Designing Lego brick and its mould for manufacturing

Kajal Bhandari

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ABSTRACT	
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Author:	Kajal Bhandari
Title:	
Supervisor (Arcada):	Mathew Vihtonen
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The Lego bricks are a creative and fun way to create anything that a person can imagine. The objective of the thesis is to find what kind of mould is suitable for production of a Lego brick and how the mould works in an injection-moulding machine. This thesis concerns how to use SolidWorks, designing a mould for Lego brick that has the possibility of producing the product. A detail study of the product, its design and designing of the whole mould. This project gives the clear idea of the process for mould designing and its production. The parts of mould are simulated separately in Mastercam software. Mastercam software helps produce g codes that are feed into CNC machine for machining the core and cavity of the mould.

This thesis concerns the theory of mould designing and SolidWorks software. The designing is done in two separate ways, making all parts separately and using mould tools. Mould tools are the features in the software SolidWorks that creates mould from the part itself. The created core and cavity are 3D printed to be clear about the design, size and how is it going to look in a real mould. In theory after Mouldflow and milling process an electro discharge process should be carried out in order to get the proper shape of the part.

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LIST OF SYMBOLS

Vf = Feed rate (mm/min)

fz = feed per tooth (mm/tooth)

Z = number of tool teeth

N = rotational speed

V_c *= cutting speed (m/min)*

d = diameter of the tool

π *= Pie*

n = Number of flutes

P= mean effective pressure

A= Area

ABBREVIATION

PLA = Polylactic acid

ABS = Acrylonitrile-butadiene-styrene

PA = Nylon

PC = Polycarbonate

PP = Polypropylene

GPPS = Polystyrene

ShM = Shell Mill

NIU = Not In Use

SP = Spherical

EM = End Mill

TEM = Tapered end mill

HS = High Spindle ratio 5

HM = Hard Metal

HSS = High Steel Speed

CAM = Computer Aided Manufacturing

CNC = Computerized Numerical Control

EDM = Electro Discharge Machine

RPM = Revolution per minute

FOREWORD

First I would like to thank my parents for encouraging me and keeping me optimistic throughout. I would also like to acknowledge my thesis Supervisor Mathew Vihtonen for his support and guidance. My special thanks to Mr. Erland Nyroth, for educating me and bestowing his knowledge about mould design and mould production upon me. Without his guidance my journey in this thesis would not be easier.

1 INTRODUCTION

1.1 BACKGROUND

Lego goes back to 1930's, in Denmark. It is an abbreviation of the word "leg godt" that means play well. Ole Kirk Kristiansen founded it in 1932. They were first made of wooden blocks. The plastic Legos were first made in 1960's. From then Lego has been a very creative toy for children and as well as for adults. (Lego Group, 2016)It encourages and inspires everybody to imagine and create it assembling the Lego blocks. These small blocks teach children how to do mathematics, create their imagination in front of them. Not only for children but for adults also, it encourages the imagination and helps them to be creative such as it can be used to create a model for a project, a playhouse for children, day-to-day products that can be made from Lego etc. The main objective of this thesis is to create a core and cavity of the Lego part and how the mould can be designed for better production. The design of the mould is according to the injection-moulding machine of Arcada's plastic laboratory. Making moulds are the easiest way to produce a product in large scale. The most feasible way to create Lego blocks is from injection moulding since it is produced in large scale. The mould that will be obtained after the completion of thesis can be produced and used in the lab to produce Lego blocks. These blocks can be used in various purposes in the lab, for projects, for different designs etc.

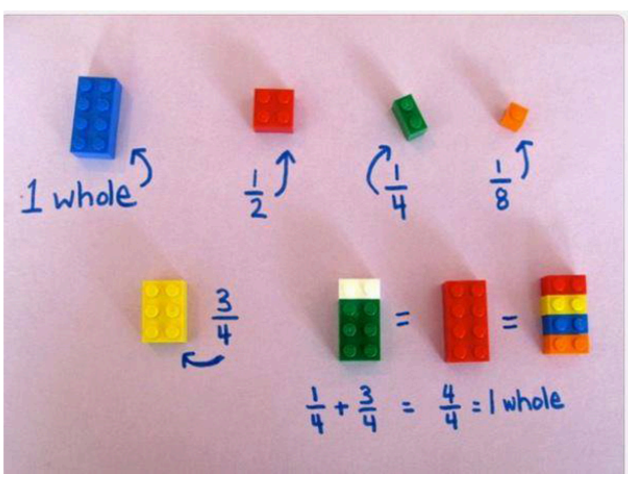


Figure 1: Lego bricks (Harmer)

1.2 OBJECTIVES

- To design a Lego part, its core and cavity and all the parts of the mould in SolidWorks
- To find a best suited runner and gating system in the mould.
- To do mastercam simulation of the parts of the mould
- To assemble all the parts of the mould.
- To describe mould tools, its functions and describe how to use it to make the mould for the product.
- To compose a proper mould design steps in SolidWorks for using mould tools.
- To make a prototype of the core and cavity

1.3 RESTRICTIONS

The Lego bricks have sharp edges and corners but while milling it is not possible to make the edges sharp. In injection moulding having sharp corners and edges is not preferable but the Lego blocks has to be sharp edged.

Another obstruction can be the draft in the Lego brick. The Lego bricks are very straight. Putting a draft in the product can ruin the purpose of the product.

Also the ridges in the inner part of the Lego piece are very small which can be difficult to injection mould.

2 LITERATURE REVIEW:

2.1 INJECTION MOULDING

Injection moulding is one of the key methods of production of processing plastics. The main idea of injection moulding involves a process in which plastics pellets are fed into the plasticizing unit of the injection-moulding machine where it is melted after which it passes through cylinder with single screw extruder and into the mould to form a product. The mould has two parts core and cavity, the core part shapes the plastic melt and gives the shape of the required product and pushes out the product when it is ready. Most common plastic materials used in injection moulding process are Acrylonitrile-butadiene-styrene (ABS), Nylon (PA), Polycarbonate (PC), Polypropylene (PP) and Polystyrene (GPPS). (British Plastic Federation, 2015)

2.1.1 PARTS AND THEIR FUNCTION

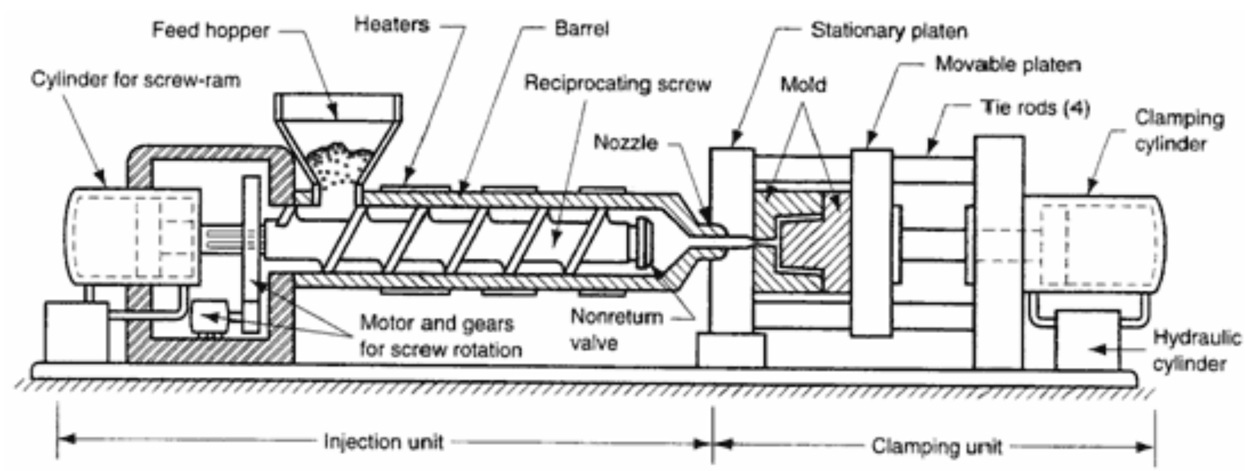


Figure 2: Injection moulding machine (British Plastic Federation, 2015)

There are two units in the injection-moulding machine:

- Injection unit: Injection unit includes the parts of the machine that plasticizes, moves the plasticizer and injects to the mould.
- Clamping unit: Clamping unit includes hydraulic press, clamp and the mould.

2.1.1.1 **INJECTION UNIT**

- Hooper: Hopper looks like a funnel from where the plastic granules or pellets are fed into the injection-moulding machine. (3d Systems, 2015)
- Barrel: The barrel contains a reciprocating screw and heaters. The heaters are implanted around the injection cylinder and nozzle helps to melt the plastic granules and give the perfect temperature for the injection moulding process. The heaters melt the plastic granules and the reciprocating screw moves the melted plastic towards the mould to form the product.
- Nozzle: Nozzle is the tip of the injection-moulding machine that lies on top of the sprue bush. It works as an inlet for the molten plastics to the mould cavity.

2.1.1.2 **CLAMPING UNIT**

1. HYDRAULIC PRESS: Hydraulic press is present in both sides of the machine. The one which is on the movable side of the mould helps in pushing and pulling the mould while the one which is present in the non movable side of the mould helps to turn the reciprocating screw to forward the plastic melt inside the injection barrel.
2. CLAMP: The clamp of the injection-moulding machine holds the two halves of the mould in proper alignment with each other. When the mould is closed it keeps the mould in place and does not let the force from the injection of the plastic to displace two halves of the mould. Also it acts as a unit that opens and closed the moving plate of the mould at the exact time. The clamping system can be hydraulic (pneumatic), hydro-mechanical or mechanical.
3. MOULD

   The mould consists of following parts:

a) Ejector plate and ejector pins: The ejector plate is the plate that holds ejector pins. The ejector pins helps to remove the product after the plastic melt has been cooled in the mould cavity.

b) Mould core: Mould core is a part of the mould that has the inner shape or the solid shape of the product. It helps to shape the plastic melt while making the product.

c) Mould cavity: It is a part of the mould, which has the outer shape of the product. The plastic melt enters this area of the mould and fills up the cavity to form a product.
d) Guide pins: These pins hold the whole mould together and helps to line up the mould and keep all the parts aligned together.
e) Sprue bush: This is the top part of the mould. Through the sprue bush the plastic melt enters the mould. It helps in consistent supply of the melt into the mould.
f) Runners. Runners are the paths for the plastic to get to the mould cavity to form the product. When product is obtained the runners are thrown away as it holds no function for the product.
g) Gate: gate refers to the part between the runner and the part. In injection moulded products
h) Ejector pins and ejector plate: Ejector pins and ejector plates help in ejecting or removal of the product after the material has been inserted in the mould. In this mould, the ejector pins are 12 in number and are cased outside the cylinder that is inserted in the core of the mould.
i) Support blocks: The support blocks or spacer blocks are lined up beside the ejector pin plates. These blocks help in keeping a safe distance between core and the ejector plates. The blocks are there to give the ejector pins a space when they are not striking the product out of the mould.
j) Cooling channel: Cooling channel in inserted in the mould cavity where the cool water passes. This passing of cool water lowers the temperature of the melt and solidifies the melt into solid form so that we can obtain a solid product. it can be created in core or cavity by milling or drilling the channel.

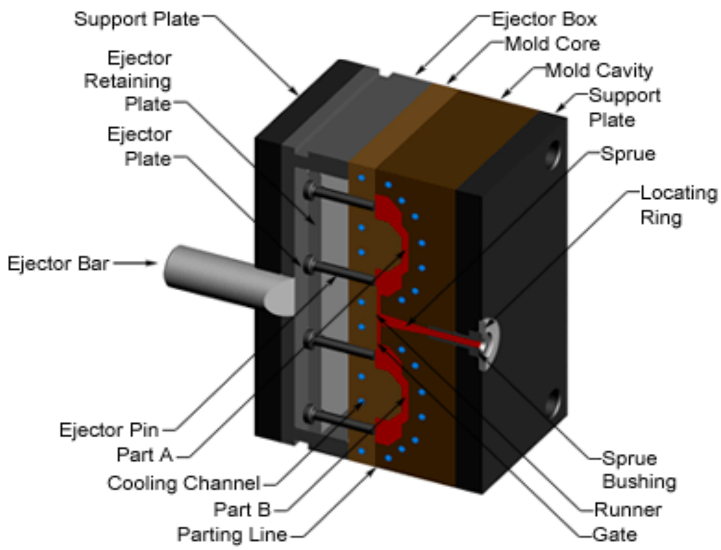


Figure 3: Mould (Customerpart.net, 2009)

2.1.2 **THE PROCESS**

The injection moulding process starts when the plastic granules or Resin material is fed to the injection barrel from the hopper. The hopper maybe fed manually by a person or vacuum fed. Dryers are attached to the hopper to remove moister from the plastic granules. The granules are put through a tubular structured part that has reciprocating screw. This screw has heaters in its walls that melt the granular plastics into the liquid consistency that is required for injection moulding process. The reciprocating screw also pushes the plastic melt forward to the mould. The reciprocating screw drives the granules forward. It melts the granules while it turns and moves the plastic melt or plasticizer forward. This process is known as drag flow. Drag flow causes polymer molecules to (Customerpart.net, 2009)over each other and produce heat. This heat melts the plastic material but is not enough for the injection moulding process. So, external heating bands are provided in order to approach proper heating temperature for the process. These bands provide external heat needed for the injection moulding process and compensates for the radiation heat loss. Three thermal couples in the barrel and one in the nozzle control the temperature. The injection nozzle remains closed while plasticization. The plastic melt is pushed forward in front of the screw working against the resistance of the barrel by the backpressure. Because of this pressure the melt remains just in front of the screw waiting for the nozzle to open and to get into the mould. The reciprocating screw has three parts.

2.1.2.1 **FEED ZONE:**

This zone is one half of the screw. It has a constant flight distance between the walls of the barrel and the screw. It helps in the constant flow of the material into the barrel.

2.1.2.2 **MELT ZONE:**

This zone has a decreased flight distance between the barrel and the screw. This decreased distance causes the material to rub harder against each other plasticizing the material.

2.1.2.3 **METERING ZONE:**

This zone has a constant flight depth and acts as a pump. The tip of the screw has a one-way valve that does not let the melted plastic to go back. The force from the valve pushes back the screw as it turns. This builds a chamber of materials in front of the screw. When there is enough material for one shot to make the product. Then the screw stops and pulls back to decompress the material.

