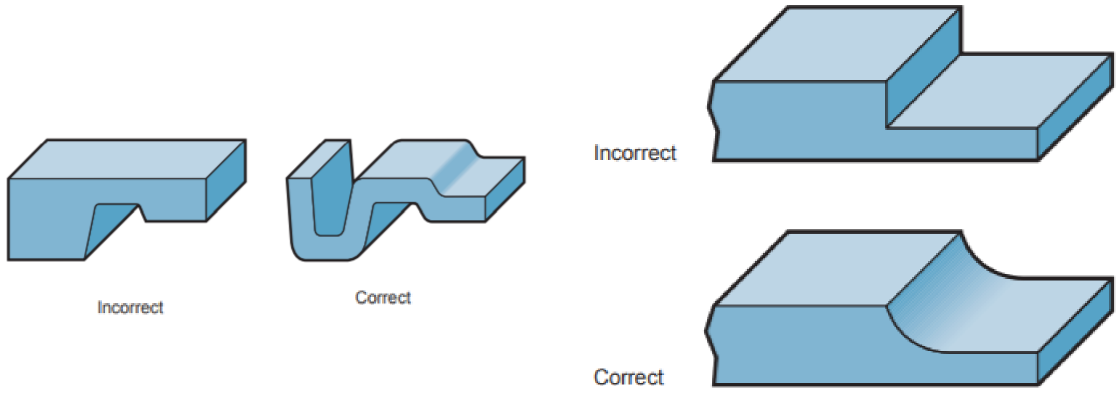


Figure 6. Wall thickness consideration Source (Covestro, 2015)

4.4.3 Draft angle: The draft angle aids with the releasing of the parts. Adequate draft angle makes it easier for the part to be ejected. It also helps to reduce damage to the part due to friction. Draft angles recommended for vertical faces, shut off and for general situations can be seen in table 2. In most situations it is desirable to use a draft of 2o but depending on the material used or section the draft value can be changed.

TABLE 2**. Draft angles for different situations. Source Bayer,(2012)**

Vertical Faces	0.5°
Most Situations	2°
Minimum for shut off	3°

4.5 MATERIAL CONSIDERATIONS

The machine being designed is not going to be used only for processing of polymers. It is going to be used for the processing of PIM as well. The manufacturing of ceramic and metal components using PIM requires hard wear resistance parts to overcome wear phenomena (Ali Panahi, 2010). Some of the materials used, due to their hardenability, to manufacture plastic injections screws and barrels are hardened tool steels like AISI 4340 or 4040. Vikas Rajoria, (2013) states that even though 4040 exhibits better heat flux characteristic 4340 has higher yield tensile strength and suggests that 4340 is more suitable for making the screw and barrel of injection plastic machines. Other components are to be designed using Stainless steel 316 which has corrosion resistance and adequate yield strength. Material properties for AISI 4340 and Stainless steel 316 can be seen in the appendix 2.

Another consideration, related to materials properties, that needs to be considered is that of the "safety of factor. The machine being designed has been envisioned so it can be modified and/or incorporated to be used with external compression apparatuses, like testing machines and presses, in the future. Therefore, the machine is designed aiming for conservative safety factors. In table 3 some recommended values for safety factors can be seen. Since the apparatus might be adapted in the future to use with other means of compression parts are design, where applicable, for a safety factor of at least 3.

Table 3. General Recommendations for Safety factors. **Source (Engineering ToolBox, 2010)**

Applications	Factor of safety
For use with highly reliable materials where loading and environmental conditions are not severe and where weight is an important consideration.	1.3 – 1.5
For use with reliable materials where loading and environmental conditions are not severe	1.5 -2
For use with ordinary materials where loading and environmental conditions are not severe	2 – 2.5
For use with less tried and for brittle materials where loading and environmental conditions are not severe.	2.5 -3
For use with materials where properties are not reliable and where loading and environmental conditions are nor severe, or where reliable materials are used under difficult and environmental conditions.	3-4

4.6 ERGONOMICS, SAFETY CONSIDERATIONS AND STANDARDS

The plastic injection moulding machine being designed is going to be manually operated. Therefore, considerations regarding the ergonomics, as compelled by AS/NZS 4024.1401-2014 Safety of machinery, must be considered.

Garg et all, (2012) state that for activities (pushing and pulling) that are considered of low frequency the biomechanical criteria should be taken into account so, forces do not exceed the recommended biomechanical limits. Maximum recommended values for activities involving pulling or pushing can be seen in table 4. They recommend not to exceed 250N for activities involving pulling from shoulder level.

Table 4. ***Recommended Upper Force Limits for Vertical Pushing and Pulling*** *(Goverment* of Canada, 2018)

Conditions	Upper Limit of Force, in Newtons	Examples of Activities
Pull down - Above head height	540 N	Activating a control, hook grip; such as a safety shower handle or manual control.
Pull down - Shoulder level	250 N	Operating a chain hoist, power grips; less than 5 cm (2 in) diameter grip surface.
Pull up - 25 cm above the floor	315 N	Stringing cable, threading up a paper machine, activating a control.
Pull up - Elbow height	148 N	Raising a lid or access port.
Pull up - Shoulder height	75 N	Raising a lid, palm up.
Boost up -Shoulder height	200 N	Raising a corner or end of an object, like a pipe; boosting an object to a high shelf.
Push down - Elbow height	290 N	Wrapping, packing, and sealing cases.

Another safety consideration that needs to be taken into account is the presence of hot surfaces. The American Society for Testing and Materials, 2009, established that hot surfaces that might be in contact with human skin should not exceed 60 C°.

The structural integrity of the apparatus also bounds to the different New Zealand's standards. Among them the AS/NZS1554.1 (2014) which imparts rules for the welding of steel structures. This standard has been specifically produced for steel structures however it can be applied to machine frames (Standards New Zealand/Australia, 2014).

WorkSafe (Government of New Zealand, 2014) compels designers to observe AS/NZS 4024.1401-2014: Safety of machinery (Design principles). Worksafe outlines the responsibilities designers are to adhere to when designing machinery (see figure 7). AS/NZS 4024 standard defines the principles that should be followed during the process of designing machinery. It applies to the synergy between worker and machinery when operating, adjusting, installing, cleaning, maintaining, repairing, disassembling and transportation. It takes the health, safety and wellbeing of the worker into account (Standards New Zealand/Australia, 2014).

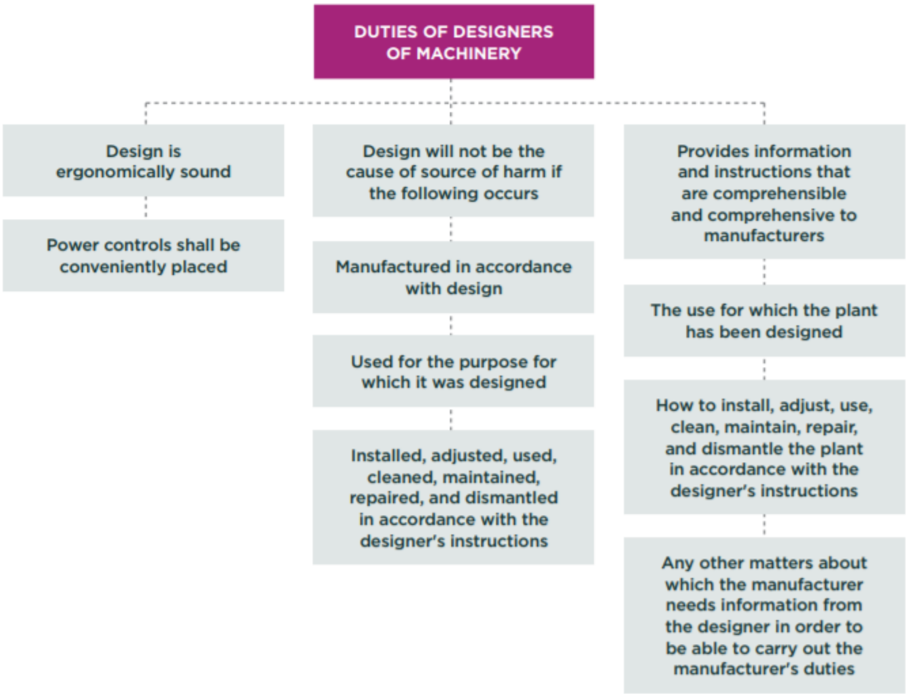


Figure 7. Summary of the duty's designers of machinery. Source (WorkSafe, Goverment of New Zealand., 2014)

Technical drawings presented in this work document are detailed in accordance to Mechanical engineering drawing standards NZSAS1100.201-199.

5.0 DESIGN METHODOLOGY

The project methodology followed a three-stage process however the progression was not linear constraints and limitations induced changes and in general the process was reiterative. The first stage (initiation) consisted in the investigation of the plastic injection moulding processes and the available technologies present in the market. Then a design stage where different configurations were evaluated taking in consideration the input from the client, budget and availability of manufacturing processes and materials. The third stage consisted on the prototyping and testing which was initiated but not completed due to constraints. Difficulties from some of parties involved in the manufacturing process rendered some of the parts not to be completed on time and therefore the prototype and testing had to be deferred for future work.

5.1 INITIATION

The initiation process was fundamental to understand the project requirements. In this phase the familiarisation with the problem was done by having regular meeting with the client.

In order to gain a better understanding of the technologies, other alternatives that have been used to develop similar machines and to identify some of the design parameters to be used a secondary research was done. For this, different information sources like journals books, manufacturing catalogues were visited. Also, people related the industry working in companies like Millennium plastics, and representatives at Plastic NZ among others were approached for first-hand information.

The planning of the process was done in this phase as well. A project task chart (Gantt) detailing the tasks necessary to carry on with the project was created (appendix 3). Some of the parameters found in this phase can be seen summarised in table 5.

***Table 5**. Identified design parameters*

Volume to be process	4 cm^3 Max
Processing Temperature	170 -230 C Based on Polyethylene
Budget	300$
Materials (Barrel)	Material hard enough for PIM use
Typical injection pressures	30 to 110 MPa

Also, as part of this phase and based on the information collected from the secondary research, three concepts were sketched and evaluated using a Pugh matrix. At this stage and based on the matrix, concept number two was chosen to be developed. This concept in the early stages of the project seem to offer the most sensitive solution to the problem. As seen in table 6, the concept had a better overall rating compared to the other two concepts but, as will be seen later in the design process, the design had to be adjusted as the project progressed and more feedback information was obtained. In figure 8 the hand sketch of this concept can be seen. The other concepts and a detail description of the selection processed followed can also be seen in the appendix 4.

Table 6. ***Weighted decision matrix design Project Plastic Injection Moulding Machine***

	Concept 1			Concept 2			Concept 3		
	Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Cost	2	0.3	0.6	8	0.3	2.4	9	0.3	2.7
Design Simplicity	6	0.3	1.8	8	0.3	2.4	5	0.3	1.8
Ease to Fabricate	4	0.15	0.6	6	0.15	0.9	6	0.15	0.9
Low Maintenance	4	0.1	0.4	9	0.1	0.9	5	0.1	0.5
Safety	9	0.15	1.35	7	0.15	1.05	7	0.15	1.05
Magnitude = 1 to 10 **Score = (%) of attribute** **Rating= factor of the above**			4.75			7.35			6.65

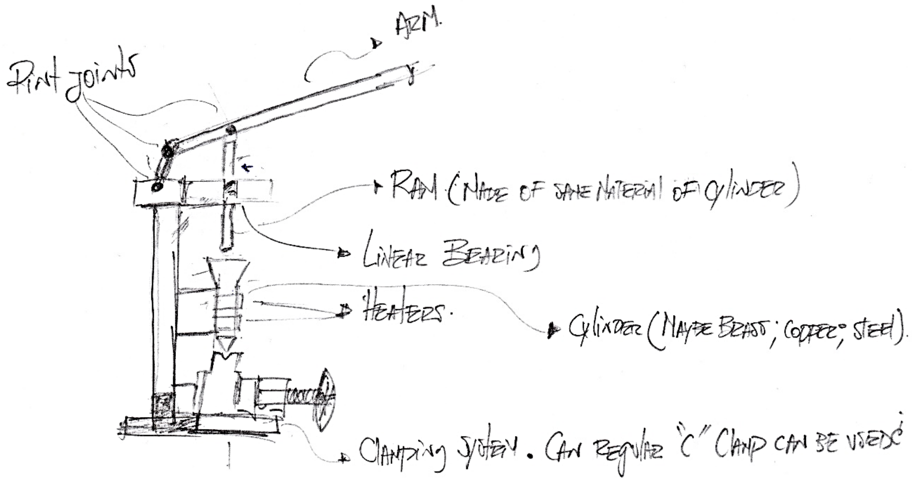


Figure 8. Concept 2. Vertical ram (piston) connected to Lever arm.

After choosing the concept to be developed a logic flow chart, seen in figure 9, was created to aid with the planning process and consequently help with the design and subsequent execution phase. The flow chart allowed to identify logically the steps necessary to proceed with the project.

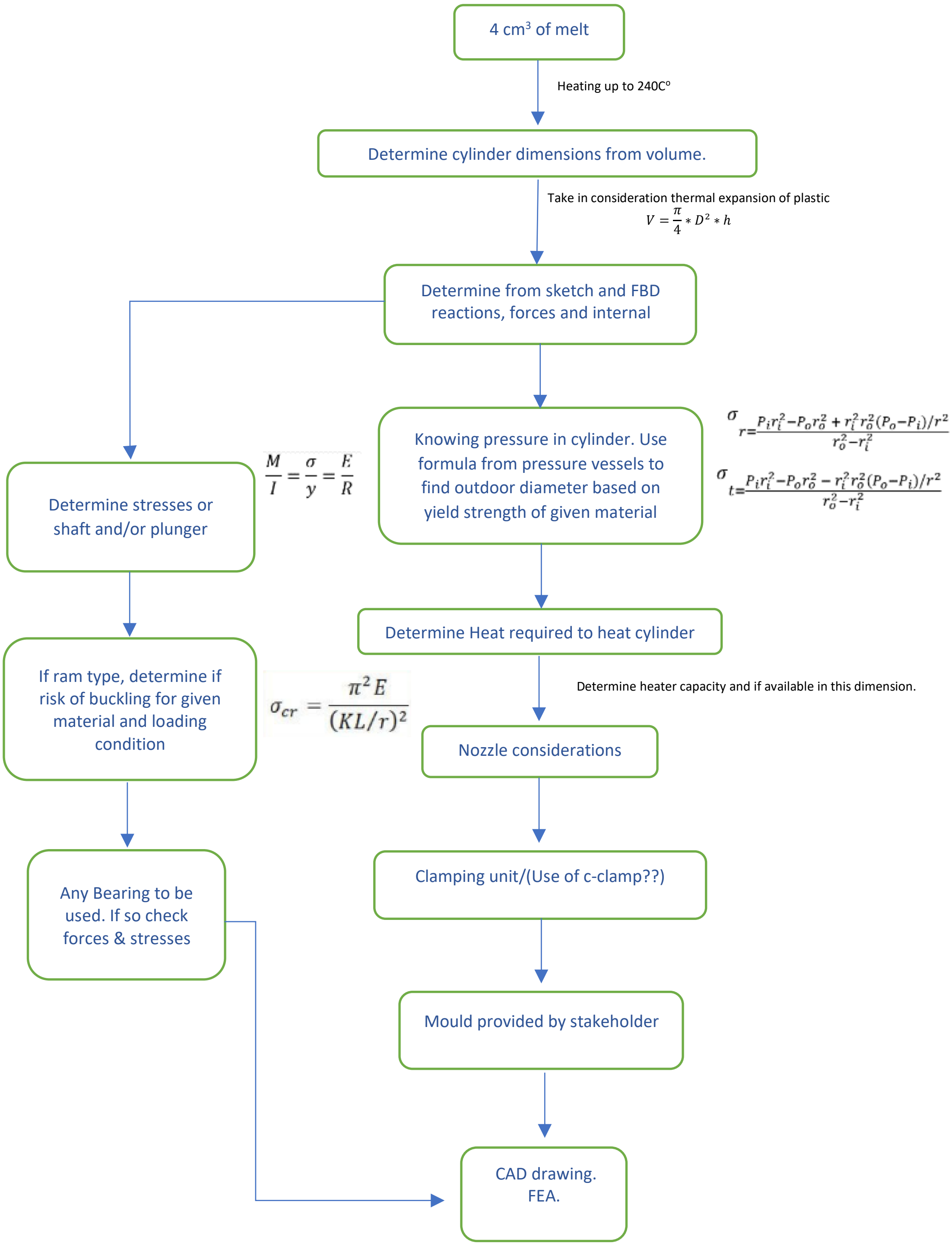


Figure 9. Methodology Flowchart. This flow chart maps out of the logical process to follow.

5.2 DESIGN PROCESS

The design process consisted in the verification of sections and some of the assemblies based on the sketch of the selected concept design. From the sketch and with the use of a CAD program (Inventor, Autodesk) the injection machine was parametrically modelled. Preliminary engineering drawings were issued, and these were used to discuss with the client. Also, the drawings were used to search advice from the different manufacturing agents and suppliers which advised in the viability of the design and availability of parts.

The design was a reiterative process. The plastic injection moulding machine concept chosen using the Pug chart was verified with calculations, check for safety factors and modelled however, after consulting with the client and receiving the advice of some manufacturing agents and considering the lead time of some of the materials/parts to be used the original concept had to be revised.

5.2.1 Development Design Concept 2.0:

Following the planning and with the aid of the logic chart, seen in figure 9, the sections and assemblies for the development of concept two were evaluated. For this hand calculations were performed to identify and verify the different sections and assemblies. A complete overview of these calculations can be seen in the appendix 5. The safety factors obtained for this design and an overview of this model can be seen in Table 7 and figure 10 respectively. Safety factors showed to be satisfactory by table 3 (under difficult and environmental condition) except for the handle lever. The lever was not redesign at this stage because after revision it was found that the lever was going to be adjusted anyway. The design consisted in a holding frame, a compression assembly (head guide and handle), barrel heated with 2 band heaters and a clamping system which was a combination of a designed-built lift and a drill vice. At this stage the heating capacity required for processing the polymer was determined which allowed to identify the heating elements required and the controller (specified heating element and controller can be seen in appendix 5). The heat required to heat the barrel plus the polymer up to process temperature it was found to be of 40W. However, market available band heaters come with minimum of 300W. This would reduce the heating time from 1 hour to approximately 15 min.

Table 7. Factor of safety. V2.0

Cylinder	**15.7**
Handle lever	**2.1**
Pins	**6.1**
Piston	**12.6**
Post-Base	**39**

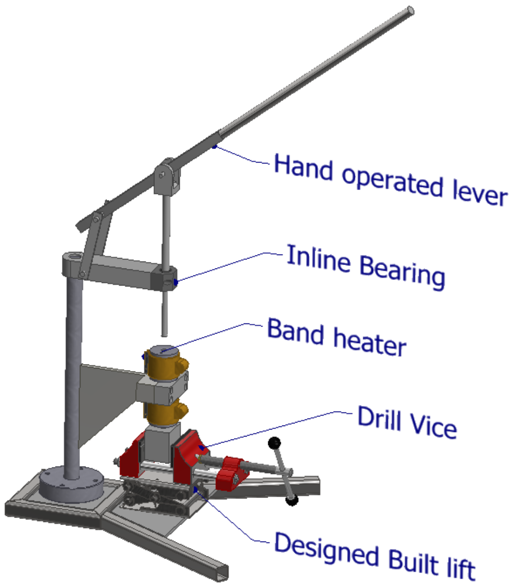


Figure 10. 3D Model of Concept 2. V2.0

Once the design was modelled It was presented to the client. Having a ball part of the costs and taking consideration other factors like lead time of some of the parts and manufacturing processes it was found that:

- Parts like the linear bearing was expensive and It was advised by the supplier of a lead time of about 6 weeks.
- With this configuration only 27 Mpa of injecting pressure would be attain.
- The designed lift it is a design built which it would increase the intricacy and cost of the project.
- There was a concern that with the budget at hand the alignment of the components (piston, cylinder and clamping system) would not be achievable since it would require special processes.

Considering the reason above mentioned a first revisit of the design was done with the objective of simplifying the concept.

5.2.2 Development Design 2.1:

After considering the input received from the client and suppliers it was decided that the design needed some changes, thus version 2.1 was issued. One of the main changes performed to the original design was the removal of the head assembly which carried the inline bearing. This change called then for adjustment of other assemblies.

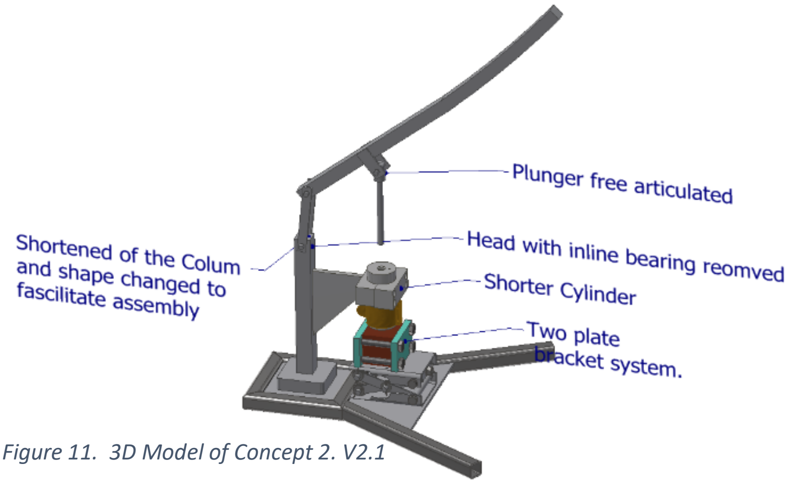


Figure 11. 3D Model of Concept 2. V2.1

The plunger in this design was to be free articulated, see 11. Since the plunger did not have a guiding system it was expected for the plunger to tend to rotate at the holding pin as the hand lever was pressing down. In order to decrease this turning action, the length of the barrel, plunger and therefor the holding column was shortened.