After that the one way valve closes and the hydraulic press pushes the screw forward by the injection cylinder. A clamping unit closes the mould. This sends the molten material through the injection nozzle and into the mould. Then through the nozzle the plastic melt enters inside the mould and fills up the cavity of the mould to form a shape. The molten plastic after filling up the cavity cools down in the mould with the help of cooling system that is fitted in the mould. The cooling system is tunnels made in the mould where cold water passes and cools the molten plastic to help form the shape of the cavity of the mould. The shape is formed and cooled in the mould. It is now time to take the part out of the mould. When the plastic is cooled no more plastic melt can be reciprocated forward. Then the screw starts turning again for the next shot. The ejector plates and ejector pins inside the mould do it. The mould opens itself and divides into core and cavity, the core par has ejector plastics and ejector pins that pushes the part out of the mould. When this process completes, it has to be ready for the next shot. The screw comes back and closes the nozzle to accumulate plastic melt in front of the screw for the next round. The packaging pressure for the injection moulding process usually ranges from 2000 psi to 30,000 psi but it can go higher too according to the requirement. Sometimes second lower pressure is also applied if needed. The temperature of the material in the molten state should be 320 too 600 degrees Fahrenheit. (Craftech Organization)

2.2 DESIGN

While designing any part there are some criteria that should be taken into account. While designing of a part, its material, size, its purpose, in what conditions it will be (temperature, pressure, weight), etc. should be taken into account before start designing any product.

2.2.1 POSSIBLE PRODUCTION ISSUES

While designing a part, there are some constraints that should be considered in order to obtain a good product. They are:

2.2.1.1 STRESS

When injection moulding plastic parts, the main concern is the stress caused in the plastic products. When the melted plastic resin is forced through the nozzle to the cavity of the mould, it passes to the entire feature. The melt is forced to go to all the cracks and crevices to fill them up. While doing so they are turned, bended and distorted to form the shape given by the cavity. After filling the shape of the mould it starts to cool down. While the melt cools, it tries to relinks the molecules and return back to its rigid form. There are stresses in the bended and twisted parts of the mould which later can create warpage, cracks, marking, premature failure etc. (3d Systems, 2015)

2.2.1.2 DRAFT:

Injection moulded parts have different types of features. After the plastic melt is inserted and has cooled down, the ejector pins pushes the part out of the core. The part that comes out should be undamaged, in a proper shape and should not stick to the mould core. When the part has features such as internal ribs, outer walls, a cylinder shape etc. they should be tapered in the direction that mould opens. This is known as draft. Without draft the part does not comes out of the core easily, hence it will be corroded, damaged or even broken because the ejector pins will be pushing the part out of the mould using force. There are different draft requirements for different types of models. At least 1 degrees draft is necessary while 2 degrees for light textures also works in most of the models and 3 degrees for medium and shut off surfaces. (3d Systems, 2015)

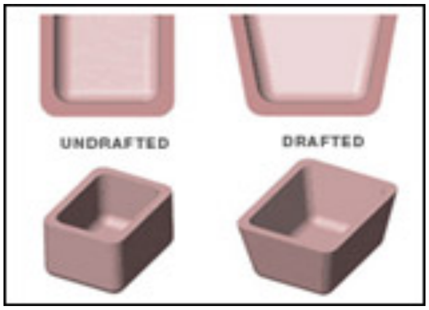


Figure 4: Difference between drafted and undrafted product (3d Systems, 2015)

2.2.1.3 **SINK MARKS:**

Sink marks are the area in which the molten plastics gets accumulated because of the structure and takes longer time too cool down than other parts of the part such as corners. The sink marks gets formed because there is more material in the area and takes comparatively longer time to cool than the other parts. Since it takes longer time to cool it sinks inwards giving the appearance of a sink from outside the part. (3d Systems, 2015)

2.2.1.4 **WALL THICKNESS:**

Wall thickness of any product is very important factor to consider while making a product. Choosing a proper wall thickness can affect the cost, manufacturing time of the product. When the product is cooled after injecting the plastic melt, it cools down very quickly and the change in the pressure, velocity, plastic viscosity all effects the product, so they should be decreased to a considerate level to get a good quality product. (3d Systems, 2015)

2.2.1.5 **PARTING LINES**

Parting line is a part of the product where two movable and immovable part of the mould join together. Every part has these parting lines and they have to be considered and put in properly for a good design. Parting lines include shutoff surfaces, side action pins and tool inserts. (3d Systems, 2015)

2.2.1.6 FLOW MARKS, WARPING AND WELD LINES:

Flow marks can occur while producing the product. It occurs if the injection speed is too slow. This can cause plastic melt to cool down in some parts of the product, which creates a defected piece. Warping is the effect that causes when the mould is not cooled properly. It causes the product to have twisted parts that is not intended. The cooling temperature, short cooling part, the tool is short in the cooling parts, these all create warping effect. Weld lines occur when the mould or material temperature is too low. This causes the plastic melt to not join properly and shows a distinct line, which is called as weld line. (3d Systems, 2015)

After these criteria analyzed, how the design is going to be made should be fixed. There are 2 ways from which the mould core and cavity can be made. They are, making the plates separately or making the core and cavity from the product itself. In this thesis both procedures to form the mould as described in the method section is carried out.

2.3 MASTERCAM (CAM) AND HAAS MILL

Computer aided manufacturing helps in designing and choosing the best toolpath for the design. It helps in choosing the best tools and how the tools are supposed to act on the design for better result. It helps in reduction of the wastes that can be created if a wrong too and toolpath is chosen while manufacturing a product. Mastercam also allows us to redesign and improve the design of the product according to our will. While producing a product, computer aided manufacturing allows us to choose the correct tool and required speed and number of reps according to the need of the manufacturer to get a better quality product. The CNC data is mainly divided into 2 sections. First one is the dimensional information that geometrically describes the part required called as geometrical data. Another one is technological data. All the data necessary for the machine tool to select the required tooling in correct speeds, feeds and depths of cut and also turn the coolant on or off automatically. (Waters, 2001)

Various machines for faster and accurate result use CNC (computer numerical control machining). The HAAS mill is used in production of the dog bone mould is also using computer numerical control machining system. This system contains toolpath, tools changes and different parameters that help in milling a product. This information is given to the machine through G-codes. G-codes are those codes or those commands that is provided by the mastercam software. HAAS mill uses mechanical sensor, which means it operates by sensing the pressure on the edge of the part to be milled making it a zero point. The X, Y, Z co-ordinates are used as zero points to mark the edge of the part to be milled and it gives correct size and design of the product. After marking the zero points, it then starts to follow through the codes and removes the material from the stock piece. It follows the instruction until the next tool changes. (Lipponen, 2015)

The following are characters of HAAS mill to be taking in consideration while making a part or a mould: (Injection Mold Design Tutorial, Technology and Engineering)

- Spindle speed: The spindle speed is the rotational frequency of the spindle of the machine. It is measured in revolution per minute (RPM).
- Cutting speed: Cutting speed is defined as the rate that the material moves past the cutting edge of the tool. It is also known as surface speed.

$$Vc = \frac{n * \pi * d}{1000}$$

Where, V_c = Cutting speed (m/min)

d = Diameter of the tool (mm)

n = Number of flutes

$\pi = 3.14$

- Retract rate: Retract rate is the time taken to change the tool.
- Clamping force: Clamp is a device, which holds two things together firmly, and clamping force is the force exerted on the block or the mould that firmly holds it without damaging it.

$$\text{Clamping force (F)} = P*A$$

Where, P= mean effective pressure

A= Area

- Feed rate: Feed rate is the rate of velocity of the cutter fed against the work piece. It is measured in units of distance per revolution for turning and boring. For milling it is expressed in units of distance per time and depends on number of tooth of the mill and rotational speed.

$$Vf = fz * Z * N$$

Where, Vf = Feed rate (mm/min)

fz = feed per tooth (mm/tooth)

Z = number of tool teeth

N = rotational speed

- Plunge rate: Plunge rate is like feed rate; it is the rate at which the cutter moves. This type of cutting generates more friction so it is usually half of the feed rate.
- Feed per tooth: Feed per tooth defined as the thickness of the chip removed by each cutting edge of the tool. It is expressed in mm/tooth.
- Rotational speed: Rotational speed is also called speed of revolution. The rotational speed of a tool is defined as the number of complete revolutions per minute. It is expressed in revolution per minute. (Woodweb Inc, 2016)

$$N = \frac{Vc * 1000}{\pi * d}$$

Where, N= rotation speed (rpm)

V_c = cutting speed (m/min)

d = diameter of the tool

In mastercam there are different kinds of features that allows us to get the required shape of the product. They are described as follows:

2.3.1 DRILLING

Drilling is a process of removal of the material from the stock by directly pushing its tip on it. The center drill helps in locating the place where a hole in intended so that later the counter bore drill has a good center to work on.

Figure 5: Drilling (AKYAPAK Gizlilik Bildirimi, 2016)

2.3.2 MILLING

Milling is a process of removal of materials from a given stock piece. It has to be done is many reps since the milling tool is under a lot of pressure and the feed per tooth is just 0,25 mm. The most common types of milling tools used are face mills, end mills and ball mills. Face mills are used for a plain milling f the stock to remove more material from it, which later on can be shaped by other tools. End mills and ball mills remove less material while they can shape the stock into required shape. End mills remove stock from all the sides and used for contouring and shaping while ball mills are used to make a round shape in the stock.

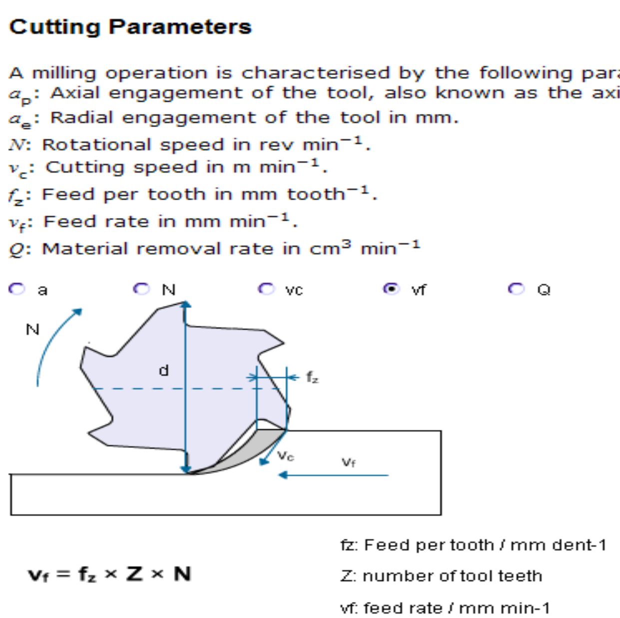


Figure 6: Milling parameters (HAAS Automation, Inc, 2008)

2.3.3 POCKET

Pocketing is a toolpath that moves according to the command given to remove the materials from a designated area. It removes all the material from an enclosed area to a fixed depth to form a pocket like structure. There is a boundary of the pocket that should be in the design of the product and the toolpath can be chosen according to the need or the structure of the pocket. The toolpath can be zigzag, zig, contour parallel or contour linier. It first makes a rough contour of the structure to be designed and then makes multiple rounds to remove the material from the area after which a finishing curve is carried out. These processes can be changed and modified according to the need of the product.

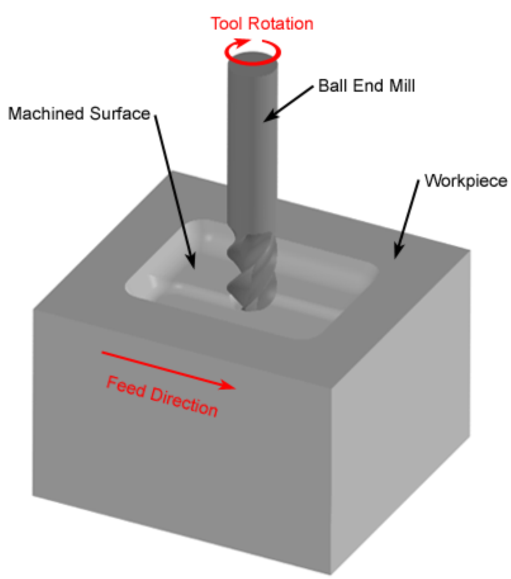


Figure 7: Pocketing (MechaTerrain Inc, 2014)

2.3.4 TOOLS

The tools that can be used in producing the mould are the HSS (high speed steel) tools for milling that are provided in the plastic lab of Arcada. HSS tools are alloys of steels and other iron-carbon alloys. These tools are the superior tools from those of carbon steel tools. They can bear high temperature and can cut faster. Because of its properties it is used extensively worldwide. The tools can be checked from the lab.

2.4 ELECTRO DISCHARGE MACHINE (EDM)

Electro Discharge machining was started in 1770 by joseph priestly. He observed that the electric discharge has removed materials from the parts. It is also known as electro discharge erosion. Then in 1940's the Soviet researchers developed the modern EDM process. The core process of this machine is that, an electrical spark that is created between the electrode and the work piece and it removes the material from the work piece. The spark created is visible. It can produce heat up to 12000 degrees Celsius. This is a very high heat and can melt most of the things known. Thus the spark is controlled so it affects only the surface of the material. There are two types of EDM's Sinker EDM and Wire EDM. (xact edm wire corporation)

2.4.1 WIRE EDM:

It is an electro thermal production process. In this process a thin single stranded wire in conjunction with de-ionized water is used. The de-ionized water is a very good conductor of electricity. The electric spark produced from this process allows the wire to cut the work piece by removing the materials between as the spark jumps across the gap. To prevent from shorting, a non-conductive fluid is also applied. (EDM Technologies Inc, 2008)

2.4.2 SINKER EDM:

This process is commonly used in the production of dies and mould. In this process, an electrically charged electrode that is of specific geometry is used to make the metal component. First the two metal components are submerged in the insulating liquid. When the machine is connected to the current, the electric tension between the parts starts to rise. The two parts if bought together, the electric tension is discharged and the spark jumps across. Where it strikes the metal starts to heat up and then it melts. After such innumerable spark spray, the desired shape is obtained in the work piece. (EDM Technologies Inc, 2008)

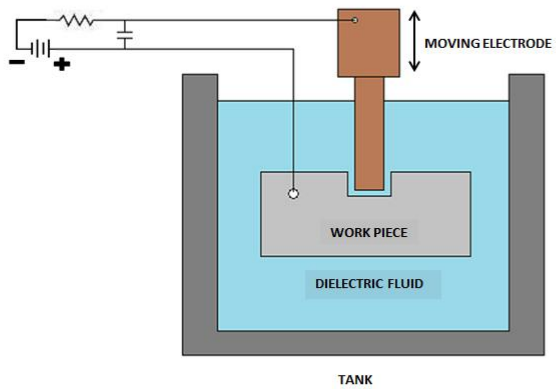


Figure 8: Sink EDM (University of Cincinnati, 2011)

3 METHOD

The process of making a mould can be divided into 3 parts i.e. designing the product, designing the parts of the mould and production of the mould. In this thesis, the focus is on designing of the mould and preparing it for the production. The designing part was done in SolidWorks and some parts were downloaded from dmeeu.com. In this thesis the designing of the mould is done in 2 ways. First the mould is prepared conventionally i.e. preparing a product, then making core and cavity and other parts separately and then assembling them together. The other process used in this thesis is using the mould tools to prepare the mould from the product itself.

3.1 DESIGNING OF THE PRODUCT:

The product designed in this thesis was, 8 studs Lego brick. It contains 8 studs on the top of the brick and 3 cylinders on the bottom. The brick is provided with 12 protrusions inside of the bottom of the brick to clasp it properly to another brick.

The two inner and outer walls of the Lego brick were sketched and boss extruded. This is the basic structure of the brick. Further the brick was drafted and rounded on the edges. The edges on the corners of the product is necessary in injection moulding because, when the plastic melt cools off in the mould it can accumulate the melt inwards and make a significant mark on the outer side of the product. Then the drafts needed on the inner walls of the brick were made. The drafts are necessary for the easier removal of the product from the core.

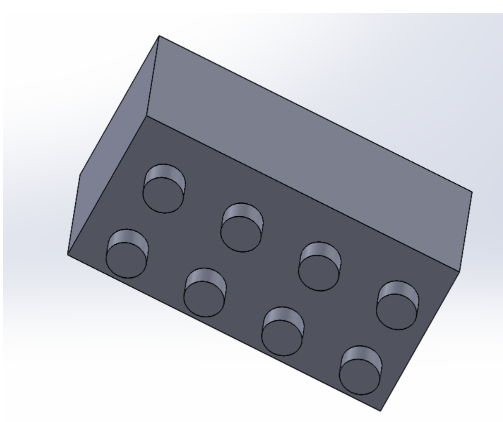


Figure 9a: Product (Lego brick)

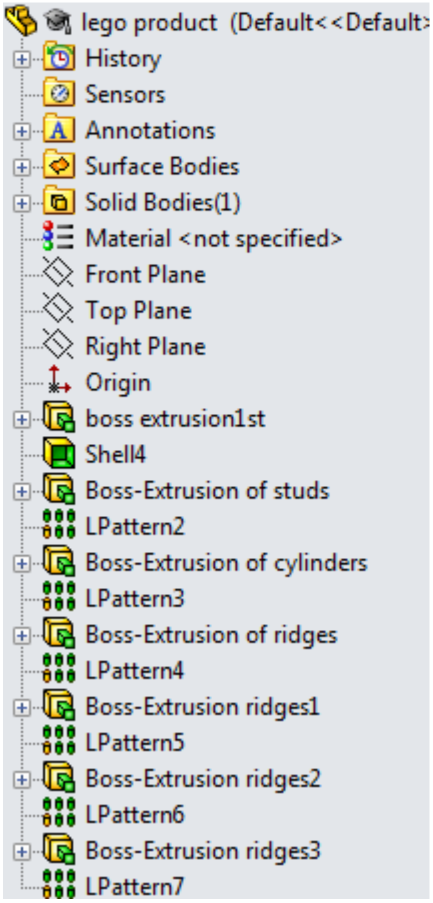


Figure 9b: Tools used in making the product

3.2 DESIGNING THE MOULD

The objective of designing a mould is to make a core and cavity, design a feed system, ejection system and cooling channel in the mould.

The downloaded parts from dmeeu.com included the back plate, front plate, guide pins, guide pin holders, support blocks and the ejector plates. The parts can be made in SolidWorks as well and can be edited as per needed. The design of the core and cavity depends on the product. While designing the core and cavity, the size of the product is important. The core of the mould was made smaller then the product and cavity was made larger than the product so the difference between the core and cavity is 1.6 mm.

After a part has been created then the next step is to make the core and cavity. The cavity of the mould includes the injection point where the plastic is injected, and the upper part of the lego block. The core includes a block with 3 cylinders on the backside of the lego block. When the core and cavity comes together they leave a space inbetween where the plastic melt goes settles and cools off to form the lego. The cylinders in the core of the mould are provided each with long pins. These long pins are (Woodweb Inc, 2016)cased by ejector pins which after the injection of the melt helps in ejection of the product from the core by pushing it forward.

3.2.1 **CORE AND CAVITY**

The main features used while making the core and cavity was linear pattern and mirror. The linear pattern is a feature that multiplies the sketch or features in a linear manner at a certain distance and mirror multiplies the sketch or structure according to the plane as desired. To make the core, an extrusion of the basic wall of the Lego was made on which the 3 holes were made. These three holes are the tubes of the Lego block that will be formed on the back. The ejector pins will be inserted in these holes so that the melt goes around the ejector pins inside these holes to form a tube structure. The cavity on the other hand is pocket milled and the 8 studs are drilled according to the size. Both core and cavity have the runner system to make a complete round runner but only cavity plate has an outlet for the plastic to run in to the cavity of the part through the gate. In the core and cavity are designed contains 4 Lego bricks. This way in one filling 4 Lego bricks can be produced.

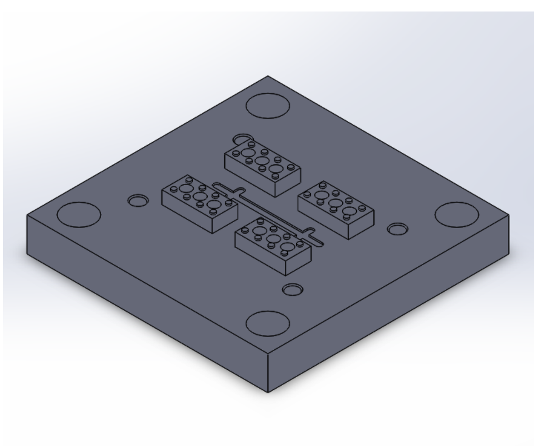


Figure 10a: Core

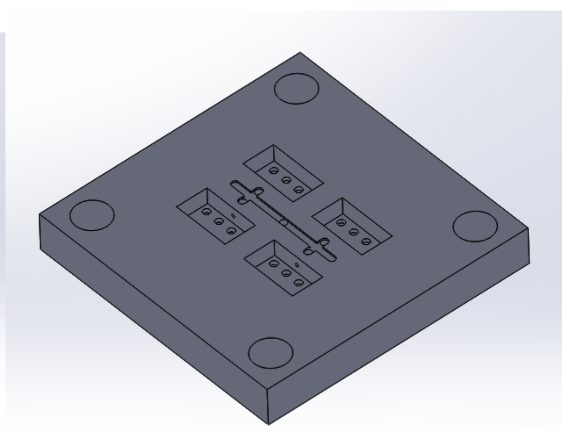


Figure 10b: Cavity

The mould is provided with feed system, cooling channels and ejection system for the plastic melt to be fed into the system, cooling the melt to form the product and ejecting the product from the mould respectively.

3.2.2 THE FEED SYSTEM

This system allows the plastic melt to enter the mould. The feed system consists of 3 main parts, sprue, runner and gate.

3.2.2.1 THE SPRUE

The sprue is designed to be tapered 3-5 degrees so that it is easier to pull it out of the tool more easily. It is highly polished so the flow of the melt is smooth. The diameter at the end is larger than the nozzle.

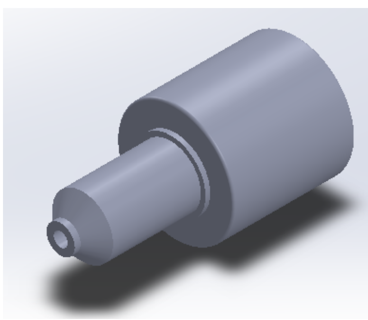


Figure 11: The sprue

3.2.2.2 GATES

Gate is an opening through which the plastic melt enters the mould cavity. The gate offers a small thin area through which the melt enters so, when a batch is complete and the product is removed from the mould, the gate is the link from which the product is detached from the runner system. Some moulds are designed such as, when the product is removed from the mould; the runner is automatically detached from the product. The gates can be in different places and of different size according to the product being made. It is preferred to be narrow in most of the cases. There are different types of gates according to the need of the product. They are: (Pye, 1989)

- Sprue gate
- Edge gate
- Fan gate

- Disk gate
- Ring gate
- Tunnel gate

In this thesis the mould contains a tunnel gate. It is also known as submarine gate. This gate is used then there is 2 plate moulds. The tunnel is machined as tapered. The tunnel is wider (3mm) in the runner side while is smaller (1mm) in the cavity side. The advantage of this gate is that it can be de-gated automatically when ejection of the product during the ejection phase. The sprue puller in the ejector plate pulls out the plastic that is cooled inside the sprue and the runner and is automatically separated from the product and the mould.

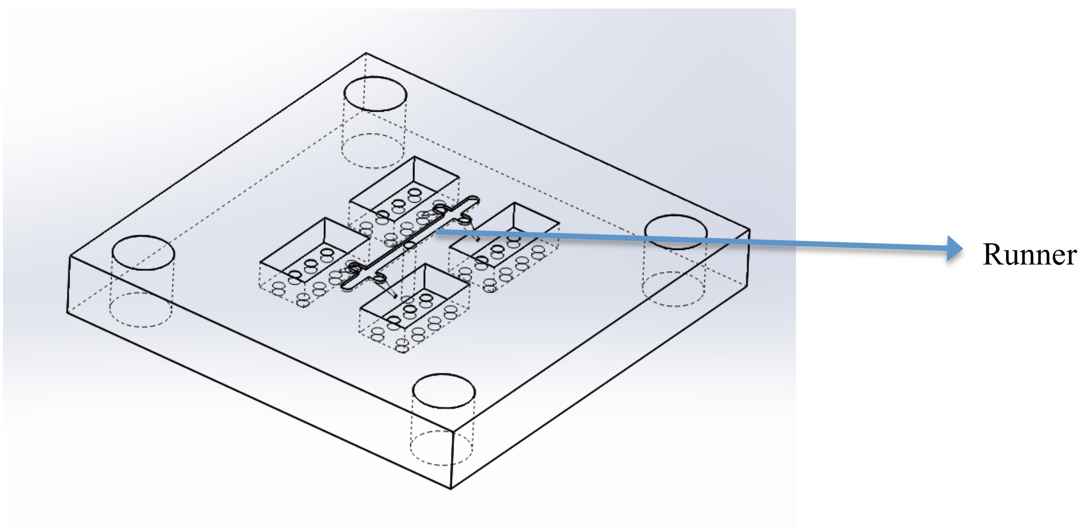


Figure 12a: Runner in the cavity (isometric view)

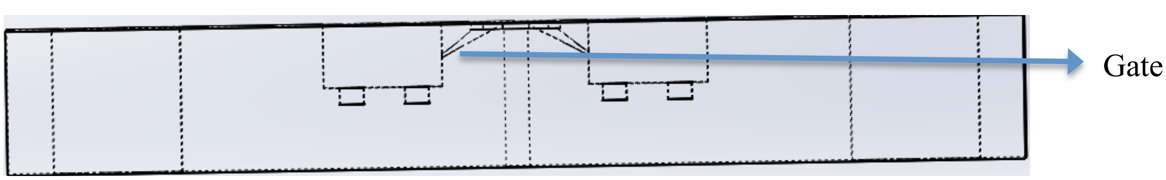


Figure 12b: Tunnel Gate in the cavity (side view)

3.2.2.3 **RUNNERS**

The runner is a system for distribution of the melt through the mould cavities. A good runner system minimizes the scrap, gives control over filling and cycle time and ejects easily from the product. The runners should be designed thin and most common is a full circular runner. The type of runner depends on how many parts the cavity contains. In this thesis, the plate contains 4 cavity parts since the Lego brick is small in size. The balance in the runner is very important. The sprue hits one punch and the melt from that batch should be balanced and shared among the cavity equally.

Deciding which runner will be used in the mould is very important. There are 2 kinds of runner cold runner and hot runner. Cold runner mould can be classified as such in which after each cycle of injecting the plastic melt the cavity, it is cooled and all of the part i.e. runner, gate and part is ejected from the cavity. In this system, the plastic melt enters the runner, then gate and to the cavity. After which it is cooled there and ejected out of the cavity. This is a simple and efficient form of solidifying a product. The disadvantage with this runner is, it produces the runners from the plastic melt, which is to be injected in the cavity. Other than that, it is easy, simple and cost effective to produce. Hot runners are usually not without runners and uses heated sprue or hot nozzle to insert the melt into the cavity. It does not need runners so the plastic melt is not wasted. It reduces the cost of production since; it lets us make the product without sprue and runners. The moulds for this kind of system are more complicated and are expensive. (J. P.Beaumont, 2007)

The runner system used in the mould is cold runner system. In the cavity and core, there is a rounded runner, half of which is in the core and half is in the cavity and they together form a complete round runner system. The runner system has 4 outlets. These outlets are tapered from the runner to the gate. The size of the hole in the runner is smaller than the one in the cavity. The advantage of doing a tapered outlet is that when the injection is finished and the melt is cooled, the runner ejection system ejects the runner with the outlet directly removing it from the part. This way, there is no need of putting an extra effort on the removal of runner from the part. The diameter of the runner can be according to the thickness of the cavity or it is also suitable for the runner to be between 4mm to 10mm. this reduces the risk of early freezing of the plastic melt in the cavity.

3.2.3 COOLING CHANNELS AND VENTING

Cooling channel is a path through which cold water passes and cools the melt after it has been set in the cavity. However a suitable cooling channel for the mould can be different according to the type of mould and the product. A proper rate of flow of water is very important for cooling of the product because if the cooling is very fast it can occur sink marks, distortion and stresses, while in the other hand if the cooling is late then the product might not set properly in the cavity. The cooling system ensures the uniform distribution of temperature in the mould cavity. A carefully designed cooling system can prevent many defects that can occur in the moulding process. A good cooling system provides optimal injection time and optimal phase for stiff and cool of polymer. Some of the cooling agents that can be used in the injection mould are, fluids, air, electric heaters, etc. while designing a cooling system, the cavity area of the part is to be considered. The cooling channel should be away from the corners of the cavity since the corners are prone to be distorted by sudden change in temperature. The diameter of the channel is greater than 5mm and the rate of flow of the cooling agent should be regulated according to different area in the mould. There are two types of cooling system, conventional and conformal cooling system. The cooling system to be used in this mould is conventional cooling system i.e. the cooling channel is drilled or milled. This is simple and can be made in a low budget.

Venting is a design idea to let the air pass from the mould in order to prevent flashing out of the melt from the mould. It is usually kept in the parting line of the mould. It helps in passing of the air from the mould. The design may vary with relation to the type of product or the material used in the product. The venting provides us the advantage of reducing incomplete filling of the mould, burning spots, corrosion of mould cavity, improve mechanical properties and remove visible weld lines in the product. (Michael Menges, 2001)

3.2.4 EJECTION SYSTEM

3.2.4.1 EJECTOR PIN AND SLEEVE

Ejector pins are the parts of the mould that ejects the product out of the core plate after injection is complete and the cooling of the melt has been finished. The ejector plates that lie on the movable part of the mould support these pins. The ejector pins are in the 3 cylindrical holes in the Lego brick. When the plastic is injected and cooled, an outer layer of the pin called helps the product to come out of the core after injection is complete. The movement of the ejector pins is adjusted accordingly, so that when the injection is finished and cooled off, it projects itself and removes the part from the core.