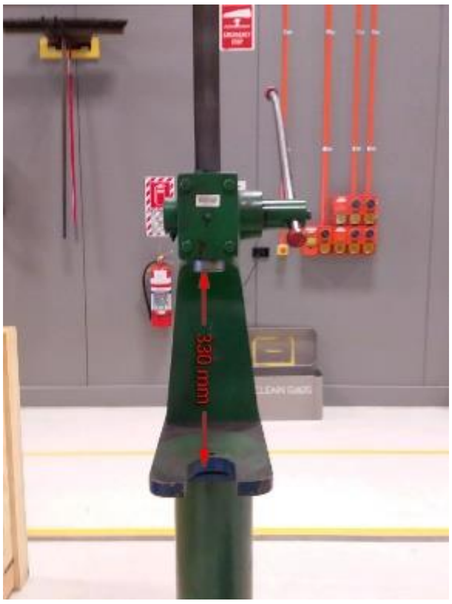
Figure 12. Different length configurations were analysed using Autodesk's ForceEffect Motion. looking into reduce the turning effect in link EF. Angles were

The free movement of the plunger as the lever was pressed down was analysed using ForceEffectMotion from Autodesk. Different length configurations were used until one with the least swing was found, see figure 12, however the turning effect was still present. Since the there was a chance that the turning motion of the plunger could jam the action a decision was made to once more go back and redesign the apparatus. Also, after meeting with the client it was realised that the two-plate clamp system devised for this version would not suffice for the task since the mould being used are 3D polymer-based inserts. Using this clamp systems would have left two of the insert faces exposed without support against the internal pressure.

5.2.3 Development Design 2.2 (Final Version):

Taking in considerations the issues identified in the last version it was necessary once more to go back to drawing board. The development of version 2.2 entitled the complete removal of the lever arm and its conforming parts. This simplified even more the design. The clamping unit was designed so it would cover in its totality the plastic insert avoiding its wall to be exposed.

The removal of the lever arm required then a new means of compression. Since some of the sections were adjusted dimensionally (shorten) for the design version 2.1 it was decided that the use of the existing 3 tone arbor press, at Wintec G block, figure 13, was ideal given the fact that its ram provides a straight vertical up down movement which would remove the moment force due to the lever arm used in version 2.0 and 2.1 .



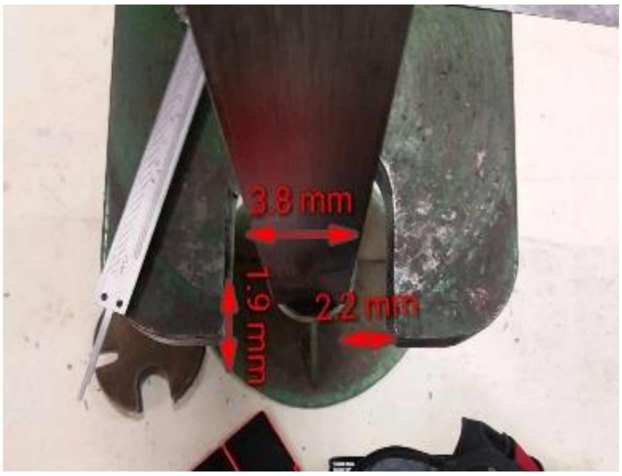


Figure 13. Existing arbor press at Wintec's G block, dimensions.

The necessary spatial dimensions of the arbor press were taken and an environment representing the arbor press was modelled using Autodesk Inventor. The modelled environment was then used for modelling the version 2.2 of the moulding machine, see figure 14. This version consists of a solid base that hosts the holding frame (holding bracket/cylinder) and the clamp system/lift. The clamp/lift creates a clamping action by means of rotating the power screw which increases the height of the assembly. Then by this action the buffer plate makes contact with the nozzle creating a sealed connection, this also avoids the hot nozzle to touch the insert. The plunger which is attached to the arbor ram then would be actioned into the cylinder injecting the polymer into the insert.

This version was presented to the client after calculations were performed and its prototyping was approved. Complete set of engineering drawings on this model can be seen in the appendix 7.

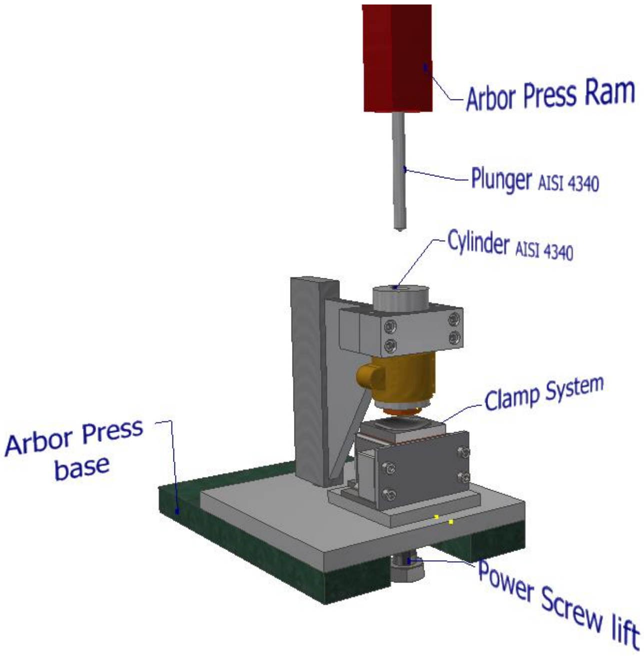


Figure 14. 3D model Final Version 2.2. The

5.3 Calculations and Discussion Final Version 2.2.

Calculations verifying for safety factors for the new parts dimensions were performed. Obtained values can be seen summarised in table 8. Detailed calculations can be seen in appendix 8.

Table 8. Factors of Safety. V 2.2

Cylinder	**5.1**
Piston	**4.6**
Bracket wall (Clamping system)	**2**
Lifting bolt Compression	**74**
Lifting bolt shear	**12.5**
Crushing of base thread	**53**
Base Threading shear	**44**

From the calculations it was found that the capacity of the arbor press should be limited down to 4905N since using the full capacity of the press could exceed the strength of the material for some of the parts, specifically the wall of the clamping system. However, with this force applied a maximum injection pressure of 68 MPa could be obtained which is an improvement compared to the first version (V2.0) of the design (27 MPa). The 68 MPa of pressure falls between the typical values of injection pressure, 30 – 110 MPa, for available commercial machines.

The model was designed assuming that all material and sections would be available however, this was subjected to the fact that the material was being donated (see prototyping in the appendix 10) and the dimensions of the material obtained were not the ones called for in the original design drawings. Therefore, it was necessary to go back and upgrade the dimensions of the model and check calculation accordingly. The material (Ad honorem) obtained for the bracket was of 8 mm thick which provided a safety factor of 2. This value which still provide a safety margin falls below the advised values (Table 3) for difficult loading and environmental conditions. Also, the clamping system was modelled without taking in consideration the connection type on the corners and it is known that higher stresses areas are found in these locations. This open the opportunity for future research to model and analyse the clamping system as square vessel using CAE tools, especially if the apparatus is used as intended with other medium of compressions that could exceed the 4905 N limit.

The safety factors for the cylinder and piston fall within the values recommended, as seen in table 3 (reliable materials used under difficult and environmental conditions) yet the values of safety related to the power screw lift are rather high. This finds explanation in the fact that a M10 bolt, see appendix 8, would have been enough to withstand the axial force exerted however, since the design called for the bolt to be attached to the bottom of the clamp/system a bolt with a larger diameter (M20) was necessary to provide enough surface area so the mating parts would not see-saw under loading.

For the assemblies FEA (Finite element) analysis was performed. Parts were verified manually however FEA was used to analyse the holding frame assembly and the whole assembly. With the FEA analysis it was found that the sections originally selected as for column and holding arm did not suffice and their section were modified accordingly. (See appendix 9.).

The whole assembly was also analysed using FEA and It was found that the plastic injection machine under the designed loading conditions of 4905N is not expected to fail (fig 15). For the whole machine an overall safety factor of at least 10 is expected with a displacement of 0.01 mm.

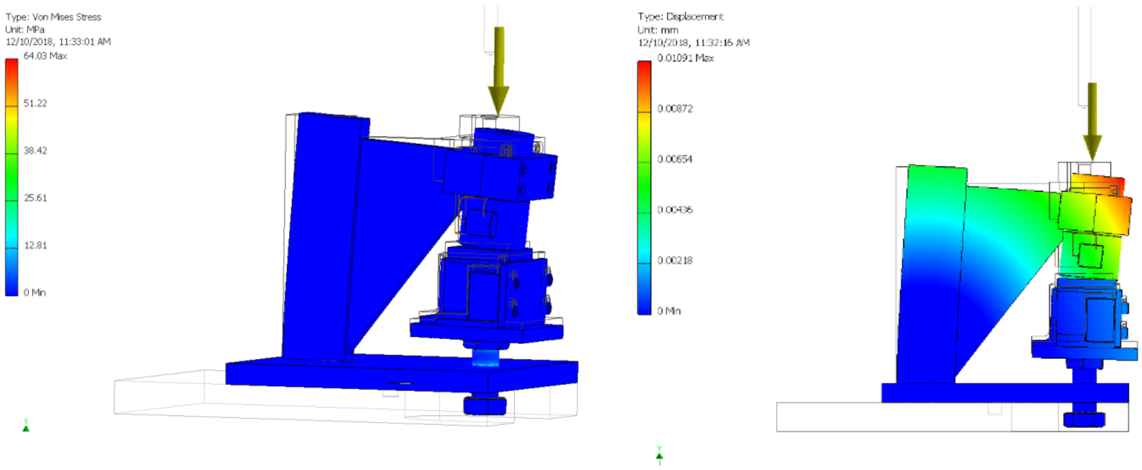


Figure 15..Under the loading contitions (4905N) the assemblies are not expected to fail. On the right for the loading condition a max displacement of 0.01 mm.

It should be stressed out that even though the results indicate that this machine will withstand the forces involved in the process there are some limitations. The calculations done on the parts and machine assemblies were done for statics conditions only. The plastic injection machine is going to be used under cyclical heated conditions and it is known that fatigue is one of the most common cause of failure in structures under cyclical loading. More over FEA analysis is an excellent tool that help to predict the behaviour of design under stress, but this should never be used as substituted for final physical testing.

6.0 PROTOTYPING & FUTURE WORK

The version 2.2 of the design was approved to go into the prototyping phase by the client. The holding assembly, cylinder and the lift/clamping system were successfully built, see appendix 10, however due to time constraints, issue with the manufacturing and communication difficulties from some of parties involved in the manufacturing processes some of the parts were not completed on time or were not machined as specified in the drawings therefore the prototype and testing had to be deferred for future work.

The calculations and the FEA study of the design revealed that for the static designed load conditions of 4095 N the plastic injection moulding machine is not expected to fail however, for validation to occurred physical tests are required. This so the predictive calculations can be corroborated. Therefore, it is recommended that this project be taken from this stage on.

Also, further research to check for fatigue is advised. This study might be done using one of the CAE tools existing in the market. The present Autodesk student version of Inventor do not come with fatigue analysis capabilities.

7.0 CONCLUSIONS.

The version 2.2 of the design make use of the existing arbor press present in “G” Block of Wintec Rotokauri. The machine is designed robustly and simple, so it could be adapted to other medium of compression in the future. The expected injection pressure is of 68 MPa which falls within the typical injection pressures for plastic injection machines available in the market. The machine should reach the process temperature of 230 ^{o}C with ease since the required heat capacity to achieve this is 40W however commercially available band heaters (for the given cylinder dimensions) have capacities that start on the 300W range.

The machine under the static load conditions of 4095 N is not expected to fail however this machine is going to be subjected to heat and cyclical loading which calls for further research to evaluate the machine for fatigue conditions.

The clamping system was modelled without taking in consideration the connection type on the corners and it is known that higher stresses areas are found in these locations. This open another opportunity for future research to model and analyse the clamping system in order to increase its safety factor.

The prototyping of the machine was initiated but due to constraints not all parts were manufactured on time therefore as part of the recommendation it is advised that the project be taken from this stage onward in order to test physically the machine and validate the predicted values obtained in the calculations and FEA analysis.

This design is subjected to future test and further research.

Limitations:

The force exerted on the machine should be limited to a force 4095 N unless modifications to the design are performed.

Recommendations:

- Continue with the prototyping to allow the testing and validation.
- Study of material under fatigue conditions.

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Glossary

De-binding= Process where polymer is removed by heat or chemically.

Meso-scale= Parts ranging from 0.1 mm to 5 mm

Micro-scale =Parts ranging from 10 nanometers to 0.1 mm

Plasticising unit = Unit where polymer is made flexible and pliable by heat, pressure and friction.

PIM =Powder Injection Moulding

Polymer = Substance made with long and repeating chain of molecules.

Sintering= Process by which a solid is compacted by use of heat or pressure

Thermoplastics= plastic material which become mouldable when heated

Abbreviations list

AISI = American iron and Steel institute

AS/NZS =Australian New Zealand Standards

σ_{hoop} = Normal stress in tangental direction which occurs in pressure vessels

$\sigma_{longitudinal=}$ Normal stress which is parallel tp axis of cylindrical symmerty

σ_b = Bending stress. Stress induced to bending

σ_{shear} = Material stress that causes slippage on parallel planes

$P_{Critical}$ = Critical Force; Maximun force a column can withsand without buckling.

CAE = Cad Aided Engineering

STUDENT DECLARATION

I have not copied any part of this report from any other person's work, except as correctly referenced. Collaboration: No other person has written any part of this report for me.

Student Name: Freddy Travieso

Student declaration of the above:

Date 15 / 11/2018

APPENDIX

Appendix 1. Some thermoplastics' characteristics.

	Processing temperature (C°)	Melting Temperature (C°)	Glass Temperature (C°)	Degree of crystallization	Elongation (%)	Modulus of elasticity (Mpa)	Tensile Strength (Mpa)	Approximate Market share (%)	Common applications
Polyethylene Low (LDPE)	149-232	115	-100	55% Typical	100 to 500	150	15	About 20	Packaging, grocery bags, toys.
Polyethylene High (HDPE)	177-260	135	-115	92% Typical	20 to 100	700	30	About 15	Packaging, pipes, crates, tanks.
Polypropylene (PP)	190-288	176	-20	High, but varies with processing	10 to 500	1400	35	About 13	Caps, Suitcases, tubes, battery casings
Acrylonitrile Butadiene Styrene (ABS)	177-260	No true melting point	105	None (amorphous)	10 to 30	2100	50	About 3	Toys, power tool housing, wall socket face plate, Pc keyboards
Nylon	260-327	260	50	Highly Crystalline	300	700	70	About 1	Fibre for carpets, apparel, tire cord.
Polycarbonate (PC)	204-354	230	150	Amorphous	110	2500	65	Less than 1	Pump impellers, safety helmets. Machine parts

Approximate market share does not add 100% since not all thermoplastics listed. This table was put together with information sourced from (Groover, 1996) and (Strong, 1996).

Appendix 2 Properties AISI SS316

800 398-4345

ASM Aerospace Specification Metals Inc.

Contact Us

AISI Type 316 Stainless Steel, annealed sheet

Subcategory: Ferrous Metal; Metal; Stainless Steel; T 300 Series Stainless Steel

Key Words: UNS S31600, SS316, 316SS, AISI 316, DIN 1.4401, DIN 1.4408, DIN X5CrNiMo17122, TGL 39672 X5CrNiMo1911, TGL 7143X5CrNiMo1811, ISO 2604-1 F62, ISO 2604-2 TS60, ISO 2604-2 TS61, ISO 2604-4 P60, ISO 2604-4 P61, ISO 4954 X5CrNiMo17122E, ISO 683/13 20, ISO 683/13 20a, ISO 6931 X5CrNiMo17122, JIS SUS 316

Component	Wt. %	Component	Wt. %	Component	Wt. %
C	0.08	Mn	2	P	0.045
Cr	Max 18	Mo	Max 3	S	0.03
Fe	62	Ni	Max 14	Si	1

Material Notes:
Molybdenum content increases resistance to marine environments. High creep strength at elevated temperatures and good heat resistance. Biocompatible. Fabrication characteristics similar to Types 302 and 304.

Applications: food and pharmaceutical processing equipment, marine exterior trim, surgical implants, and industrial equipment that handles the corrosive process chemicals used to produce inks, rayons, photographic chemicals, paper, textiles, bleaches, and rubber.

Corrosion Resistance: better corrosion resistance than 302 and 304; resists sodium and calcium brines; hypochlorite solutions, phosphoric acid; and the sulfite liquors and sulfurous acids used in the paper pulp industry.

Physical Properties	Metric	English	Comments
Density	8 g/cc	0.289 lb/in³	

Mechanical Properties	Metric	English	Comments
Hardness, Rockwell B	79	79	
Tensile Strength, Ultimate	580 MPa	84100 psi	
Tensile Strength, Yield	290 MPa	42100 psi	
Elongation at Break	50 %	50 %	in 50 mm
Modulus of Elasticity	193 GPa	28000 ksi	in tension
Charpy Impact	105 J	77.4 ft-lb	V-notch
Izod Impact	129 J	95.1 ft-lb	

Source (http://www.plasticmoulding.ca/polymers/polyethylene.htm)

Appendix 2 Properties AISI4340

Physical Properties

The physical properties of AISI 4340 alloy steel are given in the following table.

Properties	Metric	Imperial
Density	7.85 g/cm³	0.284 lb/in³
Melting point	1427°C	2600°F

Mechanical Properties

The mechanical properties of annealed AISI 4340 alloy steel are displayed in the following table.

Properties	Metric	Imperial
Tensile strength	745 MPa	108000 psi
Yield strength	470 MPa	68200 psi
Bulk modulus (typical for steel)	140 GPa	20300 ksi
Shear modulus (typical for steel)	80 GPa	11600 ksi
Elastic modulus	190-210 GPa	27557-30458 ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Elongation at break	22%	22%
Reduction of area	50%	50%
Hardness, Brinell	217	217
Hardness, Knoop (converted from Brinell hardness)	240	240
Hardness, Rockwell B (converted from Brinell hardness)	95	95
Hardness, Rockwell C (converted from Brinell hardness. Value below normal HRC range, for comparison purposes only)	17	17
Hardness, Vickers (converted from Brinell hardness)	228	228
Machinability (annealed and cold drawn. Based on 100 machinability for AISI 1212 steel.)	50	50

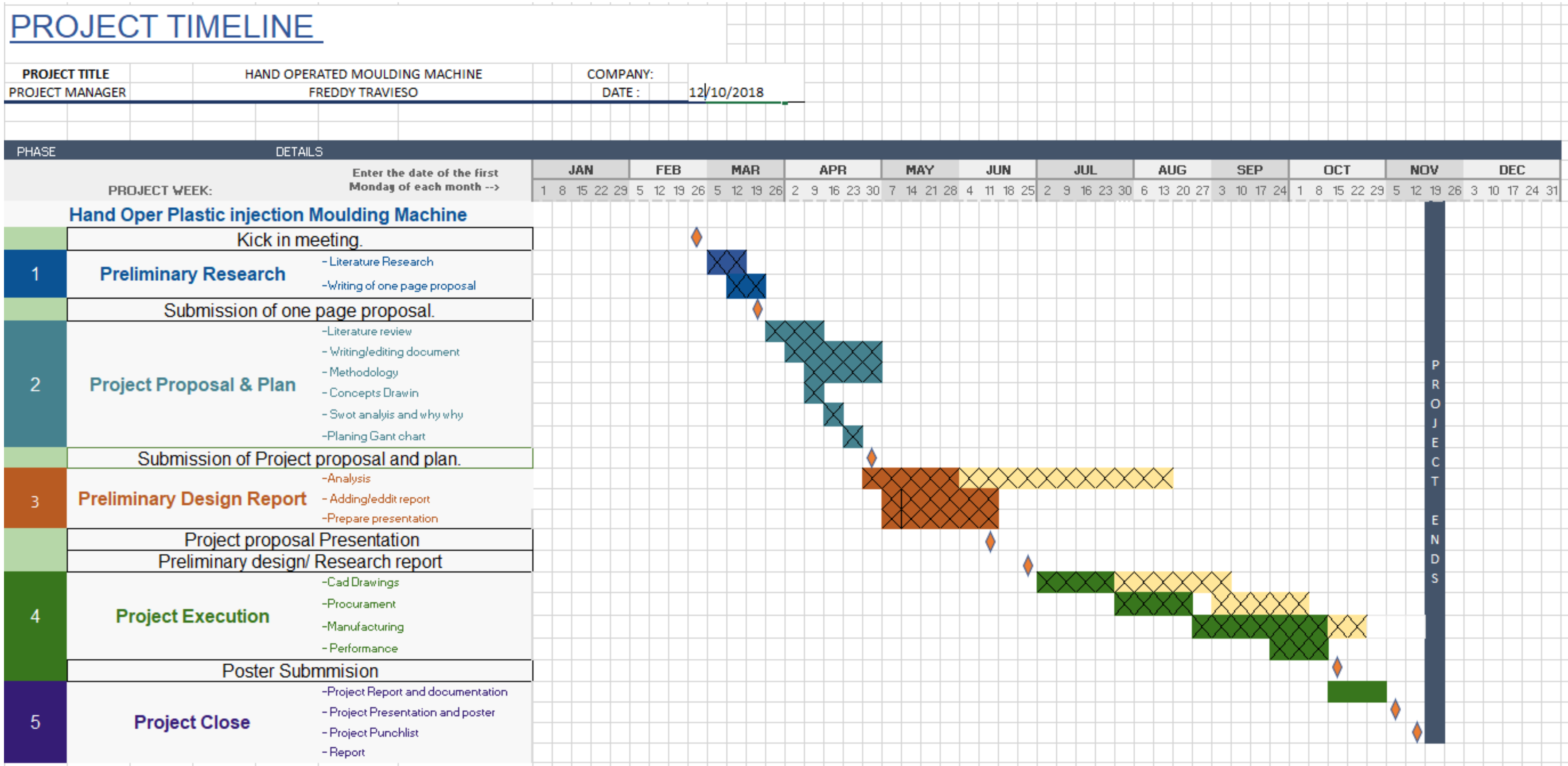
Source https://www.azom.com/article.aspx?ArticleID=6772

Appendix 2 Properties HDPE

General Properties	English Units	SI Units
CAS Number	25213-02-9	25213-02-9
Molecular Weight	0.062 lbs	28.0 g
Density	0.0336-0.0349 lbs/in³	0.930-0.965 g/cm³
Melt Density	0.027 lbs/in³	0.764 g/cm³
Bulk Density		
Pellets	35 – 38 lbs./ft³	561 - 609 kg/m³
Flake	31 – 34 lbs./ft³	497 – 545 kg/m³
Permeability Coefficients:		
Water (@ 25°C)	$1.7x10^{-12}in^2/sec^2$-atm	$1.3x10^{-10}cm^2$/(sec-cm Hg)
Oxygen (@ 30°C)	$1.4x10^{-12}in^2/sec^2$-atm	$1.06x10^{-10}cm^2$/(sec-cm Hg)
Carbon Dioxide (@ 30°C)	$4.6x10^{-12}in^2/sec^2$-atm	$3.5x10^{-10}cm^2$/(sec-cm Hg)
Nitrogen (@ 30°C)	$0.35x10^{-12}in^2/sec^2$atm	$0.27x10^{-10}cm^2$/(sec-cm Hg)
Water Absorption @ 24 h Immersion	0.03%	0.03%
Mechanical Properties		
Modulus of Elasticity (Young's Modulus)		
Homopolymer	150,000 psi	1,035 N/mm²
Copolymer	60,000 – 145,000 psi	400 – 1,000 N/mm²
Poisson's Ratio	0.40 - 0.45	0.40 - 0.45
Hardness, Shore D Scale	55 – 70	55 – 70
Coefficient of Friction	0.29	0.29
Thermal Properties		
DSC Melting Point		
Homopolymer	275 °F	135 °C
Copolymer	230 – 273 °F	110 – 134 °C
Specific Heat (@ 23°C)		2.25 kJ/kg °K
Heat of Fusion		
Homopolymer		245 kJ/kg
Copolymer		140 – 232 kJ/kg
Thermal conductivity		
Homopolymer		0.49 W / m °K
Copolymer		0.40 – 0.47 W / m °K
Vicat Softening Temperature		
Homopolymer	270 °F	132 °C
Copolymer	233 – 266 °F	112 – 130 °C
Coefficient of Linear Thermal		
Expansion	$12 x 10^{-5}$ in/(in °F)	$12 x 10^{-5}$ cm/(cm °C)
Shrinkage	0.018 -0.020 in/in	0.018 – 0.020 cm/cm

Source https://www.azom.com/article.aspx?ArticleID=6772

Appendix 3. Gant Chart



Appendix 4. Concept Selection.

Based on the project's objectives and the information collected in the first phase of the project three models were conceptualized. The sketches of these concepts can be appreciated in figure 8,9 and 10. The concepts do not show the electrical and temperature control.

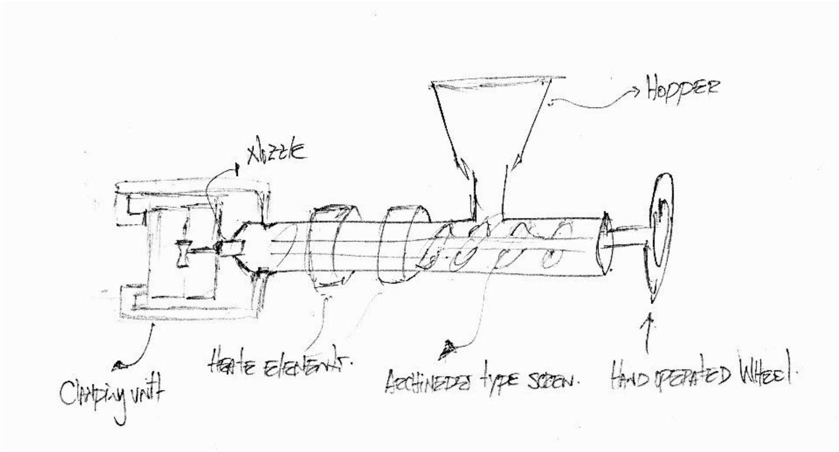


Figure 16. Concept 1. It uses a plasticizing screw.

Concept 1 consists of a horizontal cylinder. The plasticising cylinder would be mounted on a base and would be heated with a set of band heaters. A hopper attached to the cylinder would allow the material to be fed in to the cylinder. The unit uses a plasticizing screw which would be attached to a hand operated wheel. The threads in the screw's shaft would have two sections a fine thread equally spaced thread and a section with more separated thread. The mould would be attached to the plasticizing unit by a set of retractable adjusting clamps. The operation of the unit would be as follow: The controller's temperature is set up to the required temperature, given by the type of polymer to be processed. Once the desired temperature is reached the wheel would be operated manually. This would force the plastic forward towards the nozzle. The helical movement of the screw will aid with the mixing of the heated polymer. Once the screw reaches certain point it would disengage the fine equally thread and engaged the more spaced thread which would push the polymer into mould.

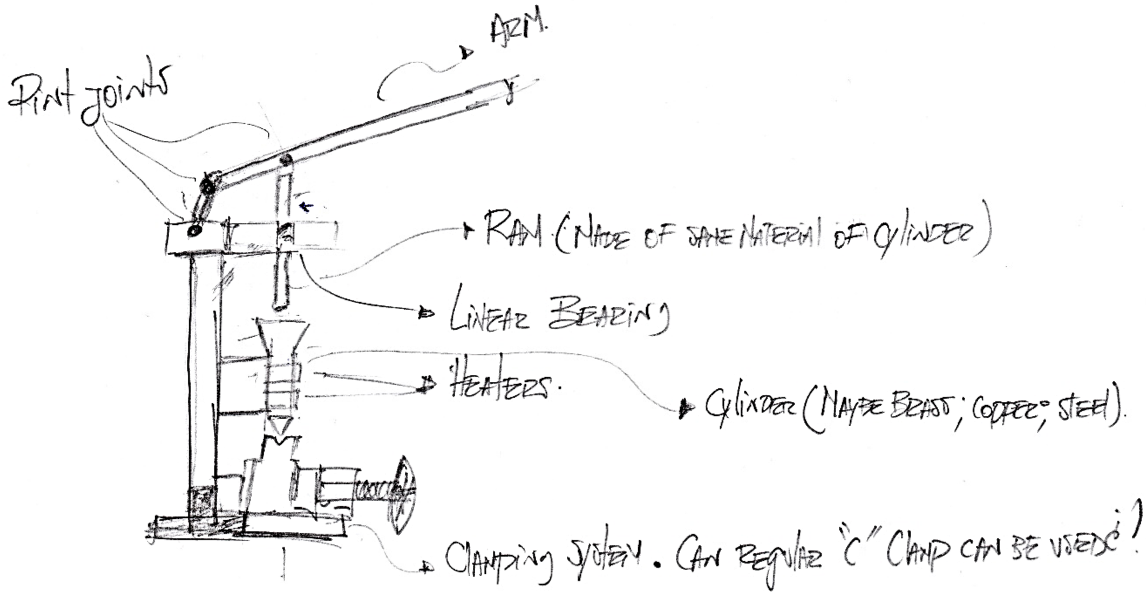


Figure 17. Concept 2. Vertical ram (piston) connected to Lever arm.

Concept 2 consists of a cylinder attached to a vertical set up frame. The plasticisation cylinder would be attached between a lever action and the clamping unit. Similar to the previous concept the cylinder would have some band heaters attached to its body. The lever action will have attached a vertical plunger. When the lever arm is pull down will cause the plunger to go into the plasticizing cylinder and ram the polymer through the nozzle into the mould cavity. The clamping unit could consist of simple C clamps or a drill press vice. The operation of this unit is simpler. Once the set temperature in the controller is reached the leaver would be actioned forcing the polymer into the mould.

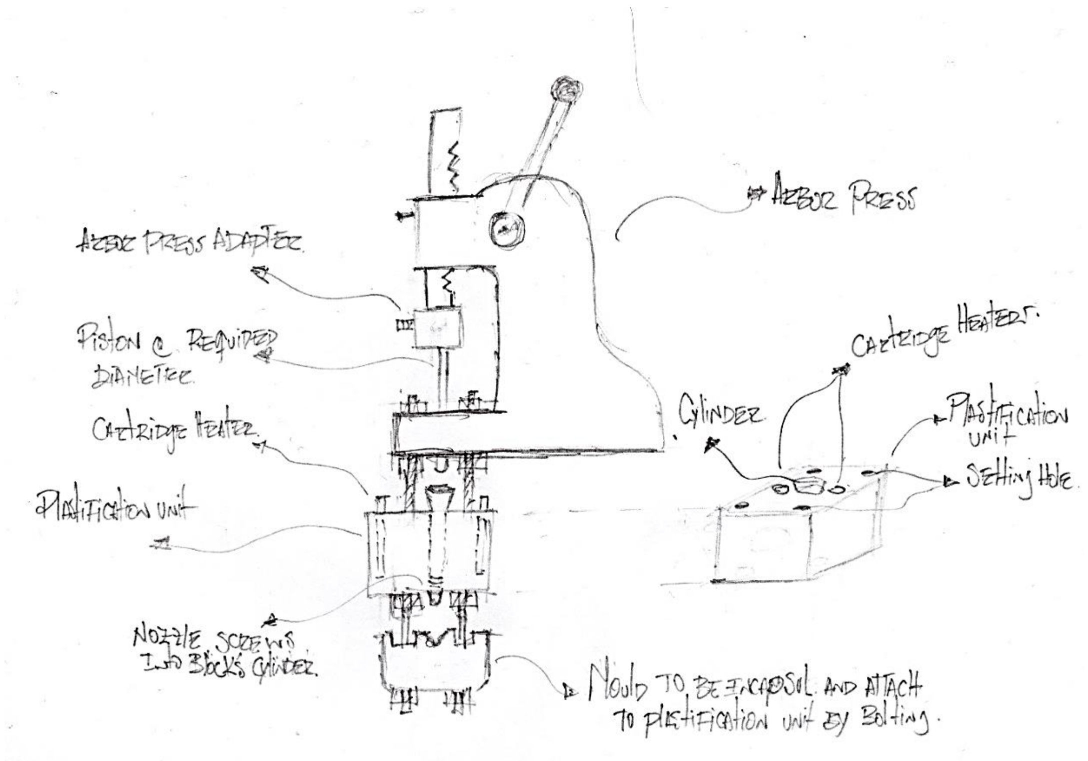


Figure 18. Concept 3. Use existing Arbor press.

Concept 3. This concept uses a pre-existing Arbor press. An adapter would be designed so a cylindrical plunger can be attached to the Arbor press's plunger. The plasticising unit in this concept would consist of a metal block. The block would have a cylindrical plasticising chamber in the centre with cartridges heaters surrounding it. This block would be attached to the Arbor press's bottom using threaded rods. The mould would be encased in between two cases or halves. The encapsulate mould is then bolted to the plasticizing unit using the same threaded rods. Like concept 2, once the set temperature is reached in the controller the arbor press is then operated and the plunger is rammed in to the cylinder pushing the melted polymer into the mould cavity.

Concept to be developed:

The attributes of the concepts previously shown were compared to determine the most feasible concept which will allow to achieve the project's goals. For this a weighing table was created, see table 6. The criteria used to determine the concept is based 100% scale where, the cost and design simplicity have a weight of 30% each. Attributes related to safety and easy fabrication each with a weight of 15% and for low maintenance 10%.

APPENDIX4. Weighted decision matrix design Project Plastic Injection Moulding Machine

	Concept 1			Concept 2			Concept 3		
	Magnitude	Score	Rating	Magnitude	Score	Rating	Magnitude	Score	Rating
Cost	2	0.3	0.6	8	0.3	2.4	9	0.3	2.7
Design Simplicity	6	0.3	1.8	8	0.3	2.4	5	0.3	1.8
Ease to Fabricate	4	0.15	0.6	6	0.15	0.9	6	0.15	0.9
Low Maintenance	4	0.1	0.4	9	0.1	0.9	5	0.1	0.5
Safety	9	0.15	1.35	7	0.15	1.05	7	0.15	1.05
Magnitude = 1 to 10 Score = (%) of attribute Rating= factor of the above			4.75			7.35			6.65

After considering the attributes of the concepts and the help of the weighing table it was found that concept 2 will be the concept to be developed.

Concepts 3 and 2, if compared to concept 1, would be considerably more economical. Concept 1 requires the manufacture of an intricate mixing screw. This part is not available on the market. The screw requires a special threading. Also, keeping in mind that the amount of polymer to be processed is only 4cc which means that the size of the screw to be manufactured is in the order of about 100mm long and 5 to 10 mm diameter. All plastic injection screw's manufacturers are based overseas. Designing and Manufacturing this intricate piece would increase cost and probably delay the project.

Concept 2 and 3 use already available materials in the market or are of easy manufacturing. Concept 3, with respect to cost, is more viable than concept 2 since it uses an existing Arbor press however, concept 2 surpass concept 3 in other characteristics.

The next attribute, simplicity of design, looks in to how easy the apparatus' operation is and its versatility. Concepts 1 and 2 would be the easy to operate. Concept 3 would require the constant bolting and unbolting of the mould from the plasticising units and the bolting and unbolting of the of the two halves encasing the mould. Concept 1 would be easy to operate however it was given a value of 5 because the design in general is complex. Concept 2 would be the easiest to learn and operate. This concept also could provide the versatility where, if the assembly of the lever action is removed, the plasticisation unit would be exposed and after modification it might be able to be used with external machinery. Using the unit with external machinery is out of the scope of this project but opens the door for a future project.

The following attribute looks into how easy the fabrication of the unit would be. As stated before concept 1 is of intricate design. Concept 2 and 3 are simpler and use materials or parts already available in the market and or easy to manufacture.

Due to the simplicity of concept 1 and 2 it is expected that the maintenance in these two are uncomplicated and easy. Most, if not all, parts are going to be exposed and going to be reachable unlike concept 1, where the mixing screw would be set in the chamber semi-permanently.

The last attribute to have been taking into consideration was the safety of the concepts. Concept 1 came to be the safest since most of the movable parts would be permanently encased within the plasticising cylinder. In concept 3 and 2 would have movable parts exposed. The heating area and elements in all concepts would be covered with guard rails.

Appendix 5. Heating Devices.

Acim Jouanin Nozzle Band Heater, +340°C Peak Temperature, 310 W, 230 V ac, 44 mm Band Diameter

RS Stock No.: 374-3031 | Mfr. Part No.: L4445C31A10 | Manufacturer: Acim Jouanin

https://nz.rs-online.com/web/p/band-heaters/3743031/

Carel IR33 Panel Mount PID Temperature Controller, 76.2 x 34.2mm 2 (Analogue), 2 (Digital) Input, 2 Output

RS Stock No.: 121-4226 | Mfr. Part No.: IR33B9MR20 | Manufacturer: Carel

https://nz.rs-online.com/web/p/pid-temperature-controllers/1214226/

Appendix 6. Calculations Model V2.0

Determination of the Volume of melt:

The amount of polymer to be processed is of 4 cm^3 or less. Since the polymer is to be heated then expansion of the material is expected. The calculations were done based for polyethylene (PE) as is the most common used polymer and according Strong, (1996) many manufacturers present their technical data founded on PE. Based on the process temperature, see appendix 1, and assuming an initial temperature of 20 °C and a working temperature of 230C the heated volume of melt was calculated as followed:

Vo=4 cm^3   *Thermal expansion of PE = 150e-6 /-K*

$$\Delta V = Vo + 3 \propto * Vo * \Delta T$$

$$\Delta V = 4cm^3 + 3 * 150e^{-6} \frac{1}{-K} * 4cm^3 * (469 - 293) = 4.31cm^3 \approx 5cm^3$$

Diameter of Piston:

The Diameter of the piston was determined by the taking the volume of PE to be processed. The length of the piston was chosen to be of 80mm to accommodate for possible polymer oozing and for the fact that this parameter would have to be adjusted anyway for band heaters and bracket availability.

$V = 5cm^3$ *Length of cylinder = 80mm*

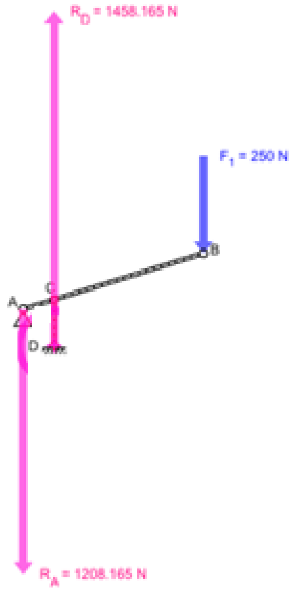
$$D = \sqrt{\frac{4 * 5e^{-6}\, m^3}{\pi * 0.08m}} = 8.92mm \approx 9mm$$

Estimated pressure in cylinder:

For this calculation it was assumed that the piston movement was completely constrained, this was done with the intention of determining the maximum pressure that could be obtained under the conditions. As seen in figure 12 the reactions forces were estimated using a software. For the giving dimensions the lever advantage exerted by the piston would be in the order of 1500N. With this value and the previously piston diameter the expected pressure that can be attain in the cylinder was calculated as:

$D = 9mm$

$Pressure\ = \frac{F}{A} = \frac{1500N}{\frac{\pi}{4}*(9e^{-3}\ m)^2} = 26.5Mpa \approx 27Mpa$



Reaction Forces. Software (Force effect)

Cylinder Stresses:

With the expected pressure in the cylinder and as compelled by AS/NZS 1200:2015 standards "Pressure equipment" the stresses of the material were calculated and verified. This was done using the available heater's diameters in the market which constraint the outer diameter of the cylinder. The smallest available heater with a diameter of 25mm is not available with enough heating capacity, see heat calculations, so the outer diameter was constrained by the next size up with enough power, which is 44mm. The Hoop and Longitudinal stress were verified as follows:

It is evident that the material offers sufficient strength to reduce the external diameter if necessary. A

$$\emptyset_{Internal} = 9mm \quad \emptyset_{External} = 44mm \quad t_{hickness} = 35 \quad AISI\ 4340 = 470Mpa$$

$$\frac{thickness\ (35mm)}{diameter\ (9)} \geq \frac{1}{20}\ then\ vessell\ is\ a\ thick\ vessel$$

$$\sigma_{hoop} = \frac{P_{ressure}*(r_e^2+r_i^2)}{(r_e^2-r_i^2)} = \frac{27e^{6}Mpa*[(22e^{-3}mm)^2+(4.5e^{-3}mm)^2]}{[(22e^{-3}mm)^2-(4.5e^{-3}mm)^2]} = 29.35\ Mpa$$

$$\sigma_{longitudinal} = \frac{P_{ressure} * (r_i^2)}{(r_e^2 - r_i^2)} = \frac{27e^{6}Mpa\ (4.5e^{-3}mm)^2]}{[(22e^{-3}mm)^2 - (4.5e^{-3}mm)^2]} = 1.36Mpa$$

$$Factor\ of\ safety = \frac{\sigma_{yield}}{\sigma_{working}} = \frac{470\ Mpa}{29.35Mpa} = 15.7$$

conservative safety factor of 4 should be enough for safety however as stated before the cylinder's external diameter is constrained to the available heater's diameters in the market.

Heat Calculations (Band Heaters):

The heat calculations to determine the heater elements were done by calculating two basic energy requirements as detailed in Tempcos, (2003) manufacturer's guide. The Start-up heat and the Operating heat. The start up heat takes in consideration the heat required to bring the product up to operating temperature and the operating heat is the heat required to maintain the desired operating temperature. The calculation of heat losses is a complicated process, especially for a compound system, which involves the solving of long and complicated differential equations. For this reason, a loss method, as detailed in Kinsky (1997), which allows for an approximation was used. Values for thermal conductivity of steel (22 W/mK), free convection heat transfer of air (0.035 Kw/m2 K) and emissivity of steel (0.51) used in the calculations were obtained from Kinsky.