3.2.4.2 EJECTION OF RUNNER BY SPRUE PULLER

The runner is the part, which comes as a by-product and is of no use for the product. The runner has to be removed manually by hands in order to get the product. But in this design, there is a puller that pulls out the runner and the gate. When the plastic is injected and cooled, the plastic shrinks. So, it gets attached to the core. Then when the mould opens, the plastic gets attached to the core and the runner and the product are separated. The product is then pushed out of the core but the runner is still in the cavity plate. So, there is a sprue puller in the core, which pulls the runner and the materials that are left in the sprue. This way all the plastic that are cooled are out of the mould making it ready for 2nd batch.

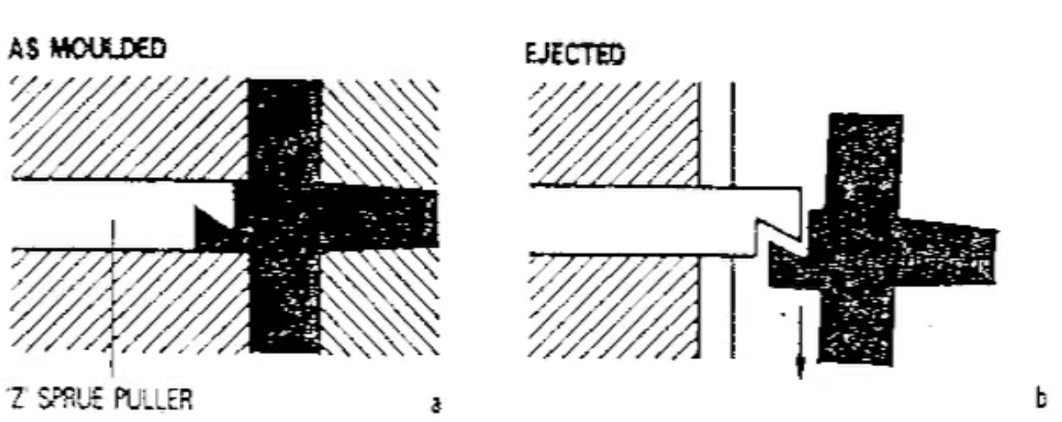
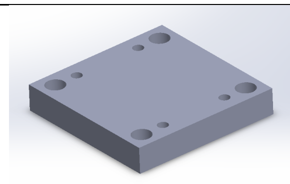
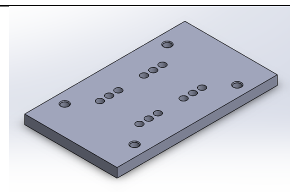
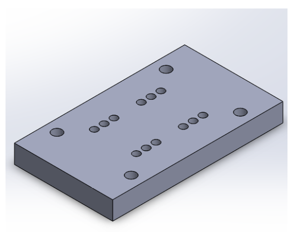
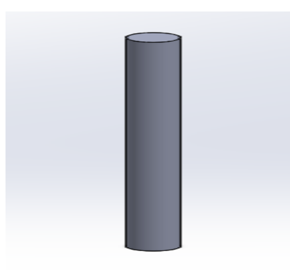
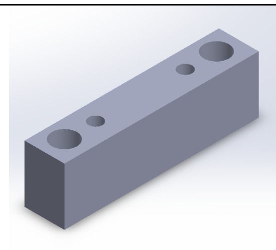
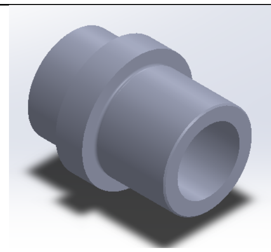
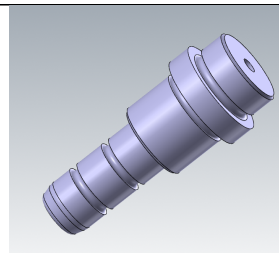
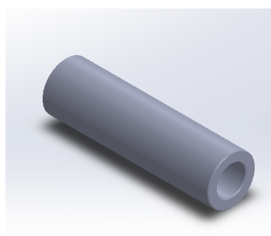
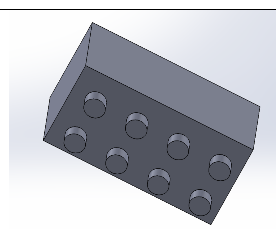
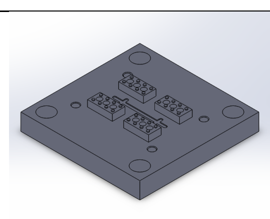


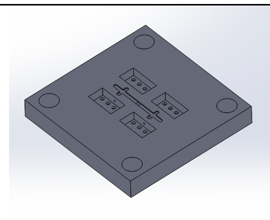
Figure 13: Ejection of the sprue (WWU Engineering and Design, 2015)

The above mentioned parts of the mould are shown below in the table 1. Some of them are downloaded from dmeeu.com and some are designed according to the need of the product Lego brick. (Dmeeu, 2016)

Table1. Parts of mould

PART	PICTURE	SIZE (mm)	NUMBERS
Front clamping plate		156*156 (Downloaded)	1
Ejector Plate and ejector retainer plate	 	156*90 156*90 (Downloaded and modified)	1+1
Ejector pins		5mm diameter 76mm (Designed)	12

Support block		156*32 (downloaded)	2
Guide pin sleeve		20mm diameter (Downloaded)	4
Guide pin and locating sleeve	 	20mm diameter (Downloaded)	4
Product		34.20*18.20*10.80 (Designed)	4 per injection
Mould Core plate Cavity plate		156*156*22 (Designed)	1+1

3.2.5 **ASSEMBLING THE MOULD**

After all these parts of the mould are designed, the next step is to assemble the mould. The assembling of the mould is done in SolidWorks assembly. All the parts are imported from SolidWorks part file and assembled in the assembly file. First part is imported and acts as a fixed part to which other parts are attached. All the parts are attached with each other using mate feature, move feature or rotate feature.

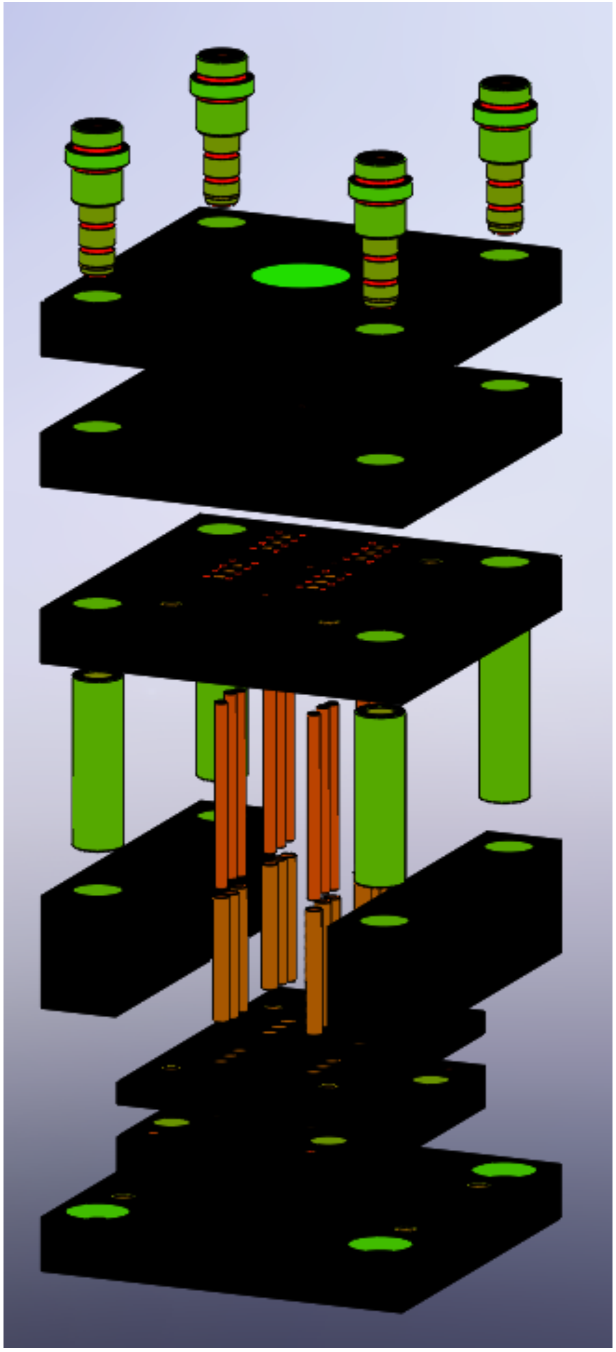


Figure 14: Assembling all the parts to form a complete mould

3.2.6 **MOULD DESIGN USING MOULD TOOLS:**

Above-mentioned process is a regular way of making the mould for any product but there are mould tools, which help to create a mould for a product without having to design the entire mould core and cavity.

Mould tools are the features that are used for creating cavity and core of the product made. These tools do not only creates the core and cavity but also helps in analyzing and modifying the product. Using mould tools also we can make the core and cavity. It is easier to make and is industrial way of making the mould for any product.

The mould tool includes 3 parts i.e. modify, analyze and creating mould. They are described below.

Figure 15: Mould tools

3.2.6.1 **MODIFY**

 **Planar surface**

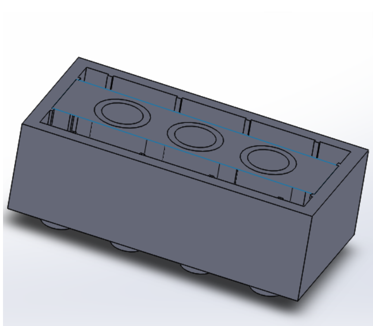


Figure 16: Planar surface

Planar surface creates a 2 dimensional thin plane on the surface required. Chose two surfaces to be joined. Then the planar surface creates a new face joining them.

 **Offset surface**

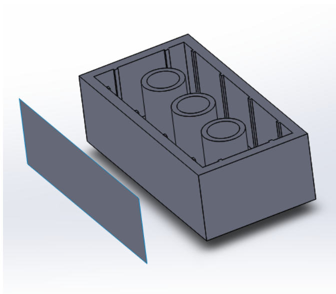
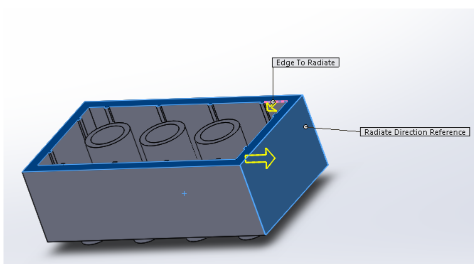


Figure 17: Offset surface

It creates an offset or copies the surface to a distance. Chose one surface to be offset. Then decide the distance and direction to which the offset is needed. Hence an offset is created.

**Radiate surface**



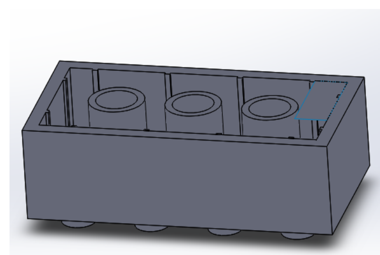
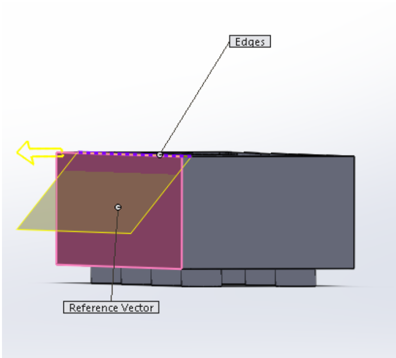


Figure 18a: Chose surface to radiate *Figure 18b. Radiating surface*

It extends the surface or plane as needed. Chose a surface such as the round surface in the picture. Then decide how much it needs to be radiated.

**Ruled surface**



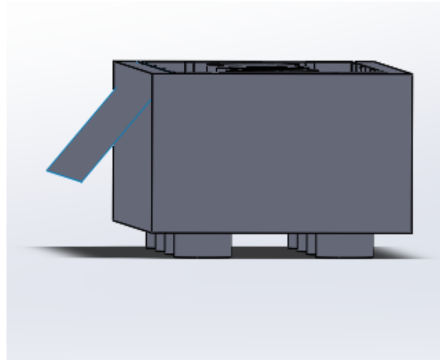
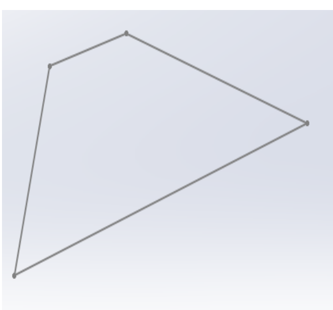
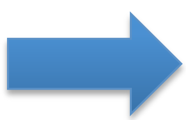


Figure 19a: Ruled surface *Figure 19b: Ruled surface*

It creates a similar surface but in any angle as desired. Chose a surface to be projected and an angle. Then the required surface will be created.

**Filled surface**





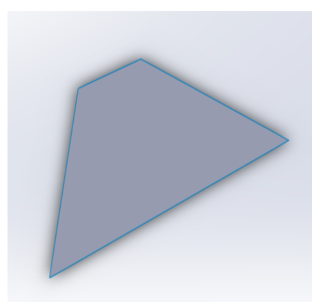


Figure 20a: Make a closed loop *Figure 20b: Filled surface*

This feature fills up the space between bounded areas. Make a sketch with bounded surface or a surface with no open points. Then this feature creates a surface in the area.

**Knit surface**

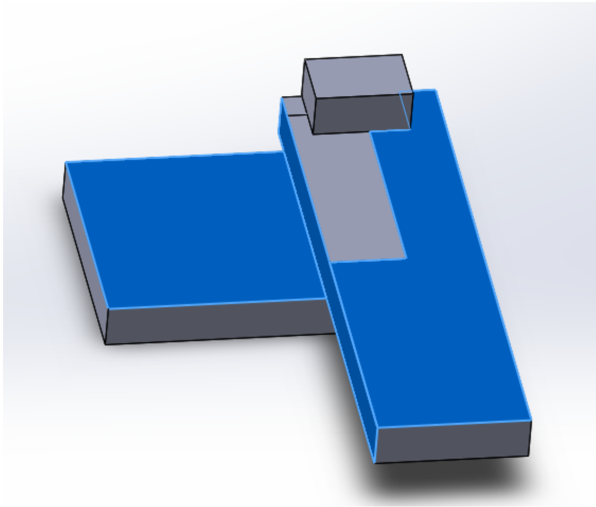


Figure 21: Knit surface

It combines two or more adjacent non-intersecting surfaces together. Chose 2 surfaces that are not intersecting. Then the knit surface feature joins those surfaces to make it one.

3.2.6.2 **ANALYSIS**

Draft analysis

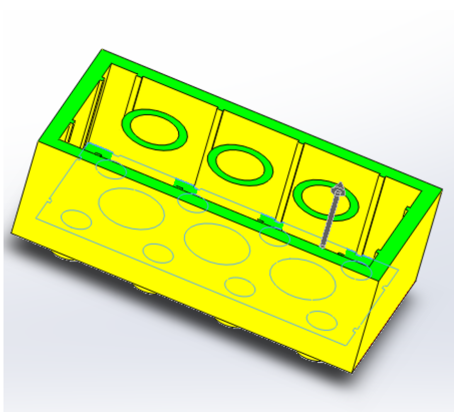


Figure 22a: Draft analysis

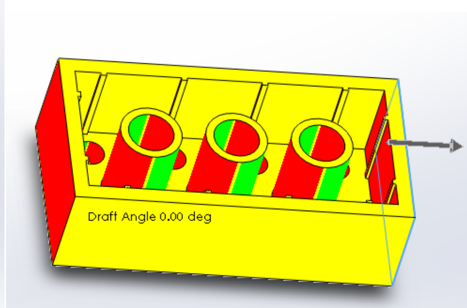


Figure 22b: Negative draft

Table 2: Draft colours

	Positive draft
	Requires draft

	Negative draft

It analyses draft angle of faces based on the mould pull direction. It allows us to know what kind of draft is needed in the part.

Undercut analysis

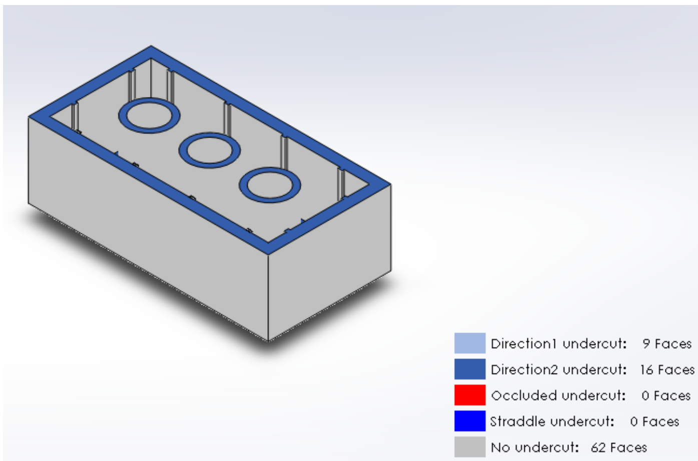


Figure 23: Undercut analysis

Undercut analysis identifies the faces that forms undercuts in the part. It works on the direction of pull. When the pull direction is specified it shows the undercuts and for those undercuts we can decide if we need an extra core for the mould.

Parting line analysis

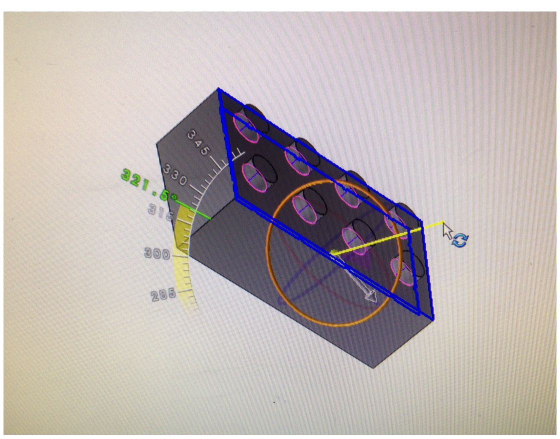


Figure 24: Parting line analysis

Parting line analysis allows us to see where the parting line fits the best for the mould according to the direction of the pull.

Split line

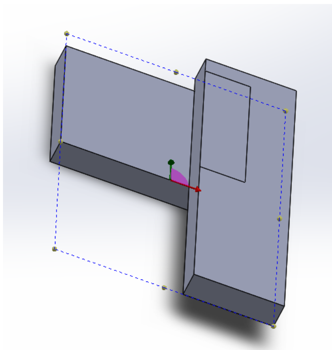
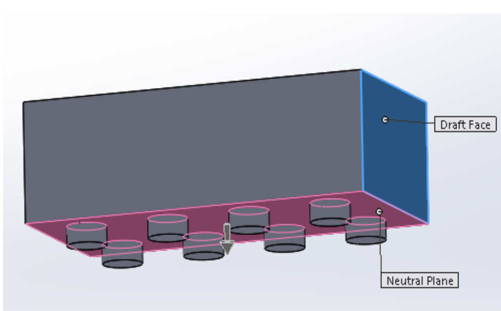


Figure 25: Split line

It projects a sketch to curved or planar faces and creates multiple separate faces. In the picture, the sketch from the lower surface is seen on the upper body because the feature projected the sketch onto the upper body.

Draft



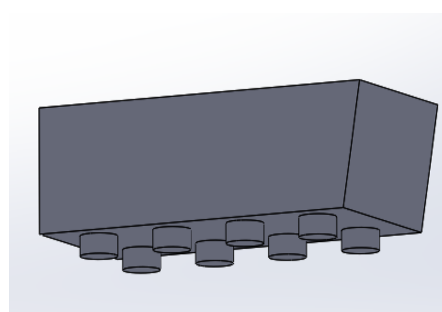


Figure 26a: Draft

Figure 26b: Draft

Draft can be created on the basis of neutral plane, parting line or step draft, by using these features the draft feature tapers the mould at a specified angle.

 **Move face**

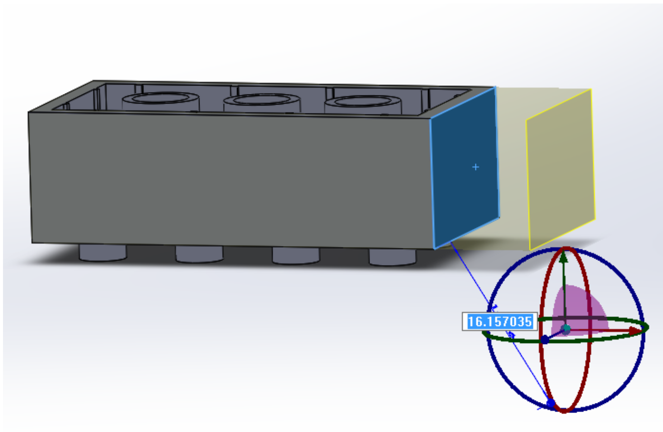
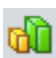


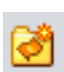
Figure 27: Move face

This feature moves/copies the faces at different angles as desired from a specified point.

 **Scale**

Scale can make the product either larger or smaller in a ratio. This feature lets the product or a face to be increased or decreased in a specified scale factor. It changes the size but does not change the dimensions of the part. But when dealing with non-uniform scaling features like cylinders may change the dimensions and even the shape.

3.2.6.3 MOULD CREATING TOOLS

 **Insert mould folders**

It creates 3 surface bodies folder for the mould i.e. core, cavity and parting surface body. These 3 surfaces are the base of creating the mould.

 **Parting lines**

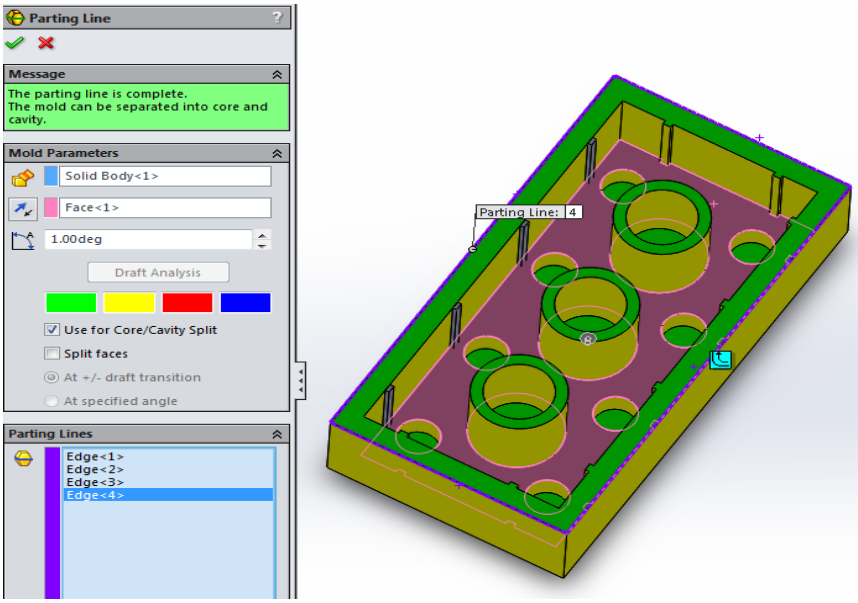


Figure 28: Parting lines

Parting line is a line that separates the core and the cavity. There can be multiple parting lines. This feature creates a parting line. The blue line in the picture is parting line.

 **Shut-off surfaces**

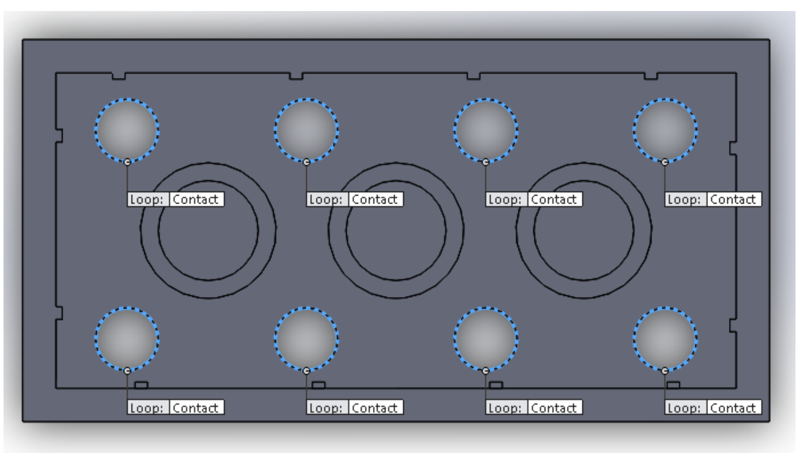


Figure 29: Shut off surface

Shut off surface helps in covering the holes in the product in order to create a continuous parting line for the mould. In this case parting line is already complete so, there is no need of making shut off surfaces.

**Parting surfaces**

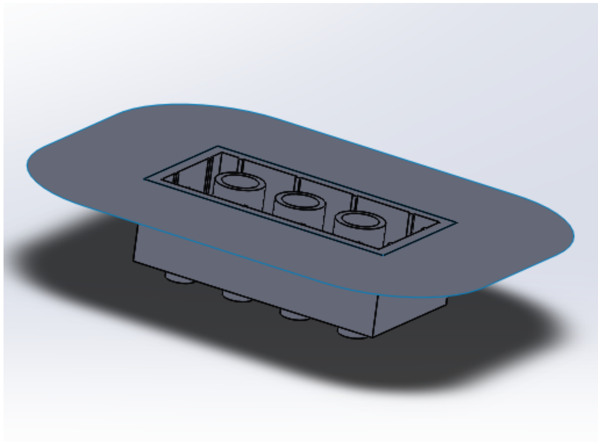


Figure 30: Parting surfaces

This feature creates surface that separates the core and cavity according to the parting line. Parting surface separates the core from cavity. The parting surface always should be larger than the core and cavity plate.

**Tooling split**

This tool creates core and cavity from the product. This feature can be used if the parting line, parting surface are all properly executed. From the parting line the core and cavity is separated.

To create a tooling split for any product, there has to be 3 surface bodies, they are: Core surface, Cavity surface and parting surface. The shut off surface is also to be taken in consideration before using tooling split. Shut off surface covers up any open loop in the product and creates a complete parting surface for the product. Then, tooling split is used. This tooling split creates core and cavity according to the parting line and parting surface.

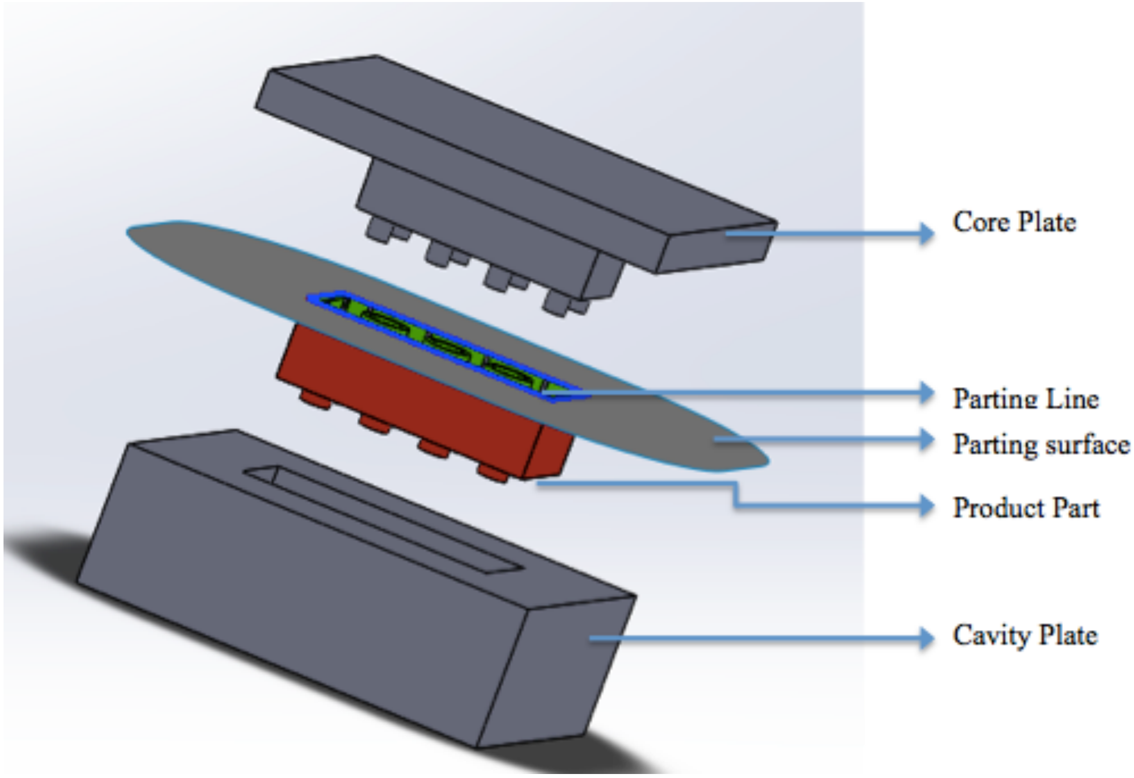


Figure 31a: Tooling split exploded view

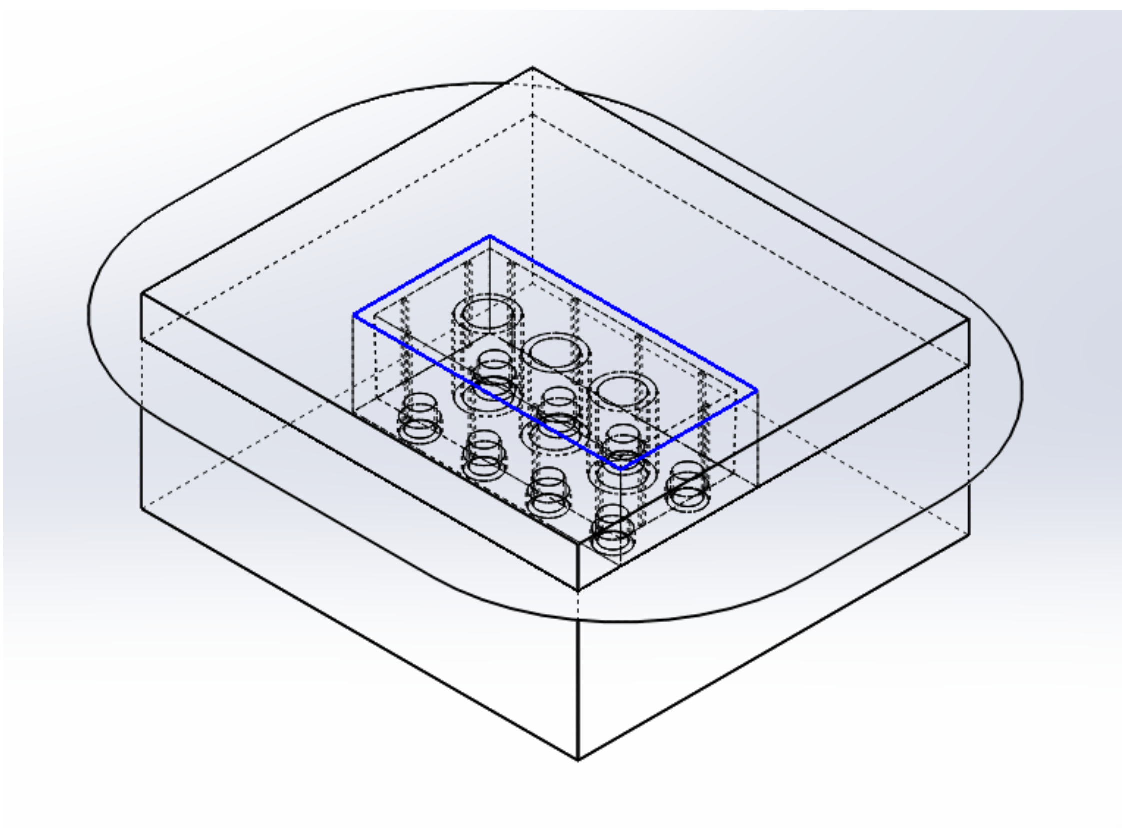
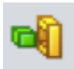