Start-up Heat:

For Cylinder: $\emptyset_{Internal} = 9mm$ $\emptyset_{External} = 44mm$ L=$120mm$ $\rho_{Stainless} = 8000\frac{Kg}{m^3}$ $\rho_{PE} = 965\frac{Kg}{m^3}$

$C_{e\ Steel} = 500\frac{J}{KgK}$ $C_{e\ PE} = 2.2\frac{kJ}{KgK}$

Mass of cylinder:

$$Vol_{Int} = \frac{\pi}{4} * {\emptyset_I}^2 * L = \frac{\pi}{4} * (9mm)^2 * 120mm = 7634mm^3$$

$$Vol_{Ext.} = \frac{\pi}{4} * {\emptyset_{ext}}^2 * L = \frac{\pi}{4} * (9mm)^2 * 120mm = 182463mm^3$$

$$Vol_{total} = 174.8e^{-9}m^3$$

$m = \rho_{density} * V_{volume} = 8000\frac{Kg}{m^3} * 174.8e^{-9}m^3 = 1.2\ Kg$

Heat for cylinder:

$Q_{cylinder} = m * C_{e\ Stainless} * \Delta T = 1.2\ Kg * 500\frac{J}{KgK}$*(230-20)C=126000j*

For polymer:

Mass Polymer

$m = \rho_{density} * V_{volume} = 965\frac{Kg}{m^3} * 4e^{-6}m^3 = 0.0386kg$

Heat for Polymer:

$Q_{PE\ sensible} = m * C_{e\ PE} * \Delta T = 0.0386kg * 2.2\frac{KJ}{KgK} * (230 - 20)C = 17833j$

$$Q_{PE\ Latent} = m * C_e = 0.0386kg * 232\frac{KJ}{KgK} * (230 - 20)C = 896J$$

$$Q_{totastratup} = Q_{cyl} + Q_{PE\ seinsible} + Q_{PE\ Fusion} = 144729\ Jouls$$

Operating heat:

For Cylinder: $\emptyset_{Internal} = 9mm$ $\emptyset_{External} = 44mm$ L=$120mm$

$Area_{Cyl=}L * \pi * \emptyset_{Ext} + 2 * \frac{\pi}{4} * ({\emptyset_{ext}}^{2} - {\emptyset_{int}}^{2}) = 120mm * \pi * 44mm + 2 * \frac{\pi}{4}[(44mm)^2 * (9mm^2)] = 48639mm^2$

For conduction:

$$Q_{cond.} = \frac{2*\pi*K*L*\Delta T}{Ln\frac{D}{d}} = \frac{2\pi*22\frac{w}{mK}*120e^{-3}m*(230-20)}{\ln(\frac{44e^{-3}m}{9e^{-3}m})} = 2195j/s$$

For convection:

$$Q_{conv} = h * A * (\Delta T) = 0.035\frac{Kw}{m^2K} * 48.64e^{-3}m^2 * (230-20) = 357.21j/s$$

For radiation:

$$Q_{rad} = \varepsilon * \sigma * A * (T_2^2 - T_1^2) = 0.51 * 56.7e^{-9}\frac{w}{m^w k} * 9.7e^{-3}m^2 * [(503K)^4 - (293K)^4]$$
$$Q = 15.88w$$

Total heat Due to losses:

$$Q_{totalosses} = Q_{cond.+Q_{conv}} + Q_{rad} = 2568.09j/s$$

For Operating heat Method Tempco, (2003) advises to add 35% safety factor for systems with many unkown conditions so.

$$Q_{totalosses} = 2568.09 + 35\% = 3466.92j$$

Total Heat $Q_{total} = Q_{totastratup} + Q_{totalosses} = 144729\,J + 3466.92J = 148195.9\,j/s$

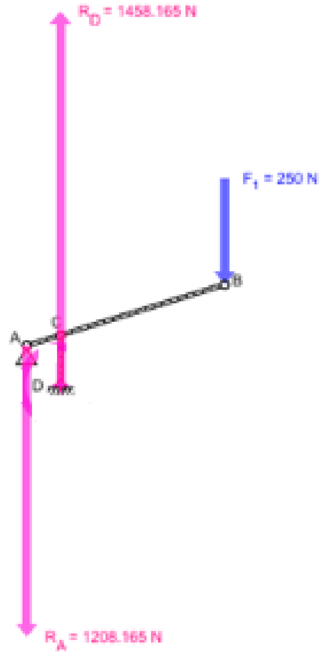
1 joule = 0.000277watt-hour

$Heater\ Capacity = 148195.9J * 0.000277\ watt - hours = 41.05\ watt\ heating\ element.$

A 41-watt heating element would be enough to bring the temperature of the system up to process temperature in 1 hour.

Handle calculations:

The lever handle calculation was performed determining the reactions and Maximum bending moment the material based on the 250N force applied on B. For this calculation it was assumed that the piston (section C-D) in picture has topped the bottom of cylinder.



$Lever_{side} = 15mm$
$Bending_{Moment\ Max=} 137.403Nm$

$Yield\ Strength\ for\ 316\ S.steel$
$=290Mpa$

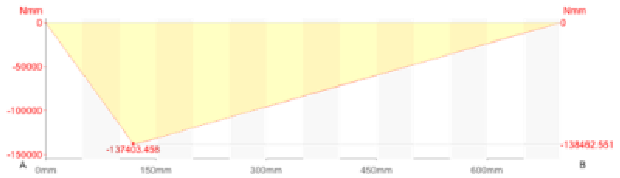
$$I_{Moment\ inertia} = \frac{b * h^3}{12} = \frac{15e^{-3}m * (20e^{-3}m)^3}{12}$$

$$I_{Moment\ inertia} = 1e^{-8}m^4$$

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

$$\sigma_b = \frac{M_{max} * Y}{I} = \frac{137.403Nm * 10e^{-3}m}{1e^{-8}m^4} = 138Mpa$$

$$Factor\ of\ safety = \frac{\sigma_{yield}}{\sigma_{working}} = \frac{290Mpa}{138Mpa} = 2.1$$



Bending moment. Software (Force effects)

-

Pin Calculations:

Pins located at A and C are subjected to double shear, so it was calculated as followed.

$$\sigma_{shear@Pin\ a} = \frac{F_{Shear}}{A_{Shear}} = \frac{1500N}{2*\frac{\pi}{4}*(5mm)^2}=38.2=\text{Mpa}$$

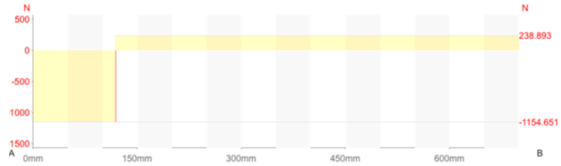


Figure 19 Shear Diagram. Software (Force effects)

$$Factor\ of\ safety = \frac{\sigma_{yield}}{\sigma_{working}} = \frac{240Mpa}{38.2} = 6.1$$

$$\sigma_{shear@Pin\ c} = \frac{F_{Shear}}{A_{Shear}} = \frac{1210N}{2*\frac{\pi}{4}*(5mm)^2} = 30.8Mpa$$

$$Factor\ of\ safety = \frac{\sigma_{yield}}{\sigma_{working}} = \frac{240Mpa}{21.4} = 7.9$$

Piston:

Slender Members under axial compression can fail in buckling. The piston calculation was performed to determine critical force. The critical force should not be exceeded by the axial force applied so:

L_{ength} =225mm

$\emptyset_{Piston} = 9mm$

Assuming one end pin and the other fix then; $Le = 0.7L$

$$Le = 0.7 * 255mm = 179e^{-3}m$$

$$K_{radiogyration} = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{\pi*d^4}{64}}{\frac{\pi}{4}*d^2}} = \sqrt{\frac{\frac{\pi*(9e^{-3})^4}{64}}{\frac{\pi}{4}*(9e^{-3})^2}} = 2.25e^{-3}m$$

$$\frac{179e^{-3}}{2.25e^{-3}} = 797 > \sqrt{\frac{2*\pi^2*E}{\sigma_{yield}}} = \sqrt{\frac{2*\pi^2*190e^9}{470e^6}} = 89$$

797 > 89; Euler to be used.

$$P_{Critical} = \frac{\pi^2 * E * A * K^2}{Le^2}$$

$$P_{Crt} = \frac{\pi^2 * 190e^9Mpa * 6.4^{-5}m^2 * (2.25e^{-3}m)^2}{179e^{-3}m^2}$$

$P_{Critical=}$ 18962N

$$Fs = \frac{18962N}{1500N} = 12.6$$

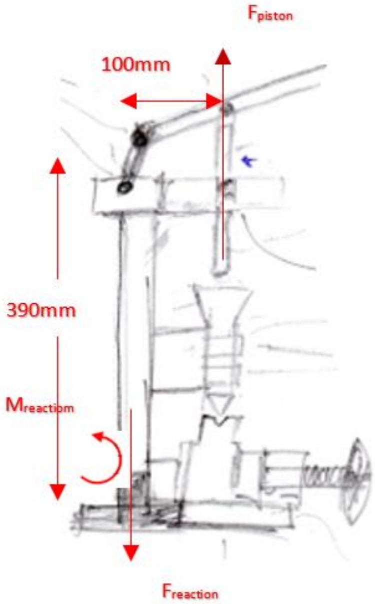
Post-Base:

The post is subjected to an eccentric loading so the reaction within the material are the same as an axial loading and bending moment acting at the same time, So:

$\emptyset_{Col} = 25mm \quad L_{Col} = 390mm$ Fpiston=1500

$A_{Column=} \frac{\pi}{4} * \emptyset^2 = \frac{\pi}{4} * (25mm)^2 = 491mm^2$

$$I_{post} = \frac{M * \emptyset^4}{64} = \frac{\pi * (25mm)^4}{64} = 3.07e^{-5}mm^4$$



Post-Base reaction diagram

Reaction Forces:

$$F_{piston} = F_{reaction}$$

$$F_{reaction} = 1500N$$

$$M_{Base} = F_{reaction} * eccentricity = \\ = 1500N * 1000mm \\ = 150e^3 Nmm$$

Stresses:

$\sigma_{Axial} = \frac{F}{A} = \frac{1500}{491mm^2}$ = 3.05 Mpa

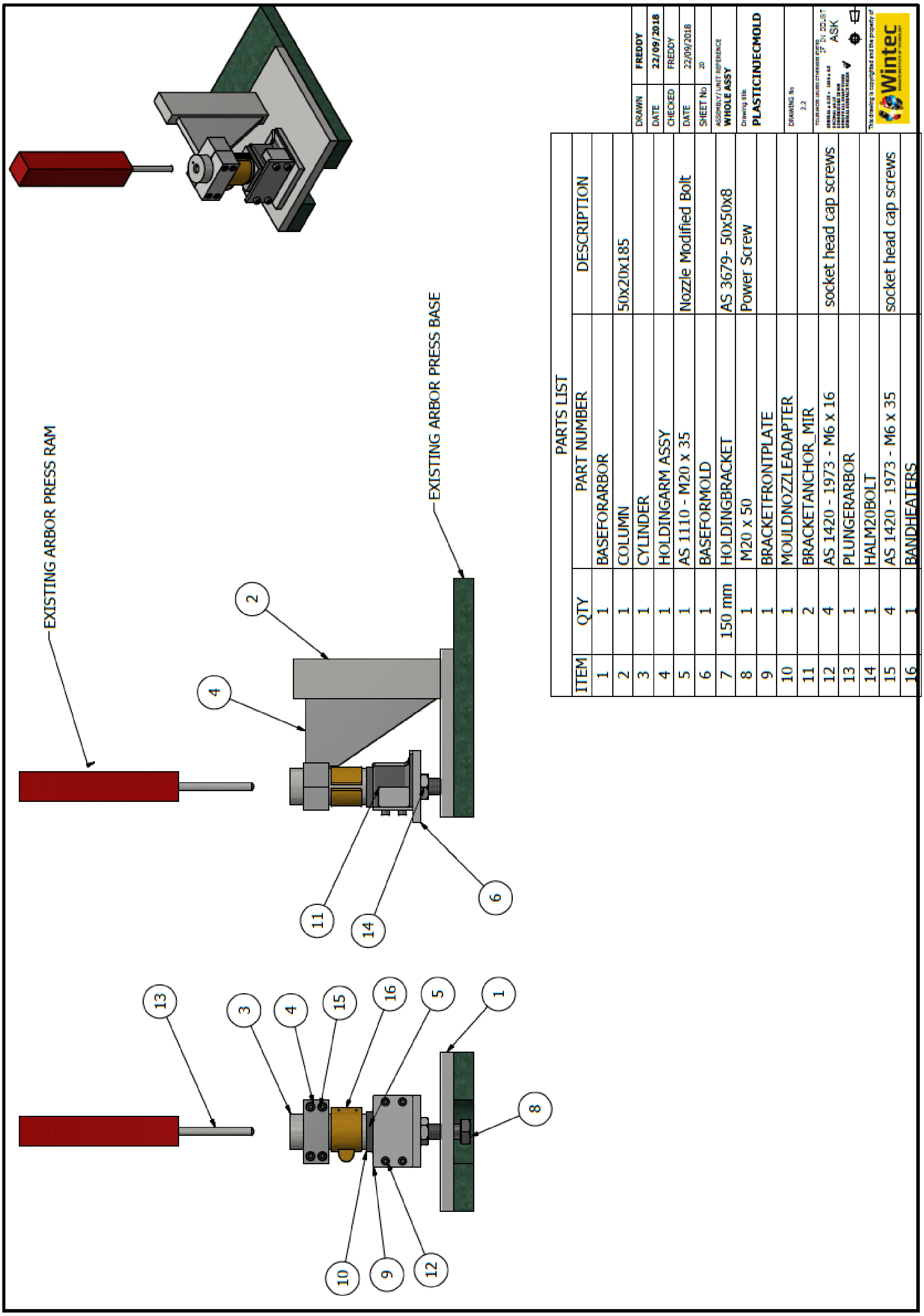
$$\sigma_{bend} = \frac{M * y}{I} = \frac{150e^3 * 12.5mm}{3.07e^{-5}mm^4} = 8.02Mpa$$

Combined Stress:

$$\sigma_{Total} = \sigma_{Axial} + \sigma_{bend} = 11.07Mpa$$

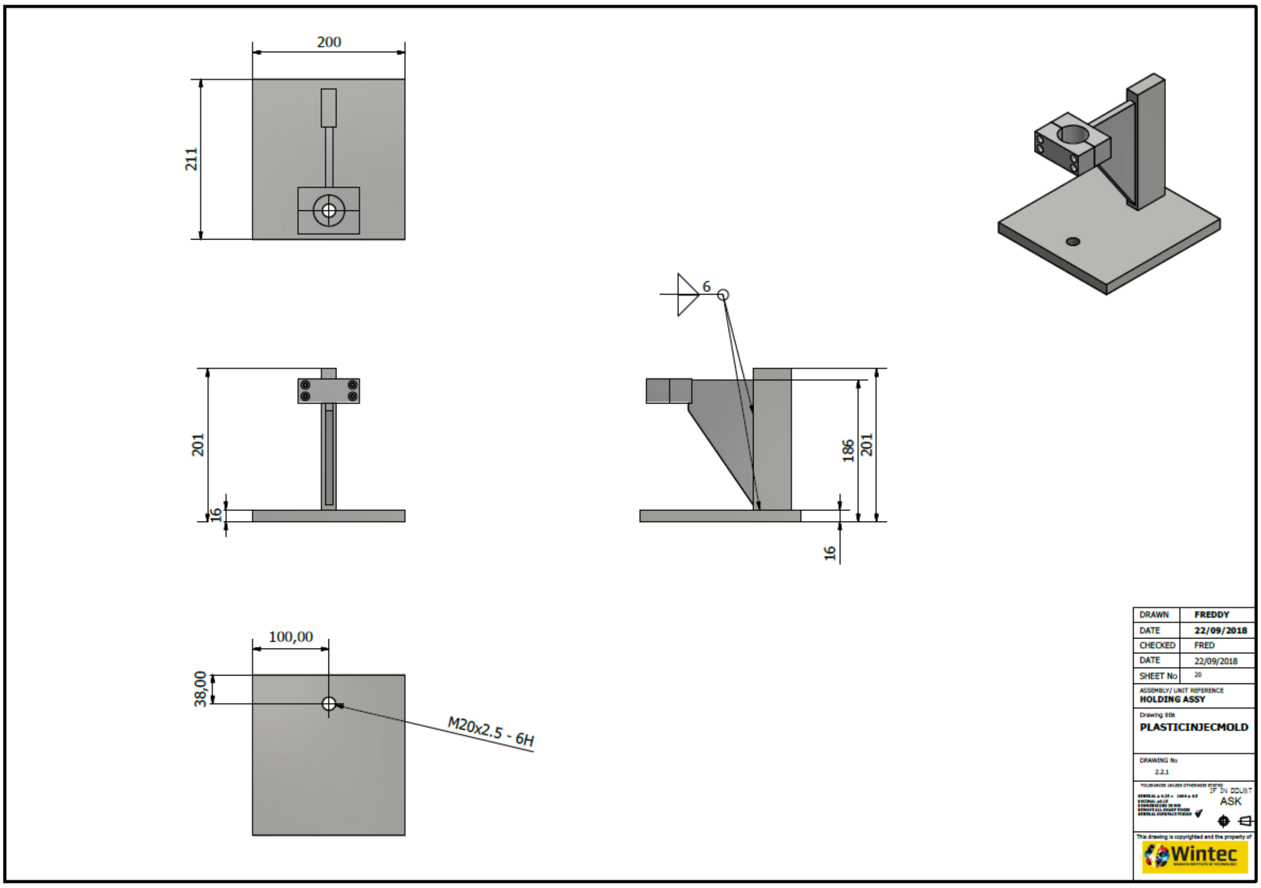
$$Fs = \frac{470Mpa}{11Mpa} = 39$$

APPENDIX 7. Engineering Drawings



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	BASEFORARBOR	
2	1	COLUMN	50x20x185
3	1	CYLINDER	
4	1	HOLDINGARM ASSY	
5	1	AS 1110 - M20 x 35	Nozzle Modified Bolt
6	1	BASEFORMOLD	
7	150 mm	HOLDINGBRACKET	AS 3679- 50x50x8
8	1	M20 x 50	Power Screw
9	1	BRACKETFRONTPLATE	
10	1	MOULDNOZZLEADAPTER	
11	2	BRACKETANCHOR_MIR	
12	4	AS 1420 - 1973 - M6 x 16	socket head cap screws
13	1	PLUNGERARBOR	
14	1	HALM20BOLT	
15	4	AS 1420 - 1973 - M6 x 35	socket head cap screws
16	1	BANDHEATERS	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SHEET No
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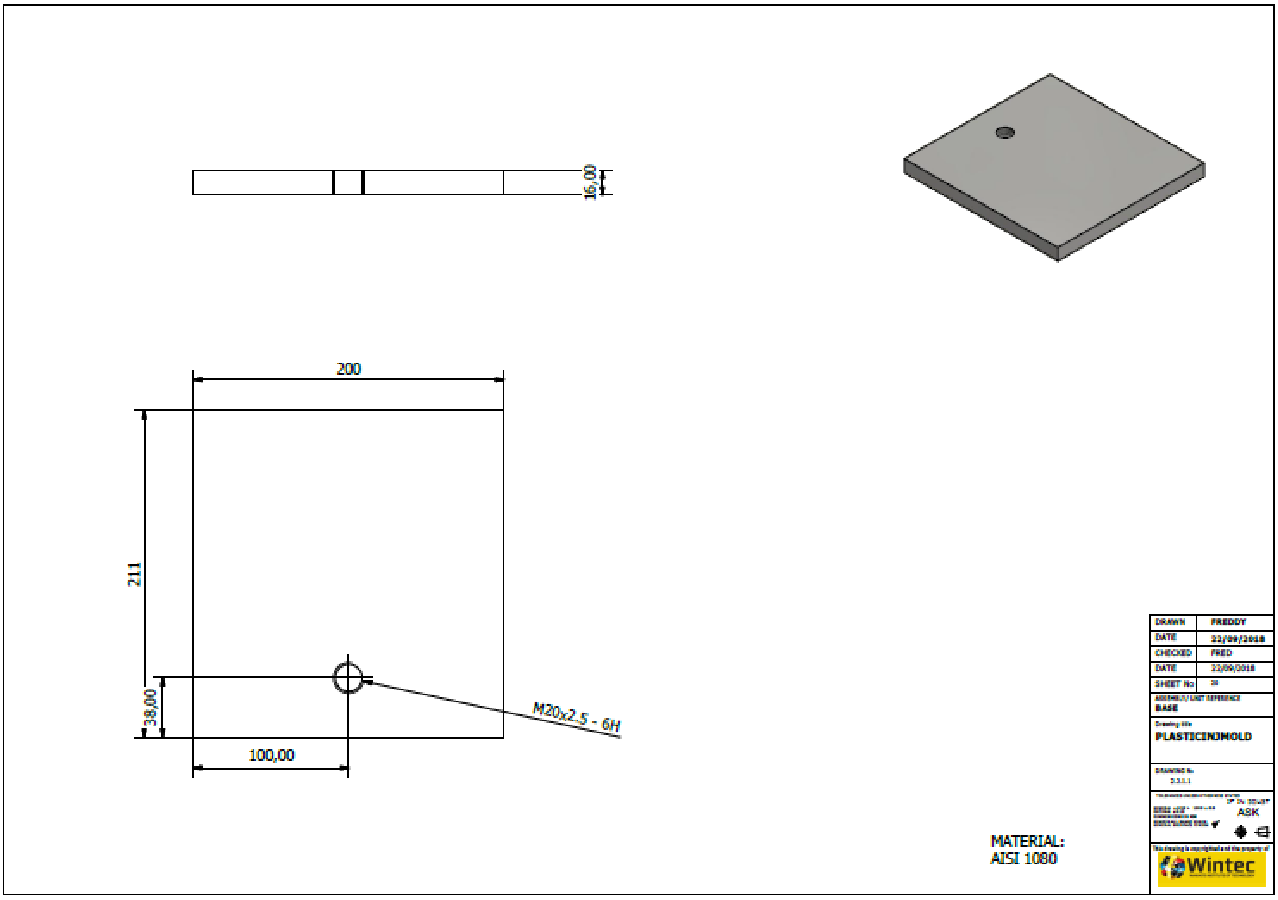
ASSEMBLY/ UNIT REFERENCE
HOLDING ASSY
Drawing title
PLASTICINJECMOLD
DRAWING No
2.2.1
IF IN DOUBT
ASK
This drawing is copyrighted and the property of
Wintec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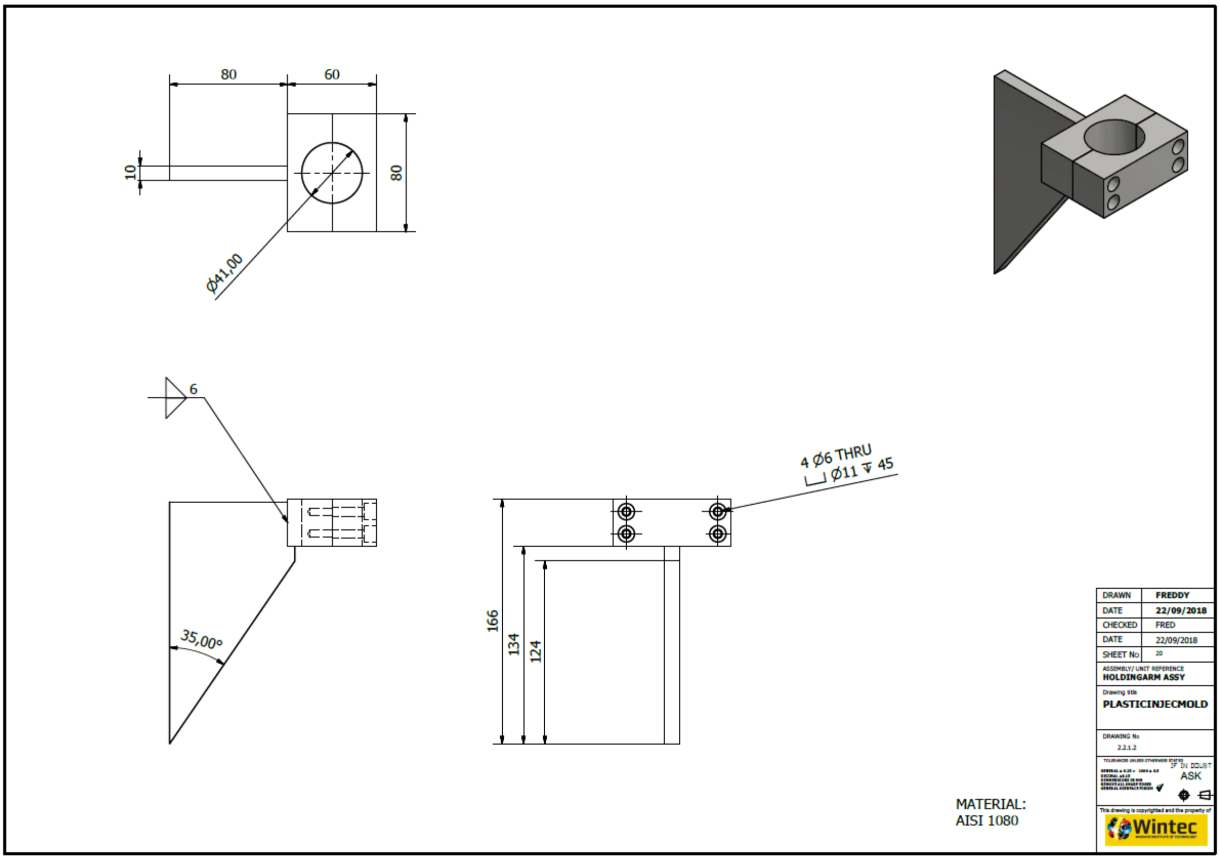
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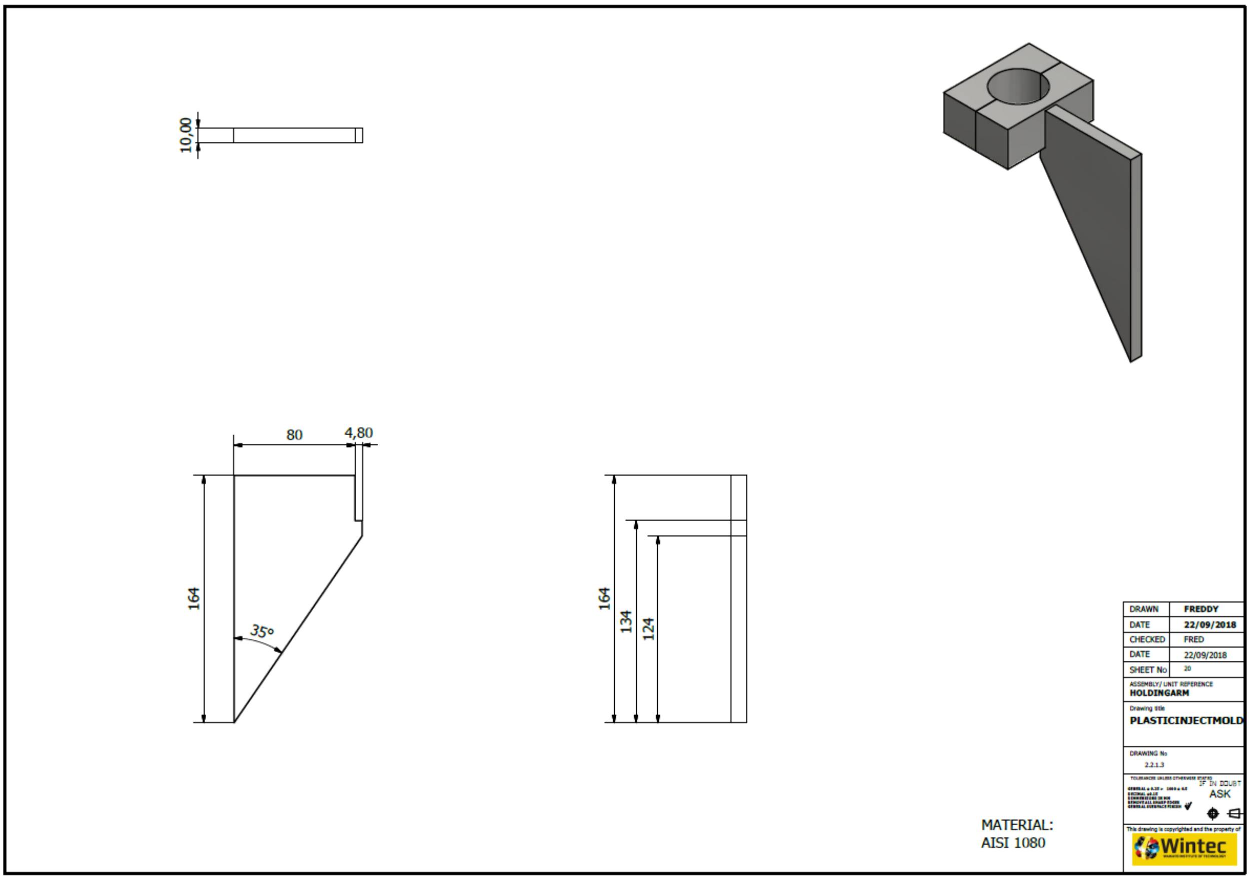
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ASSEMBLY/ UNIT REFERENCE
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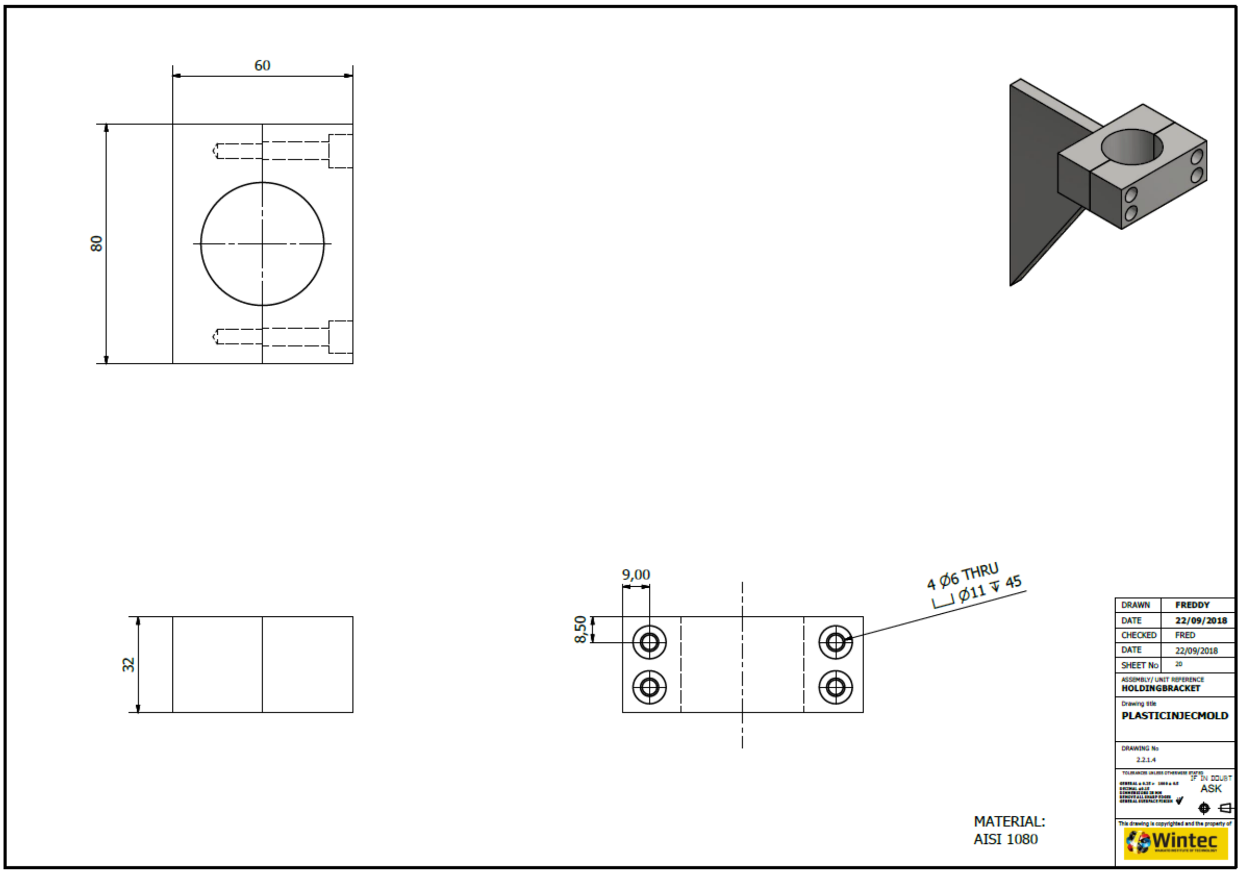
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SHEET No 20
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HOLDINGBRACKET
Drawing title
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DRAWING No
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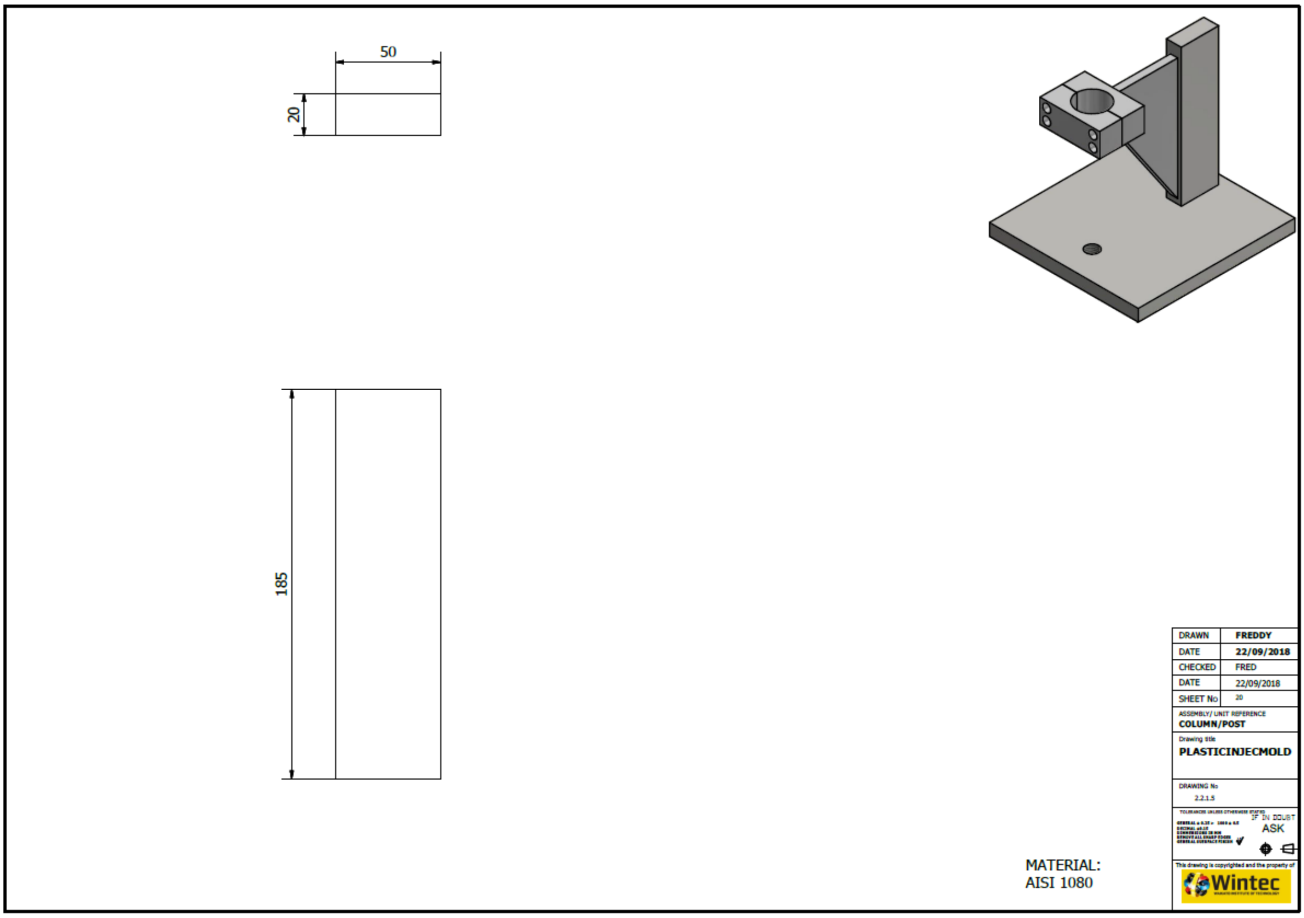
MATERIAL:
AISI 1080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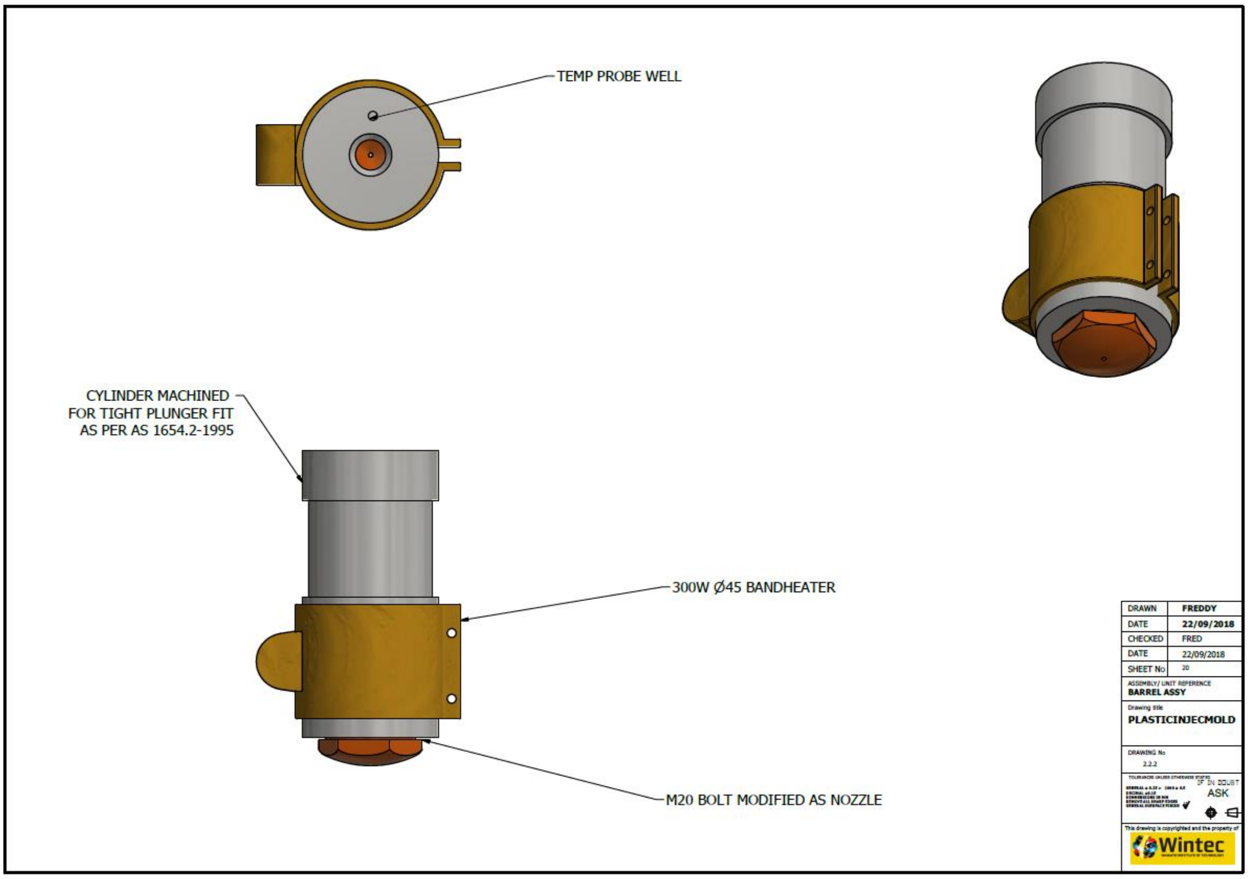
DRAWN FREDDY
DATE 22/09/2018
CHECKED FRED
DATE 22/09/2018
SHEET No 20
ASSEMBLY/ UNIT REFERENCE
COLUMN/POST
Drawing title
PLASTICINJECMOLD
DRAWING No
2.2.1.5
IF IN DOUBT ASK
This drawing is copyrighted and the property of
Wintec
MATERIAL:
AISI 1080