Figure 31b: Tooling split and making the core and cavity

 **Core**

Core as suggested by the name creates a core. This feature is used to make a side core or an undercut core. For example, if there an undercut in the part that cannot be made in the main core then this feature allows us to create that feature by creating a secondary core for the undercut.

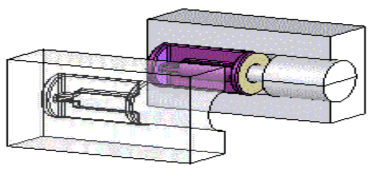
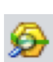
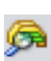
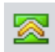


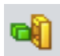
Figure 32: Extra core add in (Prolabs Inc)

In this thesis the following tools are used to make the mould for Lego brick.

1. Create a product i.e. Lego brick.
2. Use draft feature to create a small draft in the inner walls of the Lego.
3. Chose a parting line to separate mould core (1^{st} surface body) and cavity (2^{nd} surface body)
4. Perform parting line analysis to check if the parting line chosen is suitable to create the mould.
5. After choosing a parting line perform an undercut analysis to check if the mould has any undercuts that need an extra core.
6. Use shut off surface feature to close any cut through loops in the product.

7. Using the parting line create a parting surface (3rd surface body)

8. Use tooling split feature to create the mould core and cavity. It creates the core and cavity plates according to the sketch to be drawn in the tooling split feature.

9. Use core feature if there is an undercut in the product and needs an extra core. The core feature creates core according to the sketch to be drawn in the core feature.

10. Use exploded view in SolidWorks to see the core, product and cavity separately in a linear sequence. (Search “exploded view” in the search tab)

After the above process, the mould produced is shown below.

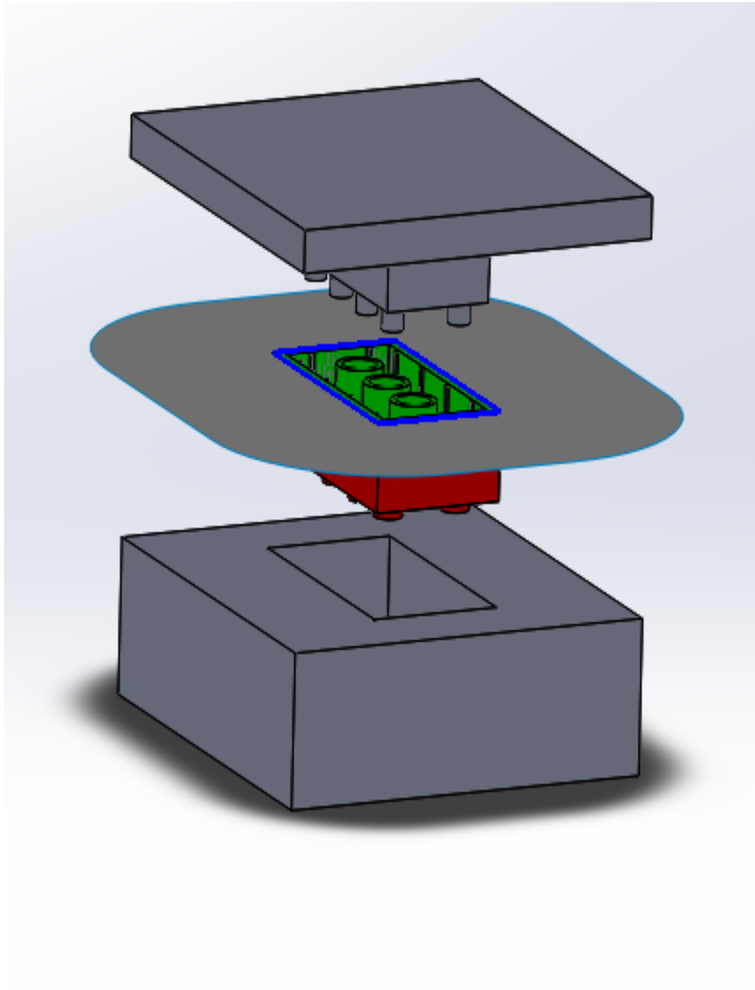


Figure 33: Exploded view of mould

3.3 MASTERCAM SIMULATION

Mastercam simulation is done to produce the product. It produces G- codes that give CNC machine information on how to make the product. Mastercam simulation of core and cavity was done. Other parts of the mould can be found readymade. The ejector pins can be ordered according to the diameter and length needed for the part. The support blocks, back plate and ejector plates can also be downloaded but ejector plates have to be modified according to what kind of ejection procedure will be executed and how many ejector pins are needed. The front plate is made according to the sprue in the injection-moulding machine. The core and cavity are milled, drilled and when they are ready, the cavity plate is subjected to the EDM machine. This way we can obtain the sharp corner of the Lego bricks, as it should be. The sharp edges are impossible to get after milling process since the tool are round in shape but if it is processed by EDM then the cavity can have the exact shape as needed.

In mastercam to use any toolpath following criteria are to be considered and filled up carefully in order to get a clear path for the tool to follow. They are tools, cutting parameters and linking parameters. In toolpath type we specify the kind of tool we will use. In cutting parameter we specify how we can use the toolpath to get the required shape. Then in linking parameters we specify clearance, retract and depth of the cut in the stock.

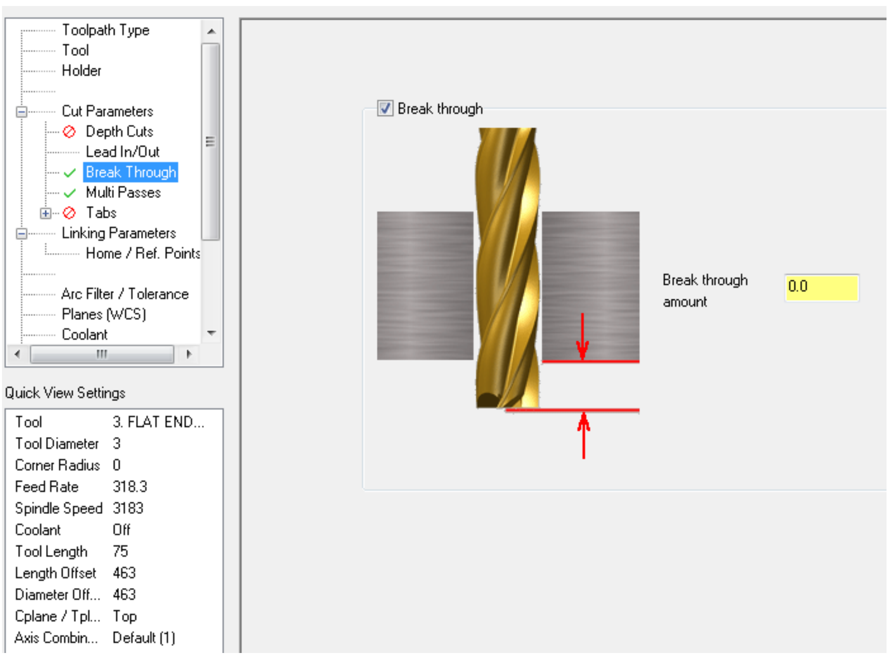


Figure 34: Cutting parameters

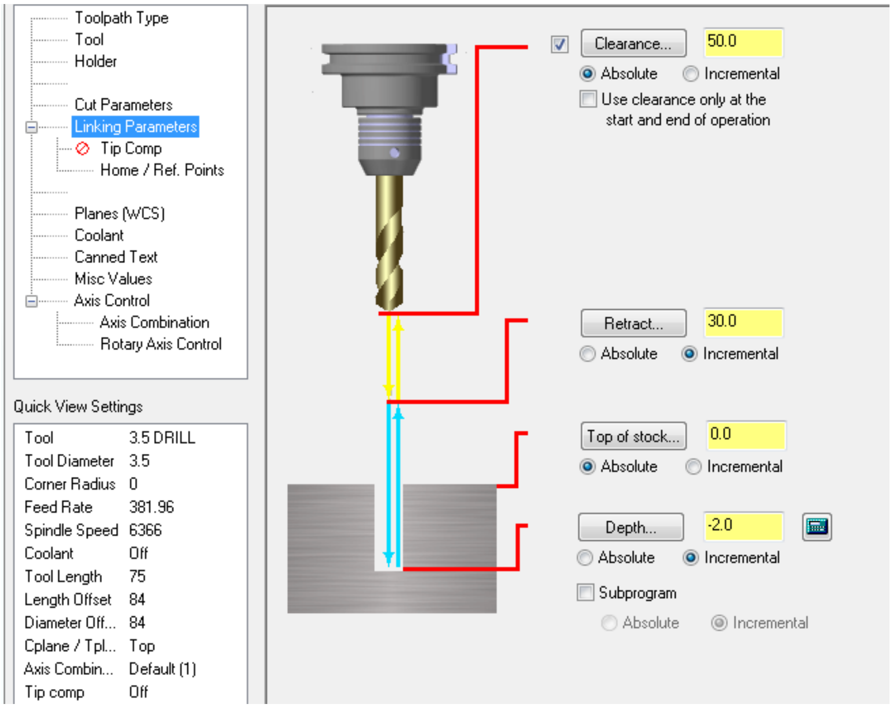


Figure 35: Linking parameters

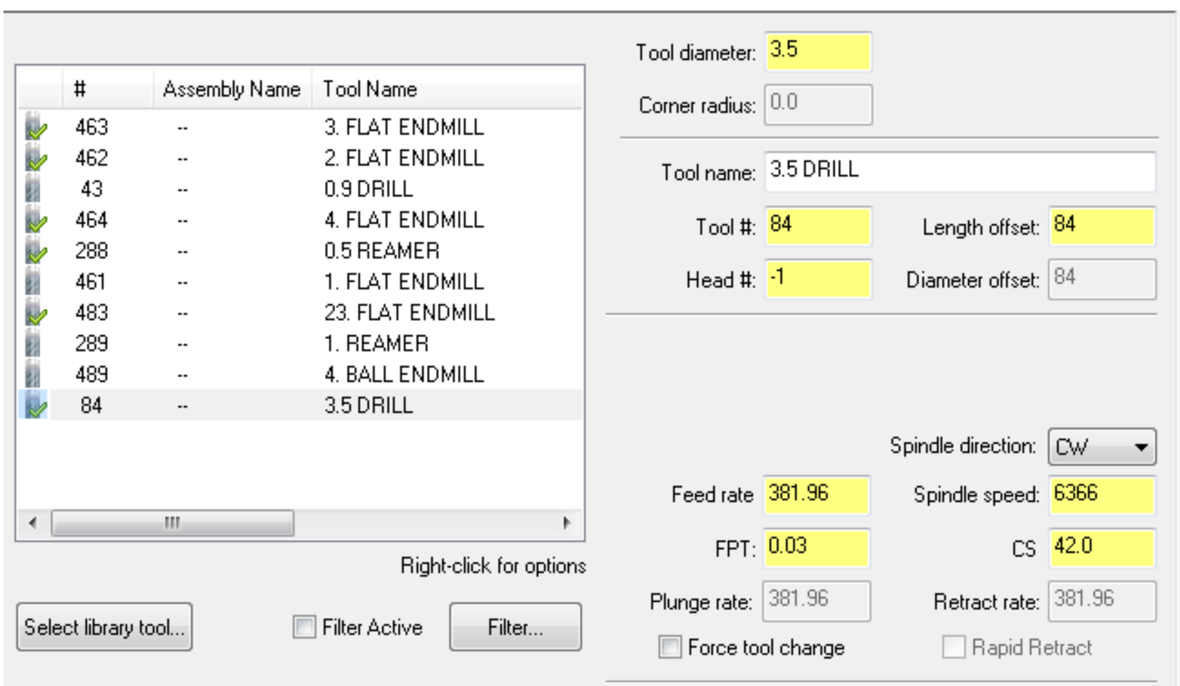


Figure 36: Choosing tool

To do the simulation of core in Mastercam, first the stock is (156*156*31.6) mm. This is because the core has to be milled and the 9.6mm height from other surfaces is removed from the stock. The small protrusions that are inside of the Lego bricks are not possible to make in mastercam. So a straight smooth core was milled. The protrusions later can be made after removing those parts from the core using electric discharge machine. The guide pinholes were first center drilled to mark the center of the circle and then drilled by a smaller diameter drill. A smaller diameter drill was used first so that the inner surface has a bit more material left. This left material was then removed by using a reamer. A reamer is a small diameter mill it removes the material smoothly and gives the surface a smooth finish. The 3 holes for the cylinders of the product are also first drilled by smaller diameter drill and then with a reamer rest of the material was removed. Milling the outer material makes the four blocks of the product. The milling starts from the outer edges of the plate and gradually is milled inside with the help of directing lines. Figure 29 and 30 shows the mastercam simulation of the core and cavity. The tools and sequence of use of tools can be changed as per the requirement of the machine that will later on use this data to manufacture the plates.

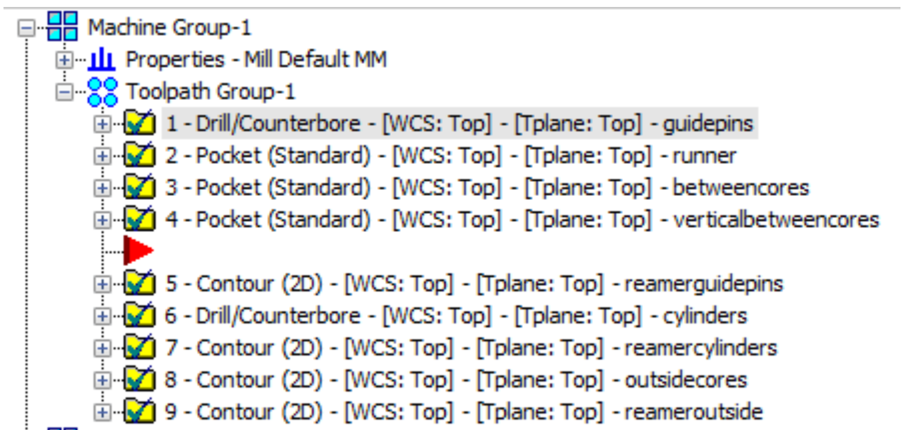


Figure 37: Toolpath for core used in mastercam

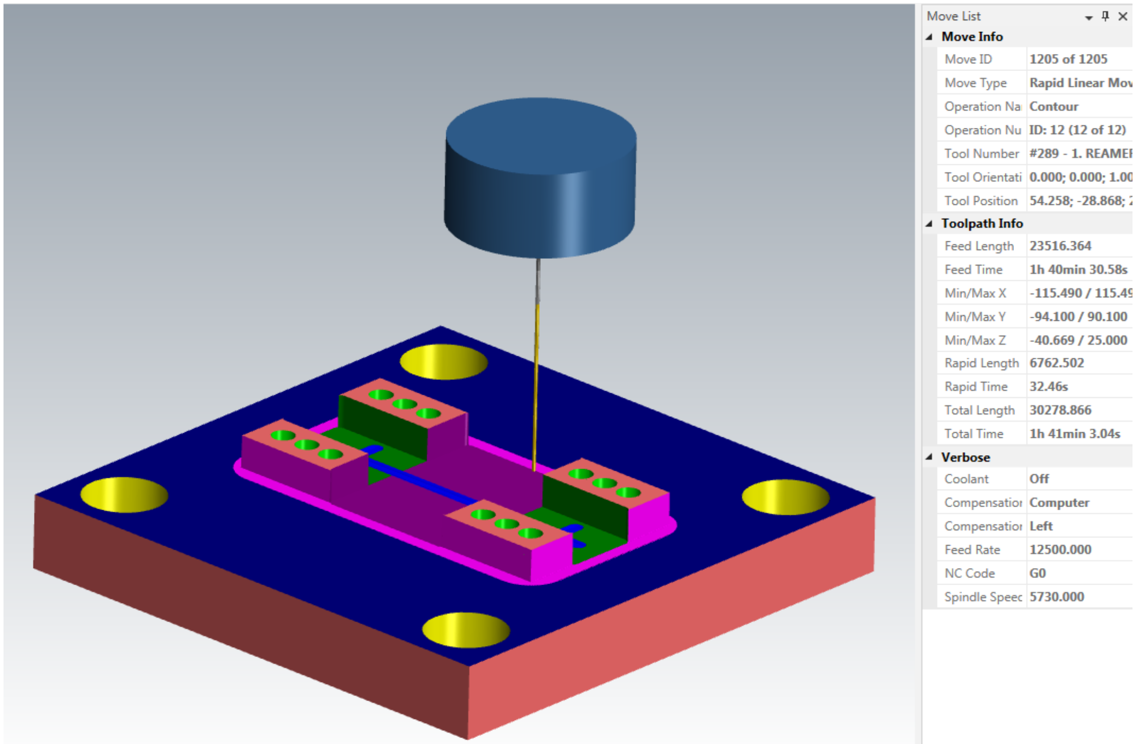


Figure 38: Mastercam simulation of core

The cavity part consists of 4 Lego cavities, a runner, 4 gates, 32 studs and 4 guide pinholes. The studs and the guide pin holes were center drilled to mark the center of the circles. Then a smaller diameter drill was used in order to make the hole. Then a reamer was used to smoothen the inner surface of both the studs and the guide pinholes. The runner and the cavity of the part were pocket milled. The type of tool used in this process is tapered. A tapered mill is used in this process because in cavity a straight wall is not preferred, as the product tends to stick to the walls of the cavity after injection. So, for better release of the product, the walls have to have a draft. Draft can be according to the product but in this case there cannot be a draft. The cavity of the part has sharp corners since the Lego blocks are sharp cornered but by milling, the part cannot have sharp edges after this process. The edges and corners are always round in shape if it is milled. So, a new process is introduced to make the edges sharp and straight 90 degrees angle walls as needed in the Lego bricks.

Figure 39: Toolpath for cavity used in mastercam

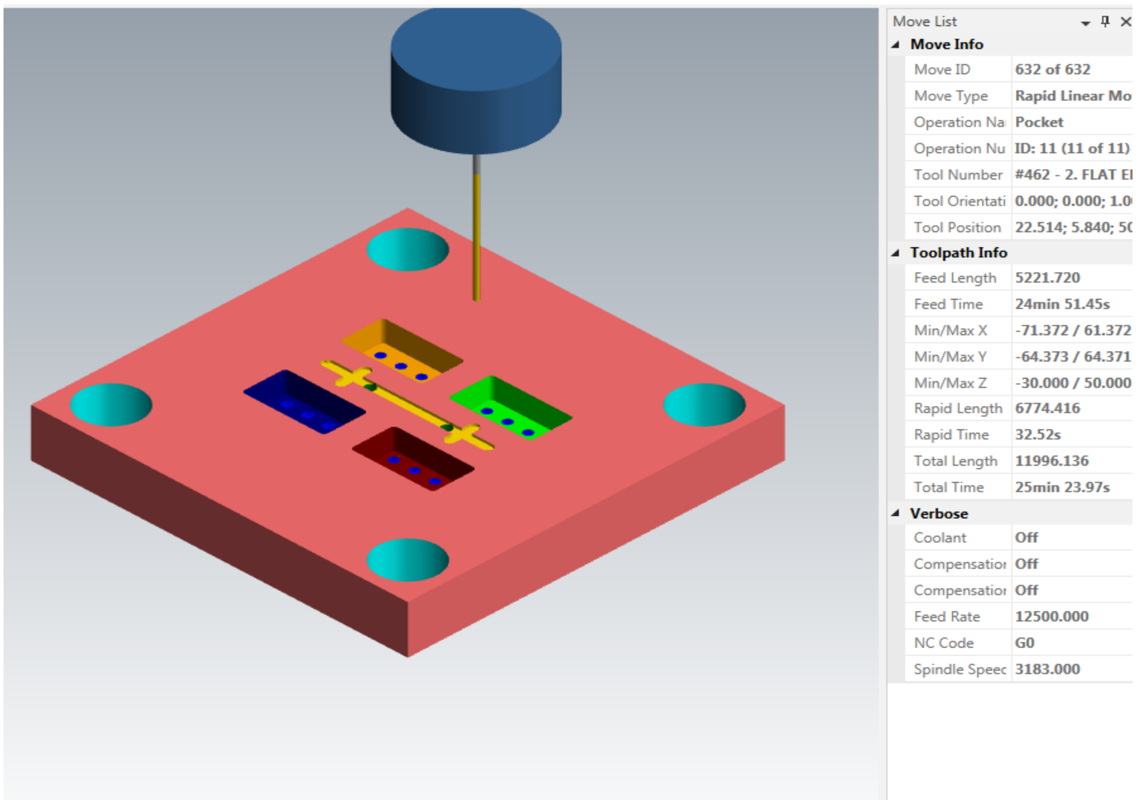


Figure 40: Mastercam simulation of cavity

3.4 ELECTRIC DISCHARGE MACHINING

After the Mastercam simulation is done. The core and cavity is produced in the CNC milling machine. The CNC milling machine receives the G-codes from the Mastercam software and then it starts to produce the plates.

The core plate, runners and the guide pinholes can be made from the CNC milling machine but the cavity is not possible to produce from the milling machine. The milling machine is not able to make sharp corners and 90 degrees angle straight. So, there has to be another solution. The solution for this problem is electric discharge machine. Electric discharge machine takes DC current to produce difference in charge between the electrode and the stock piece that is submerged in a dielectric liquid. The difference in charge creates a field and erodes away the material from the stock piece. This way the electrode makes the exact impression on the stock. This process is not executed in this thesis but after milling process, this is the final procedure to follow in order to get the required shape of the product.

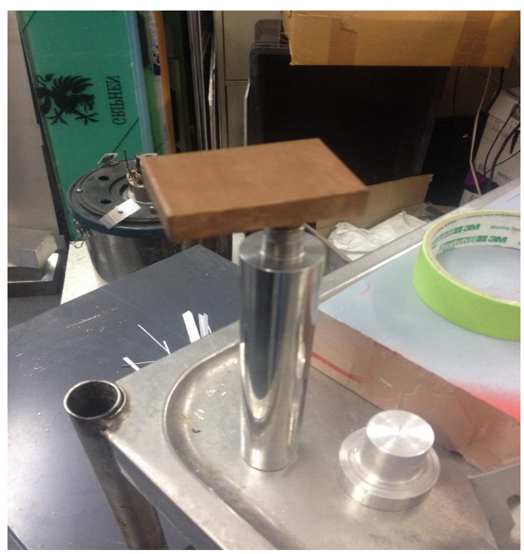


Figure 41a: EDM *Figure 41b:EDM electrode tool (Arcada Laboratory)*

4 RESULTS

4.1 CORE AND CAVITY IN SOLIDWORKS

The core plate is (156*156) mm^2 in size. It consists of 4-lego-block core. While making the core, the each core should be the width less than the cavity. So, the core is 1.6 mm less in all sides than the cavity. Each Lego core consists of 3 holes that go through the plate. These holes later on form the back cylindrical structure of the Lego block. On the sides there are 12 small cavities. These are for the protrusion grip that can be found on the back of a Lego block. They are 11.3 mm apart from the centerline. The core consists of 4 guide pinholes on all the four corners of the plate. The core plate also consists of the runner. This runner does not contain outlet or gates but it is the other half part of the runner. The runner in the injection moulding system is usually rounded shape.

The cavity of the mould consists of 4 cavity parts of the Lego blocks. These have 8 studs each which forms the upper part of the product. The plastic melt is inserted in the mould through the sprue bush that goes directly to the middle of the cavity and is supplied to all the cavities through the runner gates. The runners in the cavity are conical and are in the middle of the cavity. Through these runners the plastic melt passes and fills up the cavity. After the separation of the core and cavity the sprue puller pulls the plastic melt that is cooled in the runner and the sprue. The cavity plate also contains 4 guide pinholes on all the four corners. In addition the cavity plate consists of cooling channel. The cooling channel sets the melt in the cavity. It helps in cooling off the melted plastic and shapes it as the cavity. Hence the product is formed.

This is a normal design what a person introducing to the mould designing would do at first. There is a better way to make the mould core and cavity. While making the core or cavity, the product does not have to be in the cavity plate. This means, a separate cavity and core can be produced and then attached to the cavity plate. The advantage of this is, if the separate part has any problems or any deformities, it can be replaced easily and the whole plate does not need to be changed. If the designing is done in a regular way like in the Figure27, the whole mould plate has to be changed if there are any problems in the part.

The product is (34.2* 18.2* 9.6) mm^3 and 1.6 mm thick. There are 8 studs on the front of the Lego and 3 tubes in the bottom. It has 4 and 2 protrusions on the length and breadth of the product. It helps to hold the Lego block together when they are stack on each other. There are 4 moulds in the mould plate. The moulds are 11.3 mm apart from the centerline. The injection point has a runner and there are 4 gates from where the melt enters the mould and fills up the cavity of all 4 moulds at once.

The product that is produced from this injection moulding process has round edges while the edges in the Lego bricks are always sharp. To make the edges sharp one extra machine has to be used in the process, i.e. electro discharge machine. This machine is used in the presence of oil to make the part perfectly sharp edged. Prototyping is a first draft version of any product to be made.

In this thesis 3D printing is used for prototyping of the product. 3D printing is one of the high fidelity prototyping process which allows us to look into the product and give a better vision about how the product can me made, what type of changes does it need and to describe the process in a better way. To look into the product in a better and more productive way, prototyping of the product is very essential part of manufacturing. With prototypes, it is easier to check the functionality and defaults and hence modify it for better result.