TEMP PROBE WELL
CYLINDER MACHINED
FOR TIGHT PLUNGER FIT
AS PER AS 1654.2-1995
300W Ø45 BANDHEATER
M20 BOLT MODIFIED AS NOZZLE
DRAWN
FREDDY
DATE
22/09/2018
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FRED
DATE
22/09/2018
SHEET No
20
BARREL ASSY
PLASTICINJECMOLD
2.2.2
ASK
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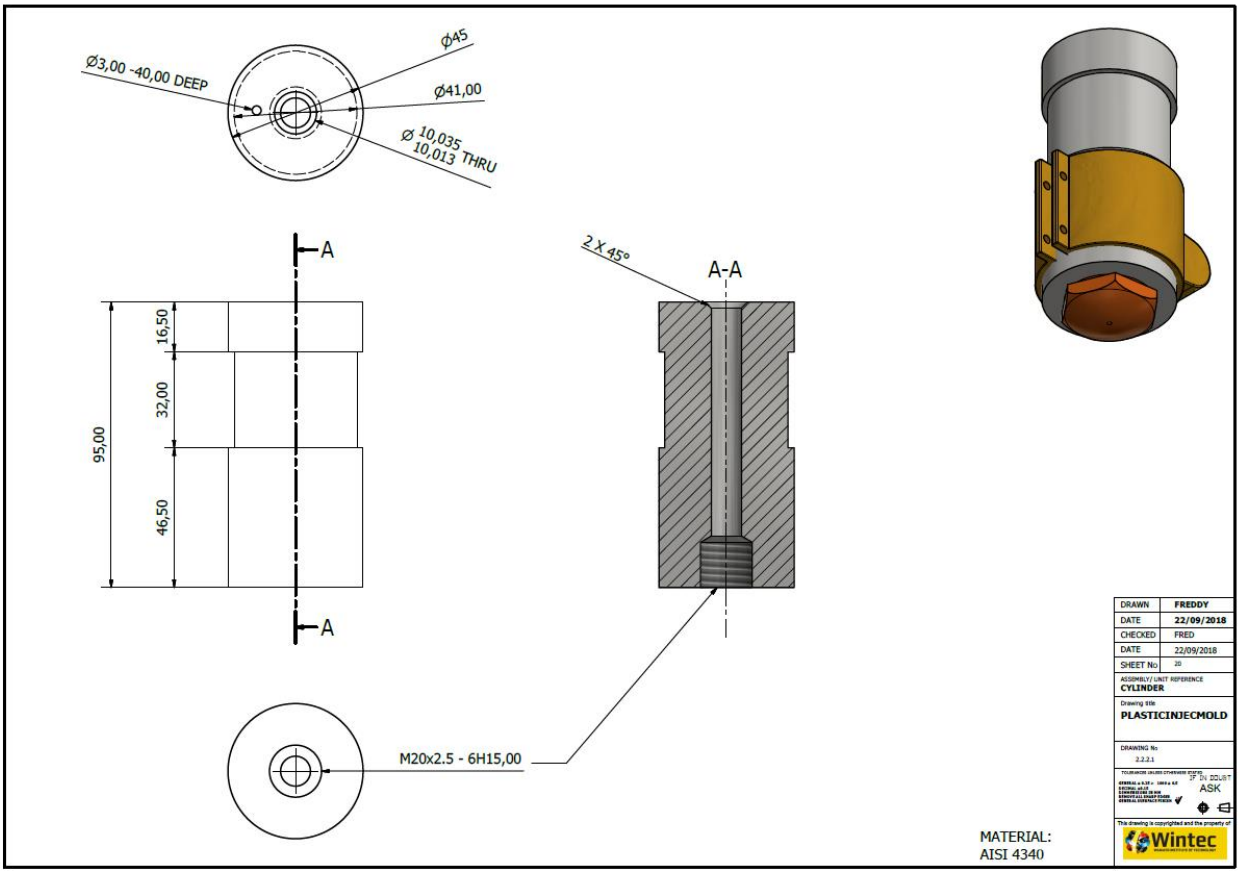
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Ø45
Ø41,00
Ø 10,035
10,013 THRU
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46,50
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M20x2.5 - 6H15,00
MATERIAL:
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CYLINDER
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2.2.2.1
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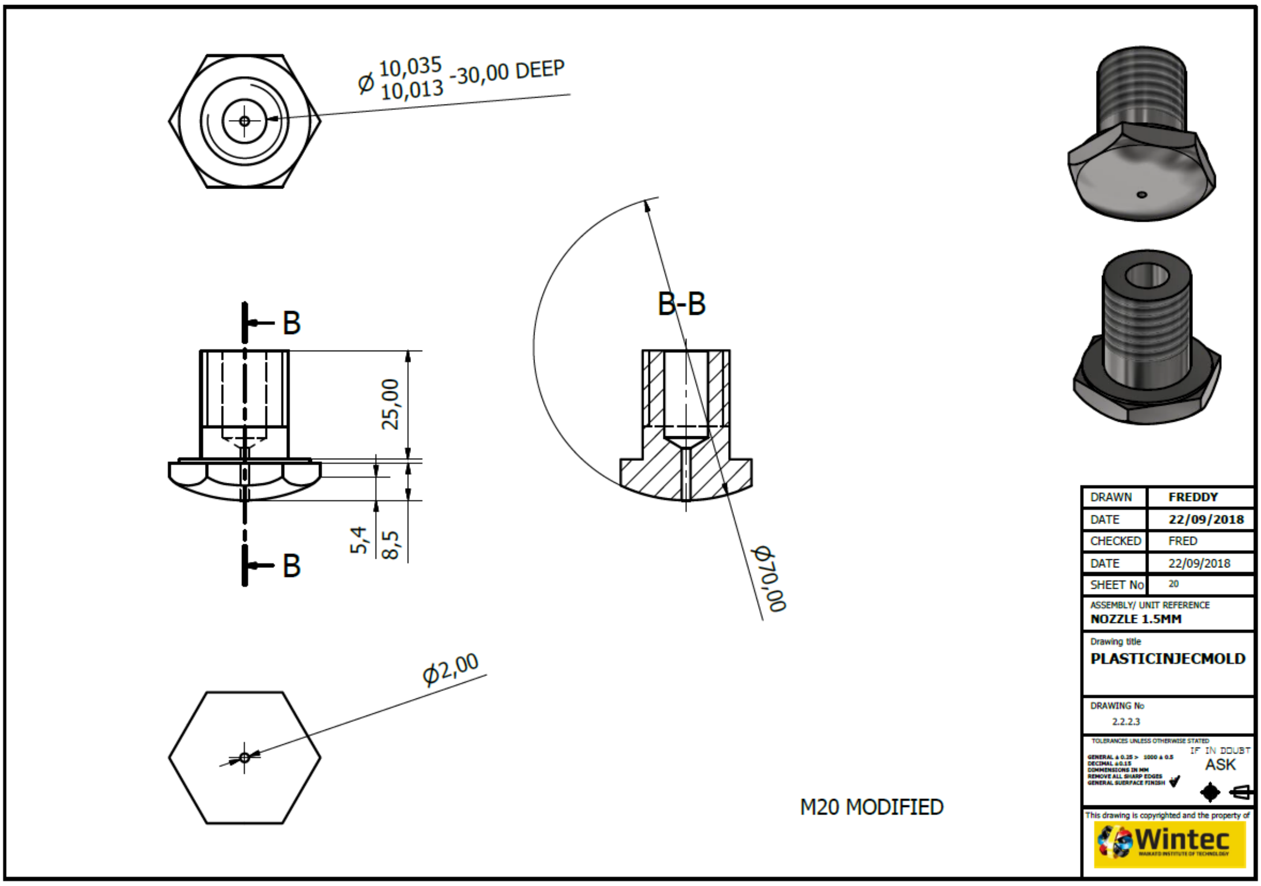

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M20 MODIFIED
DRAWN FREDDY
DATE 22/09/2018
CHECKED FRED
DATE 22/09/2018
SHEET No 20
ASSEMBLY/ UNIT REFERENCE
NOZZLE 1.5MM
Drawing title
PLASTICINJECMOLD
DRAWING No
2.2.2.3
TOLERANCES UNLESS OTHERWISE STATED
IF IN DOUBT
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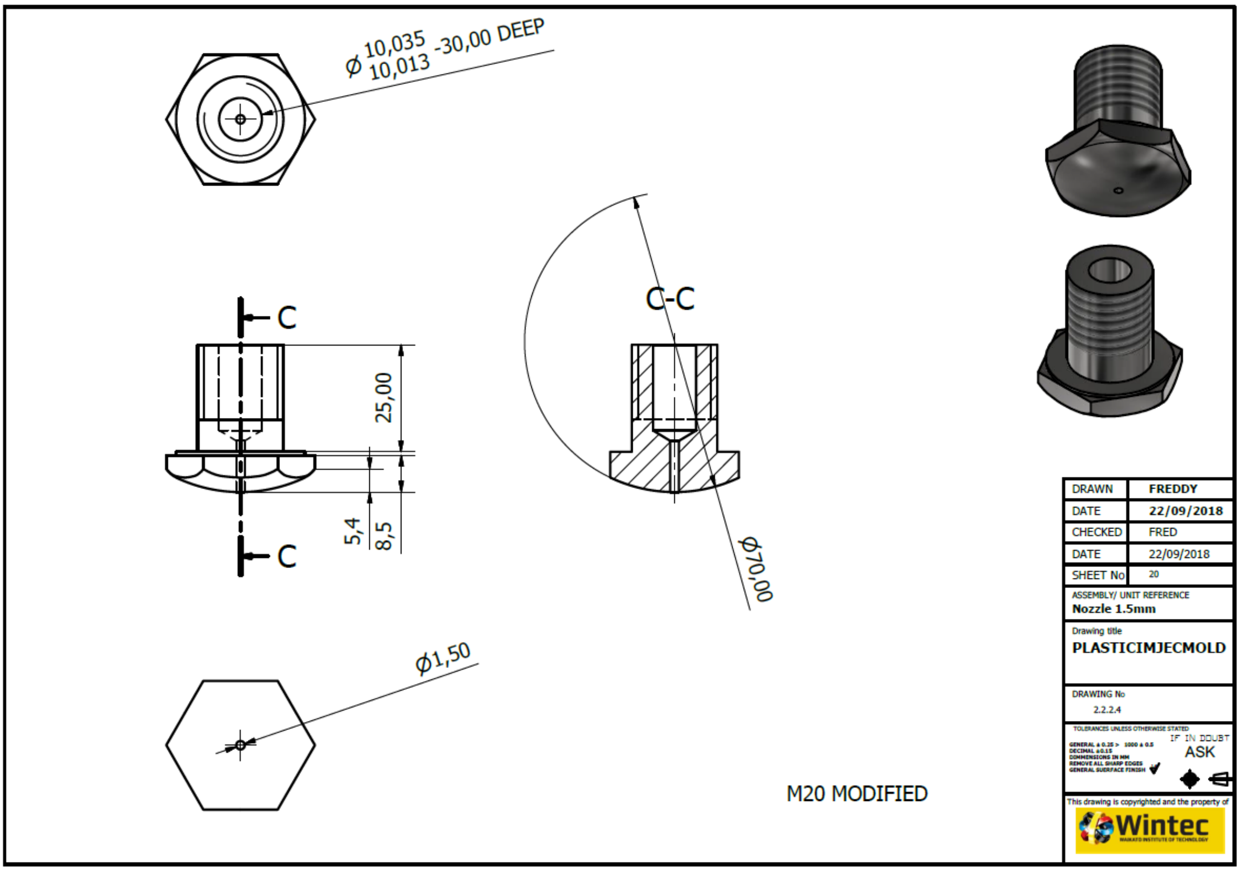

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DRAWN FREDDY
DATE 22/09/2018
CHECKED FRED
DATE 22/09/2018
SHEET No 20
ASSEMBLY/ UNIT REFERENCE
Nozzle 1.5mm
Drawing title
PLASTICIMJECMOLD
DRAWING No
2.2.2.4
TOLERANCES UNLESS OTHERWISE STATED
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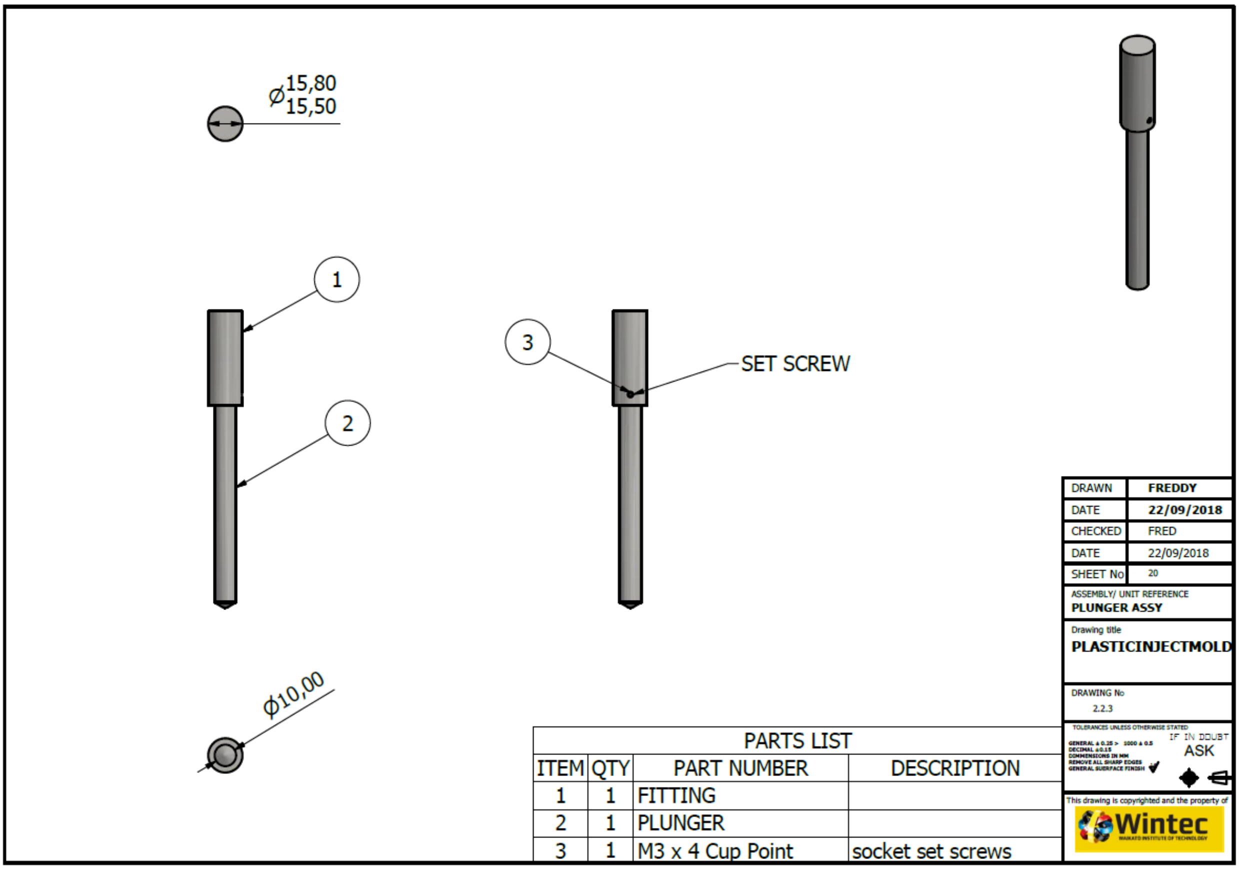
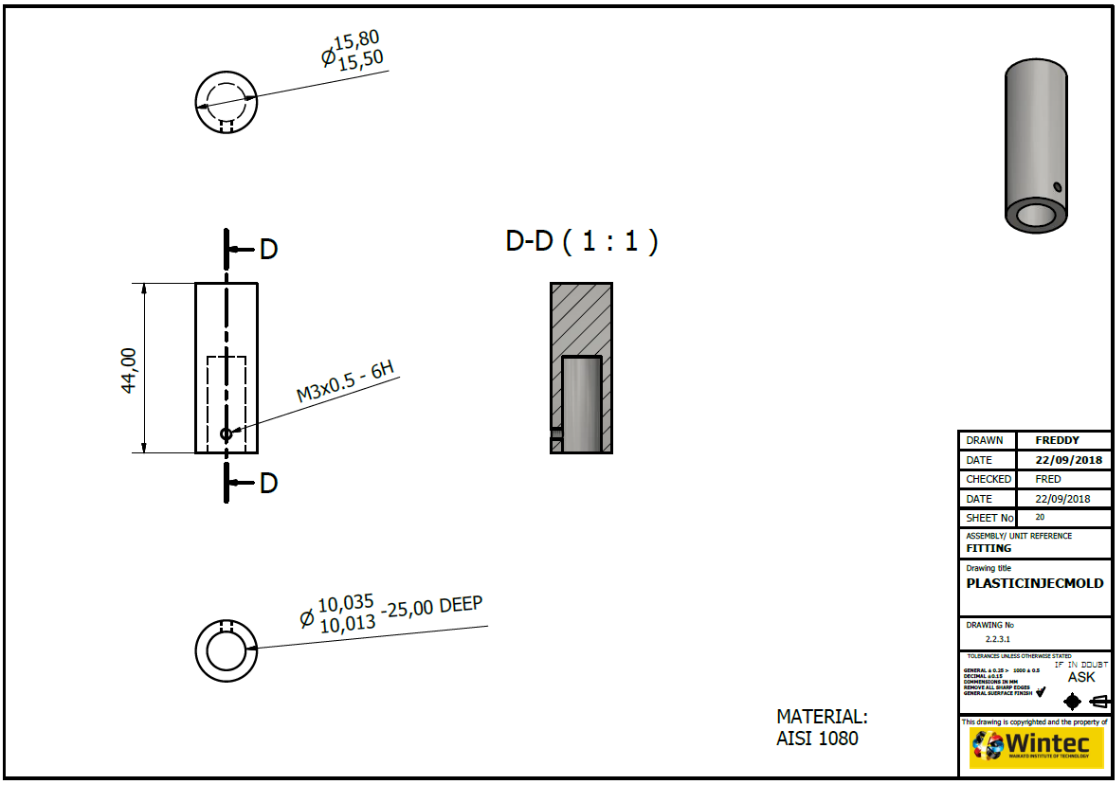
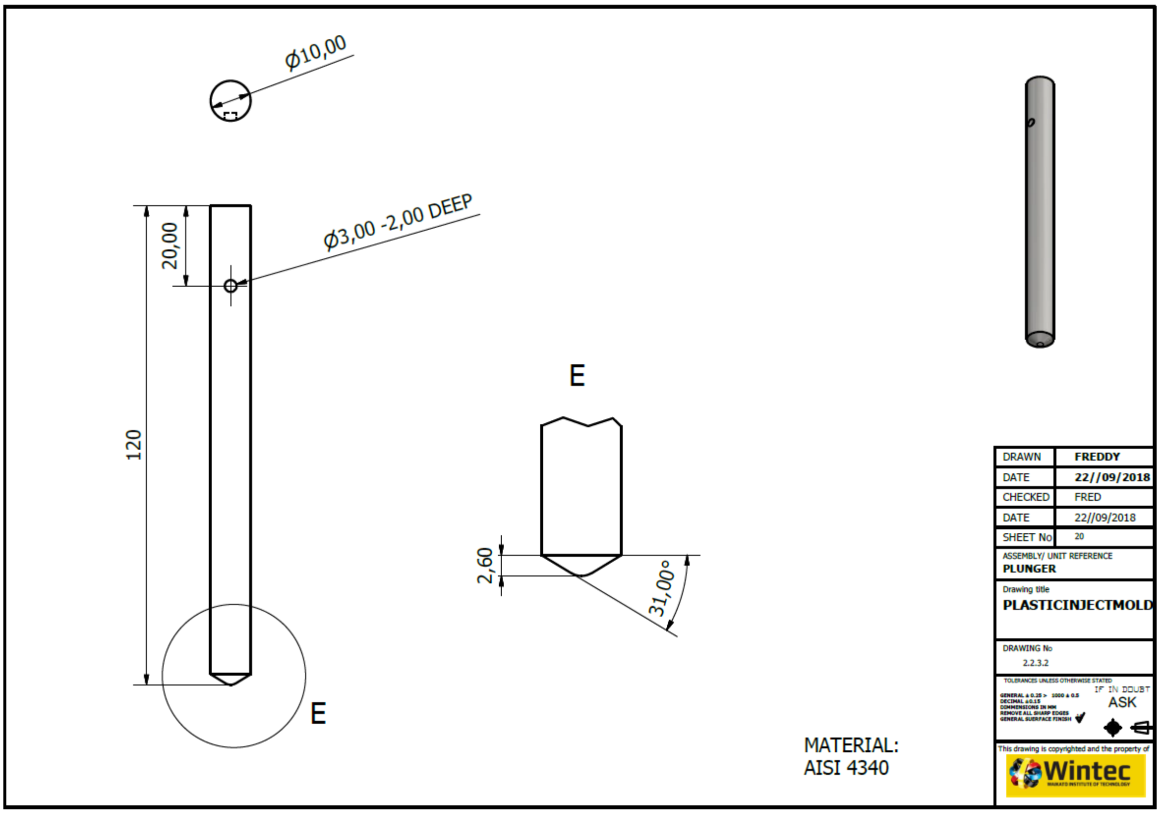
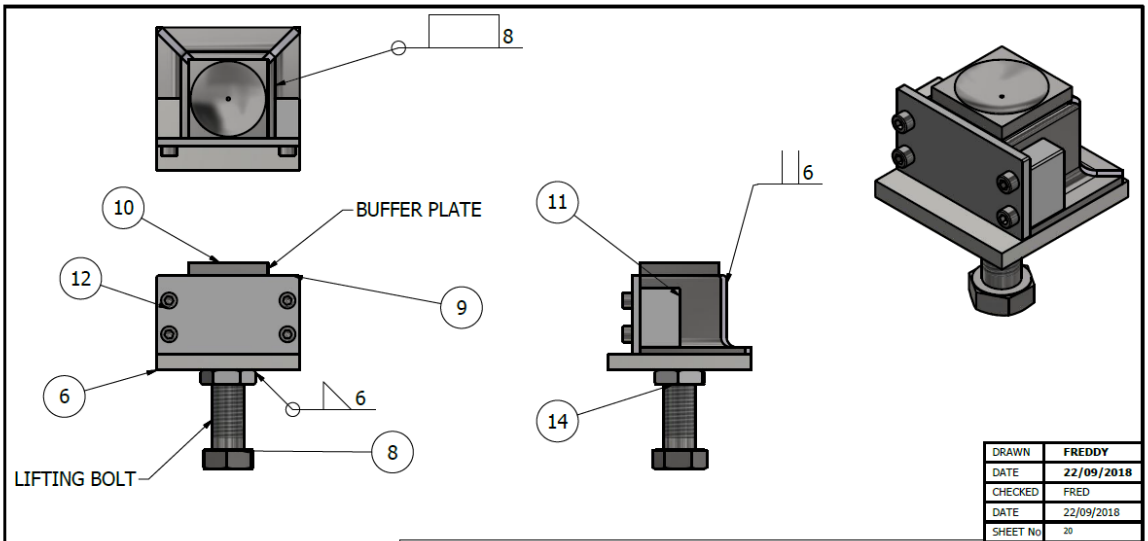


PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FITTING	
2	1	PLUNGER	
3	1	M3 x 4 Cup Point	socket set screws

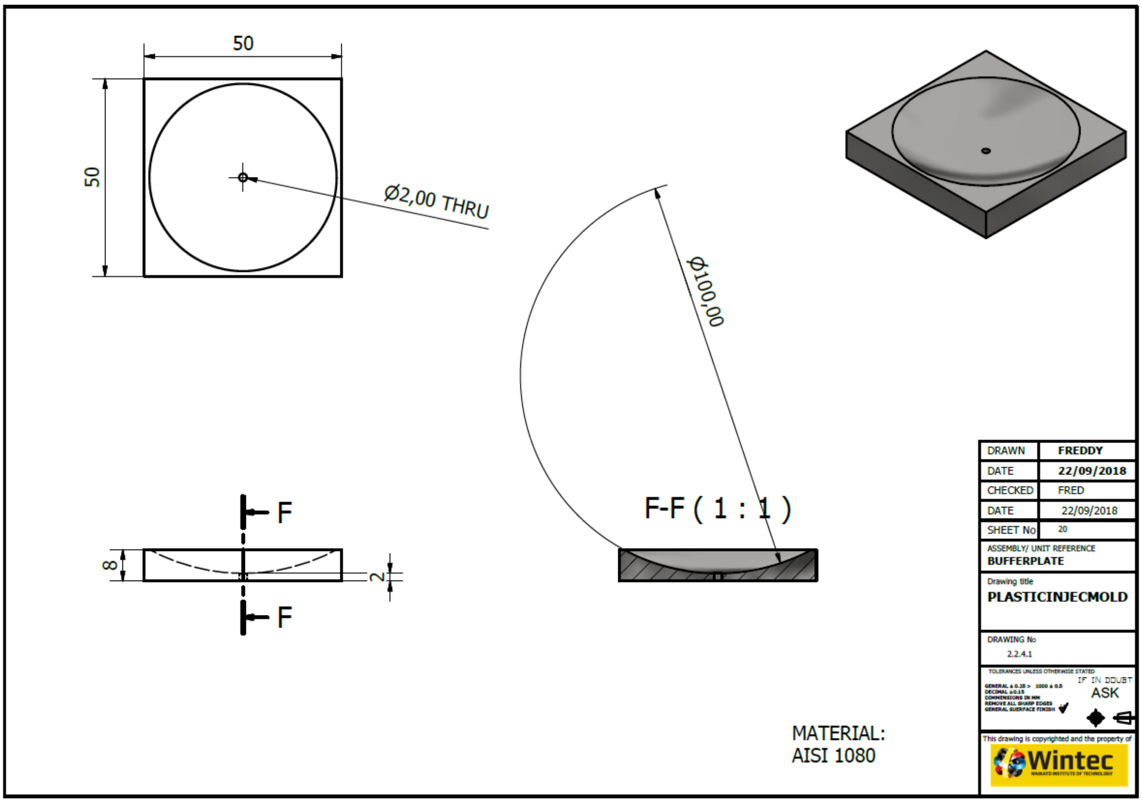






PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
6	1	BASEFORMOLD	
7	150 mm	HOLDINGBRACKET	AS 3679- 50x50x8
8	1	M20 x 50	Power Screw
9	1	BRACKETFRONTPLATE	
10	1	MOULDNOZZLEADAPTER	
11	2	BRACKETANCHOR_MIR	
12	4	AS 1420 - 1973 - M6 x 16	socket head cap screws
14	1	HALM20BOLT	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DRAWN
FREDDY
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22/09/2018
CHECKED
FRED
DATE
22/09/2018
SHEET No
20
ASSEMBLY/ UNIT REFERENCE
BUFFERPLATE
Drawing title
PLASTICINJECMOLD
DRAWING No
2.2.4.1
IF IN DOUBT
ASK
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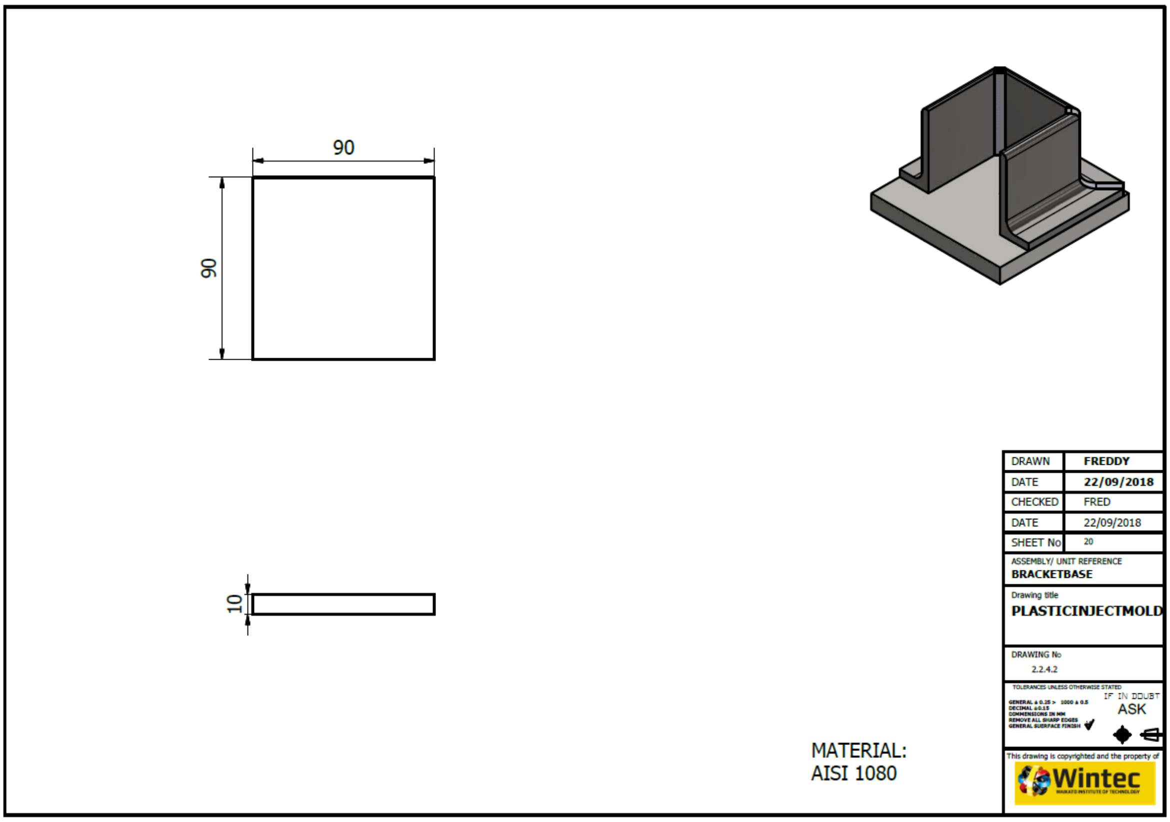
MATERIAL:
AISI 1080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DRAWN
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DATE
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FRED
DATE
22/09/2018
SHEET No
20
ASSEMBLY/ UNIT REFERENCE
BRACKETBASE
Drawing title
PLASTICINJECTMOLD
DRAWING No
2.2.4.2
IF IN DOUBT
ASK
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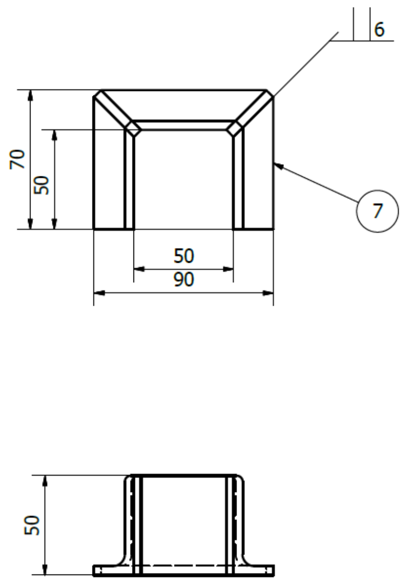
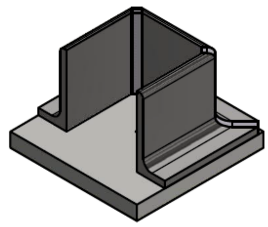
MATERIAL:
AISI 1080

00





DRAWN	**FREDDY**
DATE	**22/09/2018**
CHECKED	FRED
DATE	22/09/2018
SHEET No	20

ASSEMBLY/ UNIT REFERENCE
HOLDINGBRACKET

Drawing title
PLASTICIMJECTMOLD

DRAWING No
2.2.4.3

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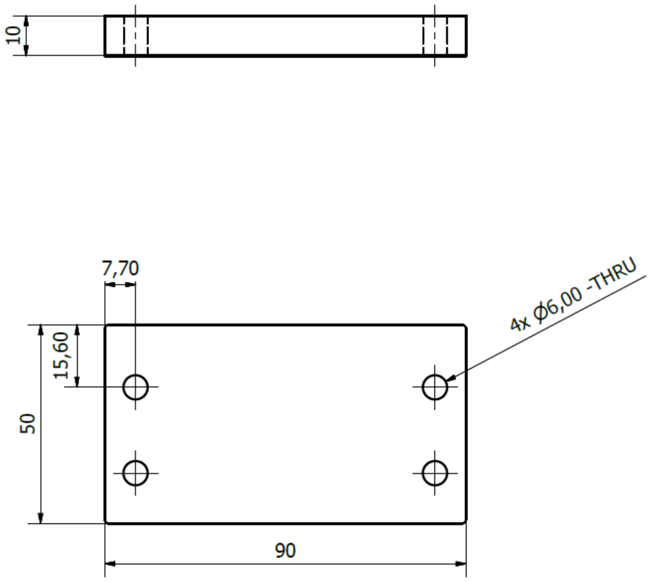
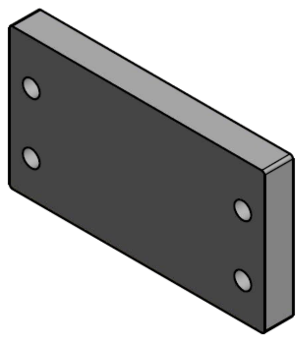
PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
7	150 mm	HOLDINGBRACKET	AS 3679- 50x50x8





DRAWN	**FREDDY**
DATE	**22/09/2018**
CHECKED	FRED
DATE	22/09/2018
SHEET No	20

ASSEMBLY/ UNIT REFERENCE
BRACKETFRONTPLATE

Drawing title
PLASTICINJECTMOLD

DRAWING No
2.2.4.4

TOLERANCES UNLESS OTHERWISE STATED
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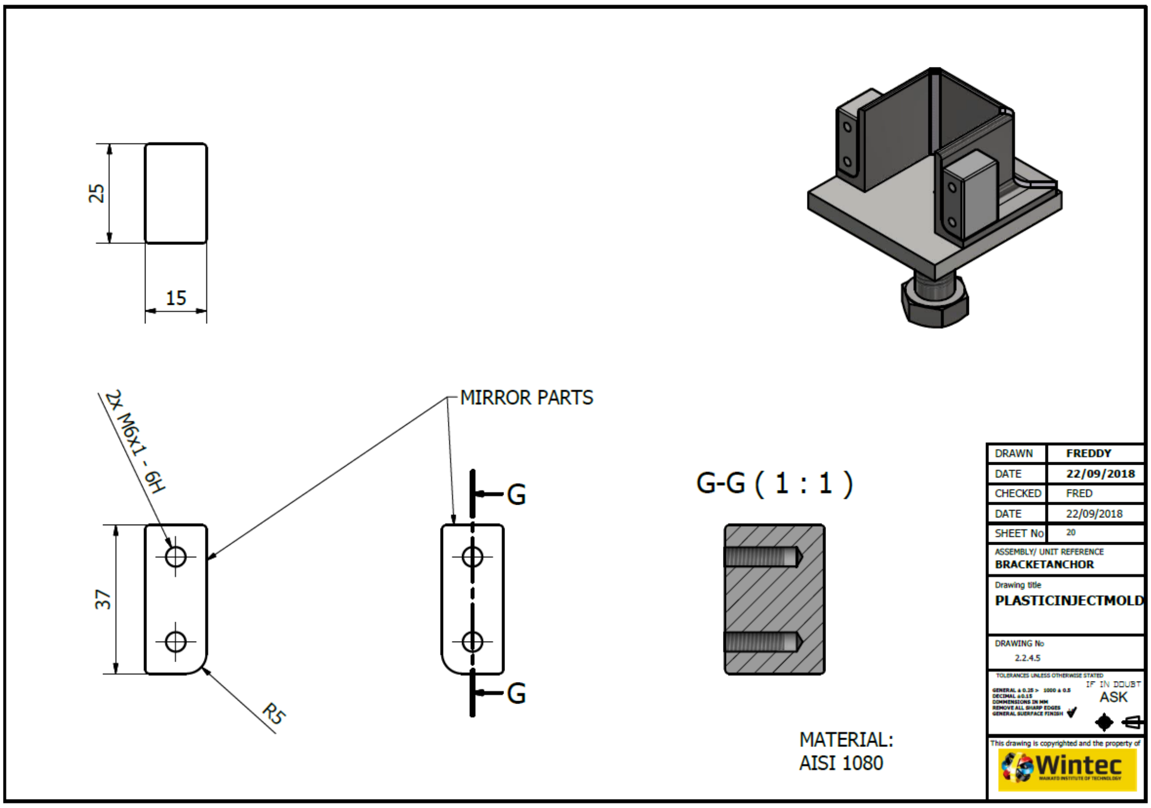
MATERIAL:
AISI 1080



APPPENDIX 8. Calculations for version 2.2

Estimated pressure in cylinder:

The cylinder diameter for version 2.2 did not change for this version however the diameter of the plunger was changed in order to reduce manufacturing cost. It was decided to use the available market dimensions of 10 mm. The other factor that changed is the force being exerted. The design is based on the existing 3 ton arbor press in Wintec's "G" block. It was decided that the arbor press capacity need it to be limited by adjusting the lever length by use of fittings on the arm so no more than 4905N of force is exerted on the apparatus since doing so could exceed safety values.

$$D_{plunger} = 10mm$$

$$Pressure \ = \frac{F}{A} = \frac{4905N}{\frac{\pi}{4}*(10e^{-3}\ m)^2} = 67.6Mpa \approx 68Mpa$$

Cylinder Stresses:

Stress calculations with the new expected working pressure were verified as followed.

$$\emptyset_{Internal} = 10mm \quad \emptyset_{External} = 45mm \quad t_{hickness} = 35 \quad AISI\ 4340 = 470Mpa$$

$$\frac{thickness\ (35mm)}{diameter\ (9)} \geq \frac{1}{20}\ then\ vessell\ is\ a\ thick\ vessel$$

$$\sigma_{hoop} = \frac{P_{ressure} * (r_e^2 + r_i^2)}{(r_e^2 - r_i^2)} = \frac{68e\ ^6Mpa * [(22.5e\ ^{-3}mm)^2 + (5e\ ^{-3}mm)^2]}{[(22.5e\ ^{-3}mm)^2 - (5e\ ^{-3}mm)^2]} = 75.06\ Mpa$$

$$\sigma_{longitudinal} = \frac{P_{ressure} * (r_i^2)}{(r_e^2 - r_i^2)} = \frac{79e\ ^6Mpa\ (5e\ ^{-3}mm)^2]}{[(22.5e\ ^{-3}mm)^2 - (5e\ ^{-3}mm)^2]} = 4.10Mpa$$

$$Factor\ of\ safety = \frac{\sigma_{yield}}{\sigma_{working}} = \frac{470\ Mpa}{75.06Mpa} = 6.1$$

Piston:

The piston was reduced in length and increased in diameter. Since working now with a force of 4905N the member was check for buckling as followed.

$L_{ength} = 135$mm
$\emptyset_{Piston} = 10mm$

Assuming one end pin and the other fix then; $Le = 0.7L$

$Le = 0.7 * 255mm = 178e^{-3}m$

$$K_{radiogyration} = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{\pi * d^4}{64}}{\frac{\pi}{4} * d^2}} = \sqrt{\frac{\frac{\pi * (10e^{-3})^4}{64}}{\frac{\pi}{4} * (10e^{-3})^2}} = 2.25e^{-3}m$$

$$\frac{179e^{-3}}{2.25e^{-3}} = 797 > \sqrt{\frac{2 * \pi^2 * E}{\sigma_{yield}}} = \sqrt{\frac{2 * \pi^2 * 190e^9}{470e^6}} = 89$$

797 > 89; Euler to be used.

$$P_{Critical} = \frac{\pi^2 * E * A * K^2}{Le^2}$$

$$P_{Crt} = \frac{\pi^2 * 190e^9Mpa * 78.5^{-6}m^2 * (2.25e^{-3}m)^2}{179e^{-3}m^2}$$

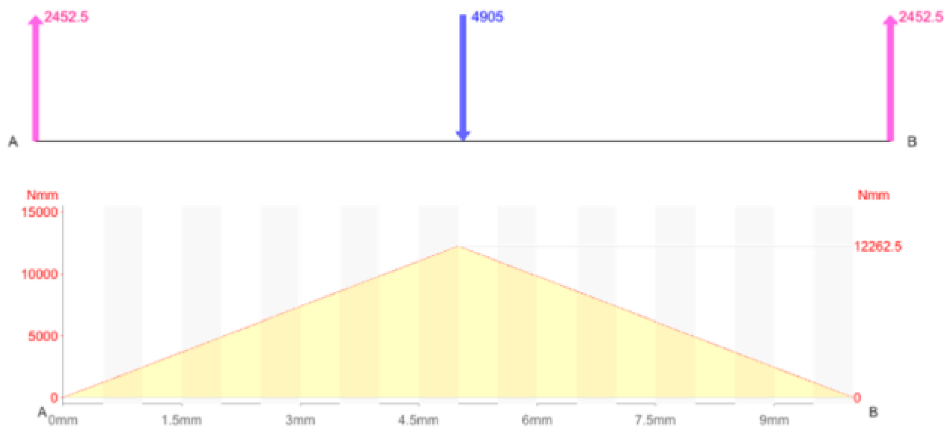
$P_{Critical=}\ 23270N$

$$Fs = \frac{23270N}{4905N} = 4.65$$

Clamping syst. wall.

In order to calculate stresses for this part it was assume that the walls of the , in this case the 50x50x8, were simple supported beams with a force exerted on the centre. The safety factor is indicative that the walls under the loading condition should not fail however it is known that high concentration areas are found in corners of a vessel of this type. Therefore, further research using one of the available CAE tools is suggested for future work.

$$I = \frac{b * h^3}{12} = \frac{10x10^{-3}m * (8x10^{-3}m)^3}{12} = 4.2x10^{-10}m^4$$



Max Bend moment. Autodesk Force effects

$$\sigma_y = \frac{M_{max} * Y}{I} = \frac{12.3Nm * 4e^{-3}m}{4.2x10^{-10}m^4} = 118Mpa$$

$$FS = \frac{350Mpa}{118\ Mpa} = 2.4 \approx 2$$

Screw lift.

The design of lift system, as other parts of the apparatus, was an iterative process. The first designed was envisioned to be drill press on a costume-built jack with however due to economical constraints it was decided to go with a more simple and economical way to provide vertical clamping action between the mould and the cylinder. For this a simple screw was used as power screw. The screw which is supported by the base of the apparatus and connected to the base of the clamping unit would provide lift action my rotating the base screw. Refer to drawing.

The lift capacity was verified by

Estimated Yield strength of M-20 class 8. With a yield of 162 KN.

$$\sigma_y = \frac{162x10^3N}{244.808mm} = 661.7Mpa$$

Calculating diameter required of the bolt using a safety factor of 10.

$$dc = \sqrt{\frac{4905N}{\frac{\pi}{4} * \frac{661.7Mpa}{10}}} \approx 10\ mm$$

The design requires a bolt with a bigger diameter to provide adequate support to the mould base, by design constraint, it would provide extra safety.

Torque required to lift

Torque required to lift is given by:

$$T = \frac{F*dm}{2} * (\frac{l+\mu*\pi*dm}{\pi*dm-\mu*l})$$

Where l = n*p and "n" is the number of starts and "p" is the pitch. Since this is a single screw then l= p=2.5. Using a friction factor of 0.26 (Richard Budynan, 2008) then we have.

$$dm = \frac{d_{max}+d_{min}}{2} = 18.6mm\ (mean\ diameter)$$

$$T = \frac{F*dm}{2} * \left(\frac{l+\mu*\pi*dm}{\pi*dm-\mu*l}\right) = \ T = \frac{4905*18.6_x10^{-3}m}{2} * (\frac{2.5_x10^{-3}m+0.26*\pi*18.6_x10^{-3}m}{\pi*18.6_x10^{-3}m-0.26*2.5_x10^{-3}m})$$

Then the torque to lift is given to be T=13.96 Nm

Checking lift bolt for Combined Stresses.

The bolt is subjected to combined stresses so:

The compressive stress is given by:

$$\sigma_c = \frac{4*F}{\pi*d_{minor}} = \frac{4*4905N}{\pi*(17.25_x10^{-3}m)} = 28.98\ Mpa$$

And the Torsional stress is given by:

$$\sigma_\tau = \frac{16*T}{\pi*d_{minor}{}^3} = \frac{16*13.96Nm}{\pi*(17.25_x10^{-3}m)^3} = 13.85\ Mpa$$

Then Calculating principal stresses:

$$\sigma_{1,2=} \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{x,y})^2} = \frac{28.98Mpa}{2} \pm \sqrt{\left(\frac{28.98Mpa}{2}\right)^2 + (13.85Mpa)^2} = \sigma_{1,2=}\ 34.5Mpa, -8.94Mpa$$

Where Maximum shear stress:

$$\tau_{max} = \frac{\sigma_x+\sigma_y}{2} = \frac{34.5Mpa+8.94Mpa}{2} = 21.72Mpa$$

$$Safety\ factor\ in\ compression\ = \frac{661.7Mpa}{8.94Mpa} = 74$$

The Shear strength is given by:

$$\sigma_{shear\ strength} = \frac{shear\ capacity}{Area} = \frac{91.9_x10^3}{245mm^2} = 375Mpa$$

$$Safety\ factor\ shear\ = \frac{375Mpa}{21.72Mpa} = 12.5$$

The bolt is safe under these loading conditions however it needs to be check for buckling.

Checking for buckling:

Screw length = 40 mm from plate to base

With the nominal screw diameter, we have that the second moment is;

$$I = \frac{\pi*(20_x10^{-3})^4}{64} = 7.85_x10^{-9}m^4$$

For a radio of gyration of

$$K = \sqrt{\frac{I}{A}} = \sqrt{\frac{7.85_x10^{-9}m^4}{\frac{\pi}{4}*(0.02m)^2}} = 4.99_x10^{-3}m$$

So, the slenderness ration is given by;

$$\lambda = \frac{l}{K} = \frac{0.04m}{4.99_x10^{-3}m} = 8$$

Since $\lambda = 8 < 40$ the screw may be treated as a short column and no buckling of the screw is expected.

Checking Stresses on the Nut side:

The load on the nut is going to be distributed through all the threads so, assuming a safe bearing pressure for a steel nut hot deep galvanised (Richard Budynan, 2008) of Pb= 15Mpa then the number of necessary thread can be determined by;

$$n = \frac{F * 4}{\pi * \left({d_{major}}^2 - {d_{minor}}^2\right) * Pb} = \frac{4905N * 4}{\pi * (19.96^2 - 17.25^2) * 15_x 10^5 pa} = 3.84\ threads$$

M20 2.5 nut being used in the design which has approximately 7 thread which is more than the 3.84 required.

Checking Thread for crushing and shear:

The thread is subjected to crushing and shear.

Crushing can be estimated by the following expression;

$$F = n * \frac{\pi}{4} * ({d_{maj}}^2 - {d_{min}}^2) * \sigma_{crushing}$$

$$\sigma_{crushing} = \frac{F}{n * \frac{\pi}{4} * ({d_{maj}}^2 - {d_{min}}^2)} = \frac{4095N}{7 * \frac{\pi}{4} * [(19.96_x 10^{-3} m)^2 - [(17.25_x 10^{-3} m)^2]} = 8.19Mpa$$

$$Thread\ crushing\ factor\ of\ safety = \frac{440\ Mpa}{8.19Mpa} = 53$$

Checking for the shearing of the thread where "t" is the thread thickness for M20 1.6mm

$$F = \pi * d_{maj} * t * n * \tau$$

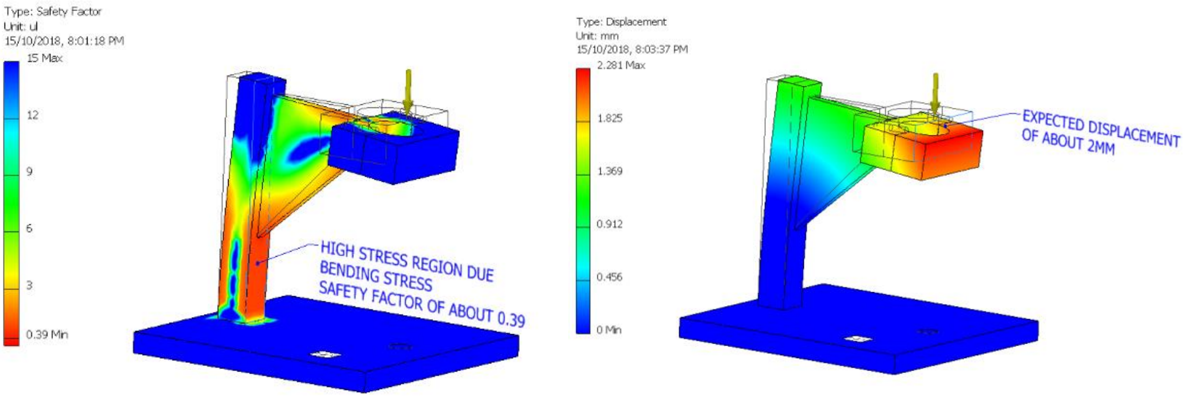
$$\tau = \frac{F}{\pi * d_{maj} * t * n} = \frac{4905N}{\pi * 19.96_x 10^{-3} m * 0.0016m * 7}\ 5.98\ Mpa$$

$$Safety\ factor\ for\ thread\ shearing = \frac{264}{5.98} = 44$$

So, failure of the nut is not expected.

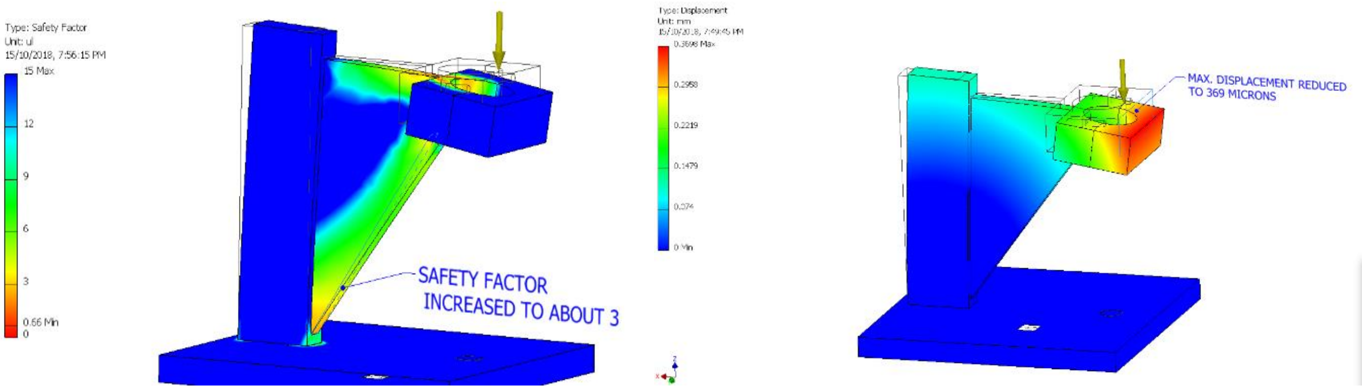
APPPENDIX 9. FEA RESULTS.

The frame assemblies were verified using FEA analysis. The sections selected at first for the column was a 25x25mm solid bar and 110x80x10mm thick plate as a holding arm. Under the loading condition of 4905N the results presented a high stress region on the column with a minimum safety factor of 0.39. High stress areas also seen on the holding arm in the top and also in the point of contact against the column. The displacement at the tip of the assembly at these conditions would have been of 2 mm



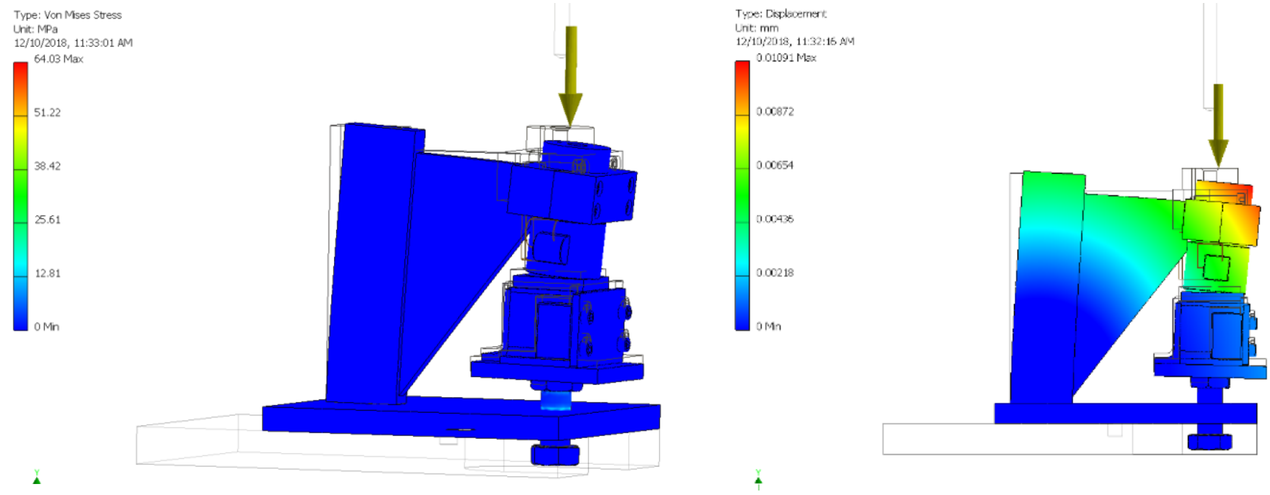
FEA Analysis with a 25x25 solid bar as Colum and a 110x80x10mm thick flat plate.

The section of the column was then changed to a 50X20 bar and the section of the holding arm was also modified to have a longer spam on the vertical. With these changes and under the loading condition the stress was reduced. In the figures below can be seen that after the changes the Minimun safety factor was increased from a 0.39 to about 3 and the Max displacement was reduced from 2 mm to 369 microns.



FEA Analysis with a 25x25 solid bar as Colum and a 110x80x10mm thick flat plate.

The complete assembly was then also checked using FEA analysis. It was found the under the designed loading conditions of 4905N is not expected to fail.



Under the loading condition (4905N) the assemblies are not expected to fail. On the right for the loading condition a max displacement of 0.01 mm.

Appendix 10. Prototype Construction

The construction of the prototype started after meeting with the stakeholder and receiving approval the version 2.2 of the design. Once the parts and assemblies were identified different manufacturing service providers and parts suppliers were approached. The construction process was planned to be a combination from the manufacturing services from Wintec, other institutions (which were kind enough to provide services ad honorem) and personal effort.

The prototype was started and good part of it was manufactured but due to constraints on time, issue with the manufacturing and the miscommunication of the parties involved in the manufacturing process some of the parts were not finished on time or were not machined as specified in the drawings. All this cause the project to be delayed.

Services Sourcing.

After the design was approved a material cut list was created. Having this information, the arrangement for the different processes and materials was required. Since the design required several manufacturing processes and WINTEC's manufacturing facilities were engaged with activities various private institutions were approached to request for their assistance.

Tim Walker and Brad wade who are the engineering managers from Foster Engineering were contacted through Dean Fletcher. After conversation with them they agreed to let some of the services they offer ad honorem provided that most of the labour came from personal effort.

Process required and service supplier.

Part	Process	Service provided by
Cylinder	Cutting - Turning	Foster Engineering /Wintec
Plunger	Cutting - Turning	Wintec/Foster Engineering/ Personal effort
Plast Injec. Base	Laser cut - weld	Marshall Profilin/ Foster Engineering/ Personal effort
Mould base	Press cut/weld	Foster Engineering/ Personal effort
Holding Arm	Laser cut-weld	Marshall Profilin/ Foster Engineering/ Personal effort
Nozzle	Cutting Machined	Wintec (Pending)
Buffer plate	Press Cut Machined	Wintec (Pending)
	Deburring Sanding	Foster Engineering/Personal effort
	Welding	Foster Engineering/Personal effort

The other institution that was approached for service was Marshall Profiling. Conversations were held with the production's coordinator Denis Danilov. Marshall profiling agreed to provide laser cutting service for some of the parts and some of the material ad honorem as well.

Materials

Some of the materials used were identified early in the secondary research. In the research it was identified that due its nature PIM materials has high abrasive characteristics and that AISI 4340 have been found to offer the best option for use therefore it was decided that the cylinder and the plunger were to be manufactured using this material. The other parts of the machine were initially thought to be manufactured using stainless steel which would offer good strength and corrosion resistance however after checking with the suppliers (Easysteel Hamilton) it was proven not to be cost effective. Due to its similarity in strength AISI 1080 was then selected but price and availability also prove to be prohibited. The holding frame assembly of the prototype was then to be built using the material available at WINTEC and the material provided pro bono by the companies previously mentioned.

Sourced Materials

Part	Material	Sourced
Cylinder & Plunger	AISI 4340	Easy steel
Moulder Base, bracket base, bracket front holding bits and holding arm	Mild	Marshall profiling (pro rata)
Column	Mild	Wintec
"L" shape angle for brackets, bolts, buffer plate, clamps syst base	Mild	Foster Engineering. (Pro Rata)

Manufacturing

Grand part of the manufacturing process occurred at the Foster Engineering shop located at 181 Arthur Porter dr. in Hamilton. After a run through their premises and a safety induction the company allowed the use of their space and machinery. Every Friday from the period of 7/09/2018 to12/10/2018, their schedule permissible, time was spent in their shop for the manufacturing of the prototype. After the base and holding system have been put together it was planned for the work to continue at Wintec's premises

The first assembly to be work on was the lift/clamping unit. For this material donated by the company (Foster) was used. The base was press cut and the walls were cut to size using a provided a 50x50x6mm angle. The designed called for 8mm thick angle but given the fact that the material is donated the 6mm would have to suffice for the prototype. For this a drop bandsaw was used. All edges were made safe by use of a benched belt sander.

On the left cutting of the angle. On the right, measuring parts for cut and weld.

The cylinder/plunger material was ordered from EasySteel (Hamilton) the subsequent week conjointly with the parts to be laser cut by Marshall profiling. The cylinder and laser cut parts were delivered the week after. This same week the cylinder's bracket groove was machined in Foster Engineering and subsequently handed to the Wintec staff the same week. The boring and tap threading of the cylinder and the machining of the buffer plate and nozzle was arranged to be machined at Wintec.

Groove on cylinder being machined. Foster Engineering. being heavy fabrication do not have boring too for small dimension so, Boring process and tapping done at WINTEC.

Work on the lift/Clamping unit continue in the following three weeks. The work had to be done when Foster Engineering machinery was available and not in used so, long waiting time between tasks were a norm. In this period welding of the clamping system/lift was done. The prototype's base was tap threaded also ready for the bolt used as power lift. The cylinder bored at Wintec was handed back however with 10 mm off the called-out dimensions in the design drawing.

Cylinder compared to 1:1 scale drawing. Part machined is off by 10 mm

On the left Welding of the clamping clamp. On the centre view of the clamp system. On the right thread tapping of the bracket front plate.

The Welding of the holding frame onto the base was done on the week of 12/10 which completed the work that was going to be done at Foster Engineering. The next phase would occur at Wintec where the prototype would be put together using the parts provided by the client (control/heating elements) and the parts made at the institution.

Holding frame ready for Next Phase.

easysteel
A FLETCHER BUILDING COMPANY
Cyclone

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HAMILTON

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Ph :
Fax:

Ship To : 108139
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CASH SALES ACCOUNT ONLY
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Fax:

GST Reg No. : 76 487 448
BPCS Number : 425425
Order Date : 14/09/2018
Your Order No. : FREDDY WINTEC
Taken By : Louise Gould

We have pleasure in acknowledging receipt of your official order as listed below,
and it is accepted to our standard Terms and Conditions of Sale on www.easysteel.co.nz

LINE	ITEM NUMBER	ITEM DESCRIPTION	ORDER QUANTITY	UM	DELIVERY DATE	UNIT PRICE	EXTENDED VALUE
1	6030379	HTM 45 X 4140CD X CTO 4140 BRIGHT Quantity 1 @ · Length .150 · UM LM · Bndl · Bundle Reference	.150	LM	18/09/2018	85.50	12.83
2	6030995	HTM 10 X 4140CD X CTO 4140 BRIGHT Quantity 1 @ · Length .150 · UM LM · Bndl · Bundle Reference	.150	LM	18/09/2018	4.77	.72

CUTTING	10.00
SUBTOTAL	23.55
GST	3.53
TOTAL	27.08

Marshall Profiling

Specialist CNC Plate Processing

Quote: **09324**

Issue Date: 16-Sep-18

P: (07) 850 8336
E: profiling@marshallprofiling.co.nz

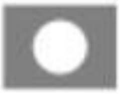
To: **Foster Engineering Ltd**

Attn: **Rebecca Hopson**

Client Ref: **32gr350x1 -Plate**

It is with pleasure that we provide this quotation for your consideration. If you have any questions please feel free to contact us.

Quoted by	Payment Term	Valid Till	Delivery	Delivery Time
Kathy Suk		**16/Oct/18**	**Pick Up**	**3 - 5 Working Days**

Part No	Part Description	Picture	Total Weight (kg)	Thick	Grade	Process	Qty	Each	Total
118903	32gr350x1 -Plate Grain: N/A	 80 X 60	0.9	32	350	Gas	1	$37.41	$37.41
108478	Delivery - Courier Grain:					Delivery - Courier	1	$15.00	$15.00

Total Part Weight (kg): .9000

Total (excl. GST)	**$52.41**
GST	$7.86
Total	**$60.27**

Please note:

- This quote is prepared on the basis that we will supply the required material.
- We cannot accept responsibility for electronic drawing files not supplied at a 1:1 Scale.
- All goods remain the property of MARSHALL PROFILING LTD until the account is fully paid.
- Delivery time stated is from receipt of order, material and drawings approval.
- Quoted prices are for the quantities shown only.
- The above prices are based on our standard tolerances of +/- 0.3mm for laser cut work, +/- 1.5mm for plasma and gas work. If different tolerances are required, please contact our office.
- Due to fluctuating material prices, we will only hold the price on this quote until the "valid till" date on this quote.
- Carbon steel grades are compliant with the tensile test and chemical composition requirements of AS/NZS 3798 and AS/NZS 1594 as appropriate but these standards may not be explicitly identified on mill certificates.

Marshall Profiling Limited appreciates your business

Order Confirmation 15573

Marshall Profiling
Specialist CNC Plate Processing

Required Date: **21-Sep-18**
Created by: Denis Danilov
Created Date: 19-Sep-18
Quote No:

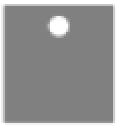
P: (07) 850 8336
E: profiling@marshallprofiling.co.nz

To: **Marshall Profiling Ltd - No Charge**
Attn: **Staff**
Your Ref: **Denis**

Shipping Address
26 Shefield Street

Te Rapa Hamilton 3241

It is with pleasure that we provide this confirmation of your recent order. If you have any questions, please feel free to contact us.

Part No	Part Description	Picture	Material	Thick	Grade	Process	Qty	Price	Total
119422	16MMBRACKETSBITS		Carbon	16	350	Laser	1	$9.94	$9.94
	Grain: N/A	15.4 X 37.4		Part Created: 19/09/2018 13:35					Total Weight (kg): 0
119423	16MMBRACKETSBITS(2)		Carbon	16	350	Laser	1	$9.94	$9.94
	Grain: N/A	15.4 X 37.4		Part Created: 19/09/2018 13:35					Total Weight (kg): 0
119424	BASE16MM		Carbon	16	350	Laser	1	$27.17	$27.17
	Grain: N/A	200 X 211		Part Created: 19/09/2018 13:35					Total Weight (kg): 5
119421	10MMPLATE		Carbon	10	350	Laser	1	$19.07	$19.07
	Grain: N/A	90 X 49.6		Part Created: 19/09/2018 13:35					Total Weight (kg): 0

Total (excl. GST) **$.00**
Including Discount @ 100 %
Total Order Weight (kg): 5.70

Please note:

- Marshall Profiling Standard Terms and Conditions and standard tolerances of +/- 0.3mm for laser cut work and +/- 1.5mm for plasma and gas cut work apply.
- All goods remain the property of Marshall Profiling Limited until the account is fully paid.
- We cannot accept responsibility for electronic drawing files not supplied at a 1:1 Scale.
- Unless otherwise stated all prices are exclusive of GST.
- Every effort will be made to meet the scheduled completion date, however, this may vary depending on prevailing work loads.
- Carbon steel grades are compliant with the tensile test and chemical composition requirements of AS/NZS 3798 and AS/NZS 1594 as appropriate but these standards may not be explicitly identified on mill certificates.

Marshall Profiling Limited appreciates your business