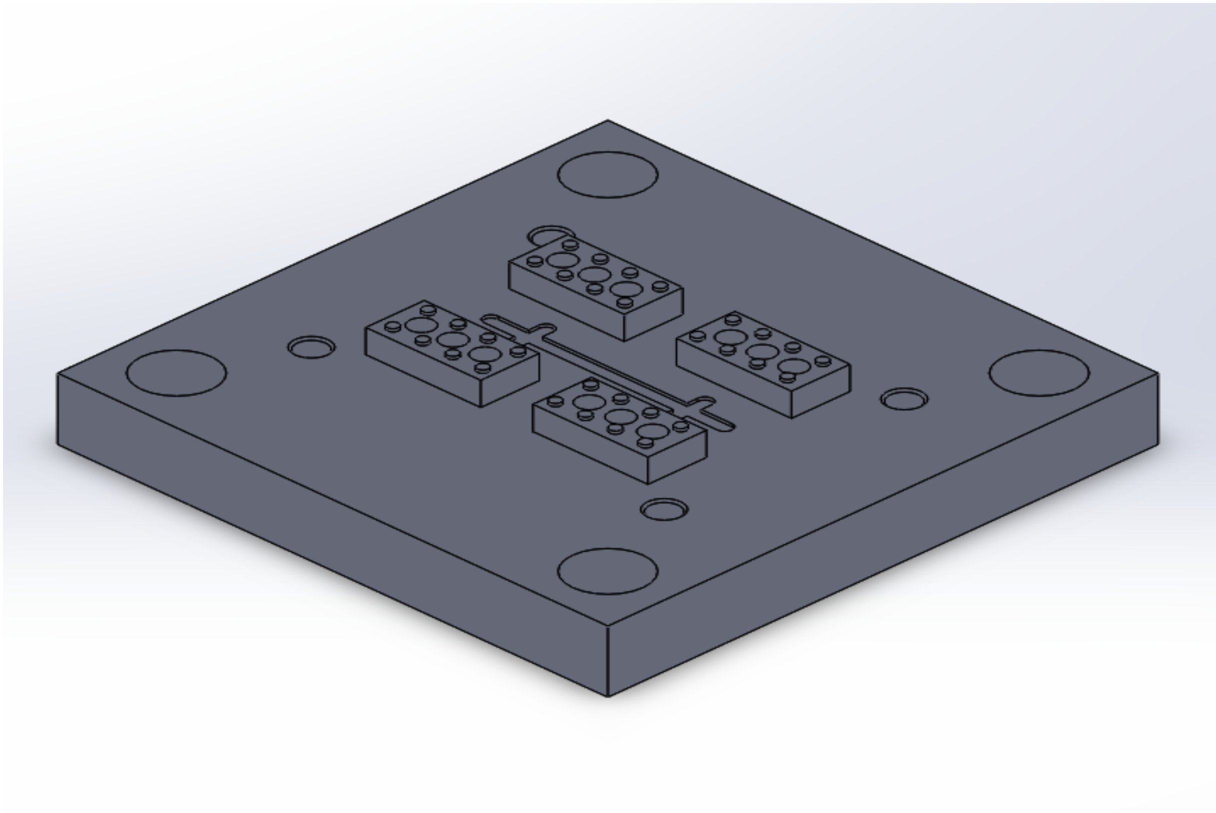


Figure 42: Core

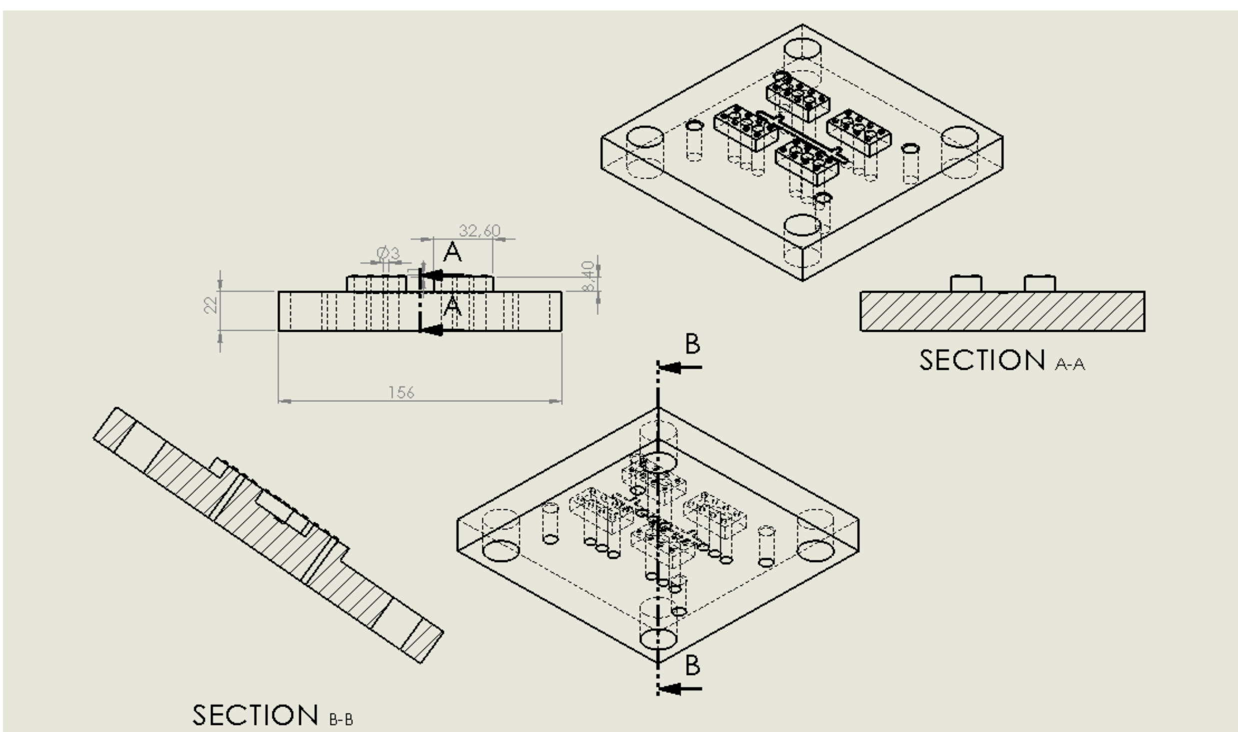


Figure 43: Draft of core

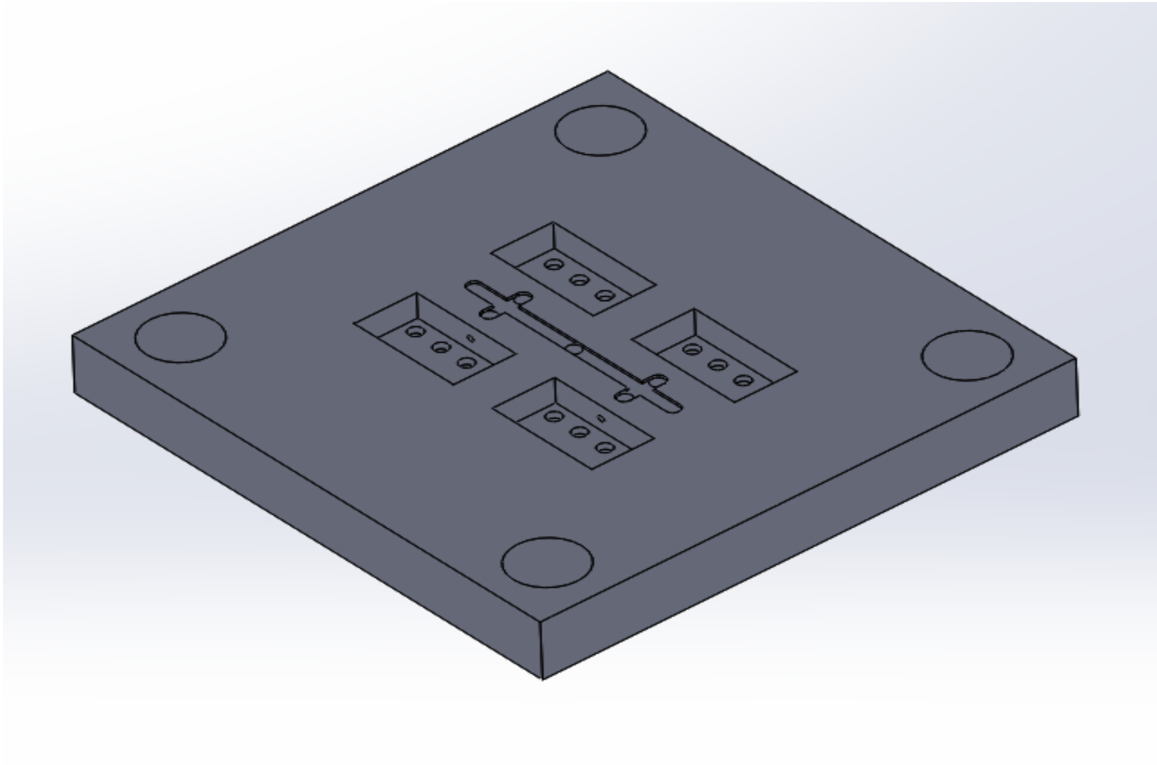


Figure 44: Cavity

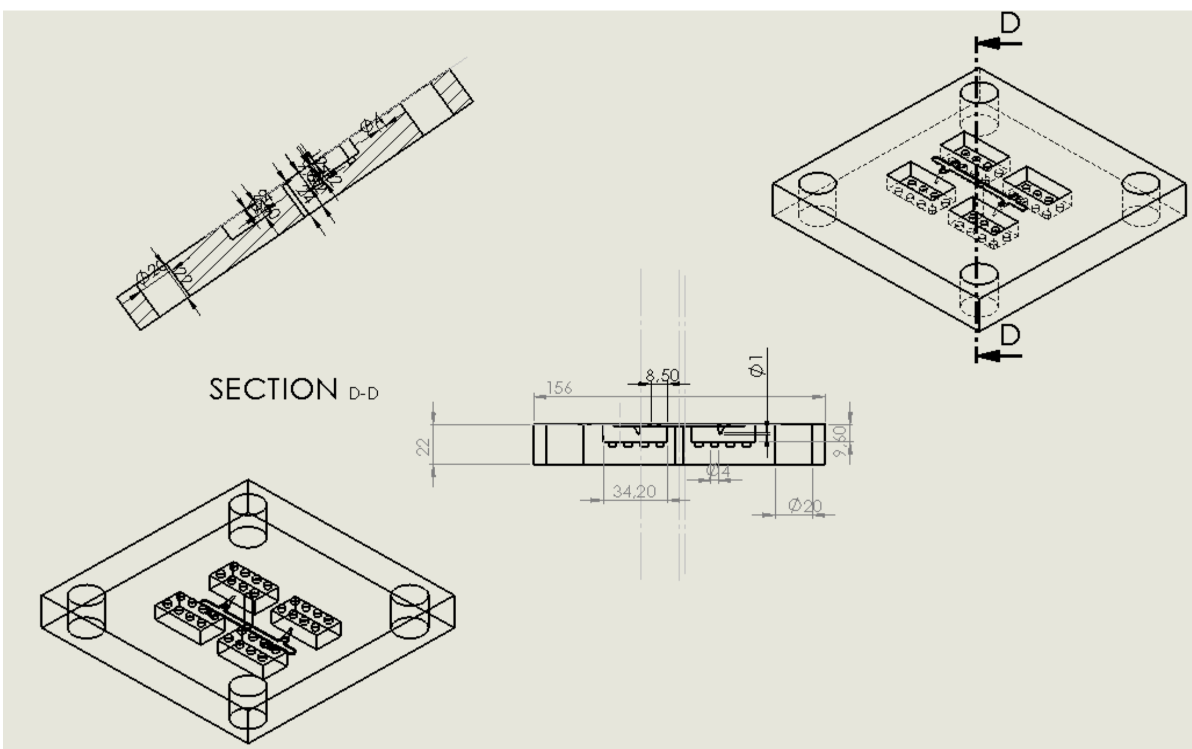
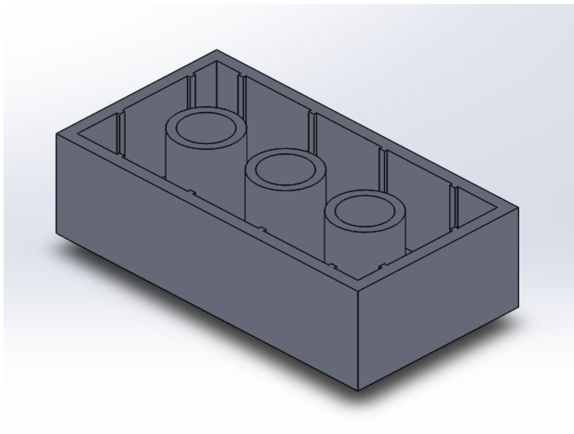


Figure 45: Draft of cavity



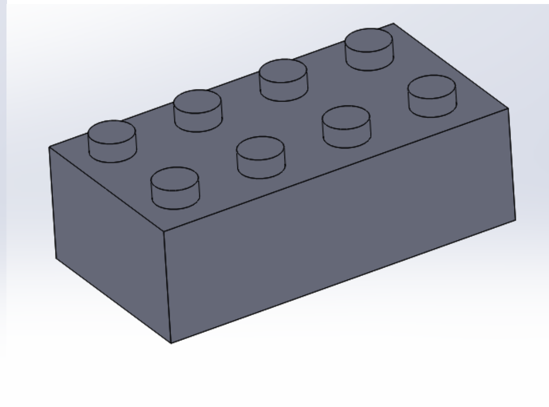


Figure 46a: Product back

Figure 46b: Product front

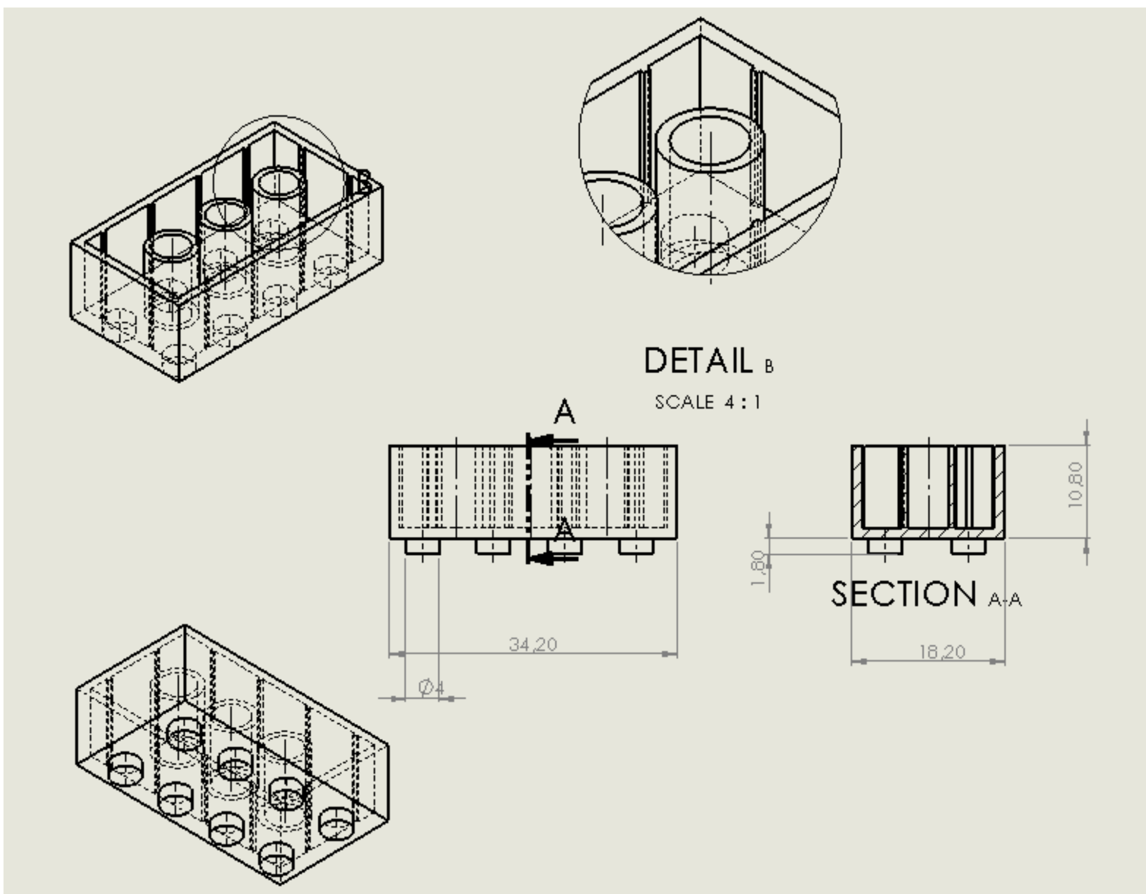


Figure 47: Draft view of product

4.2 **ALIGNMENT:**

The alignment of the mould is linear. The guide pins and the support blocks keeps the mould aligned in a linear manner. While designing the mould, the alignment of all the plates with the guide pins and ejector pins becomes tricky. Similarly moulds also can have interlocks. Interlocks are small guiding locks that assure the alignment of the mould and guiding the plates together. If all the parts and plates of the mould are aligned together in the draft view we can see fine and straight lines without overlapping each other.

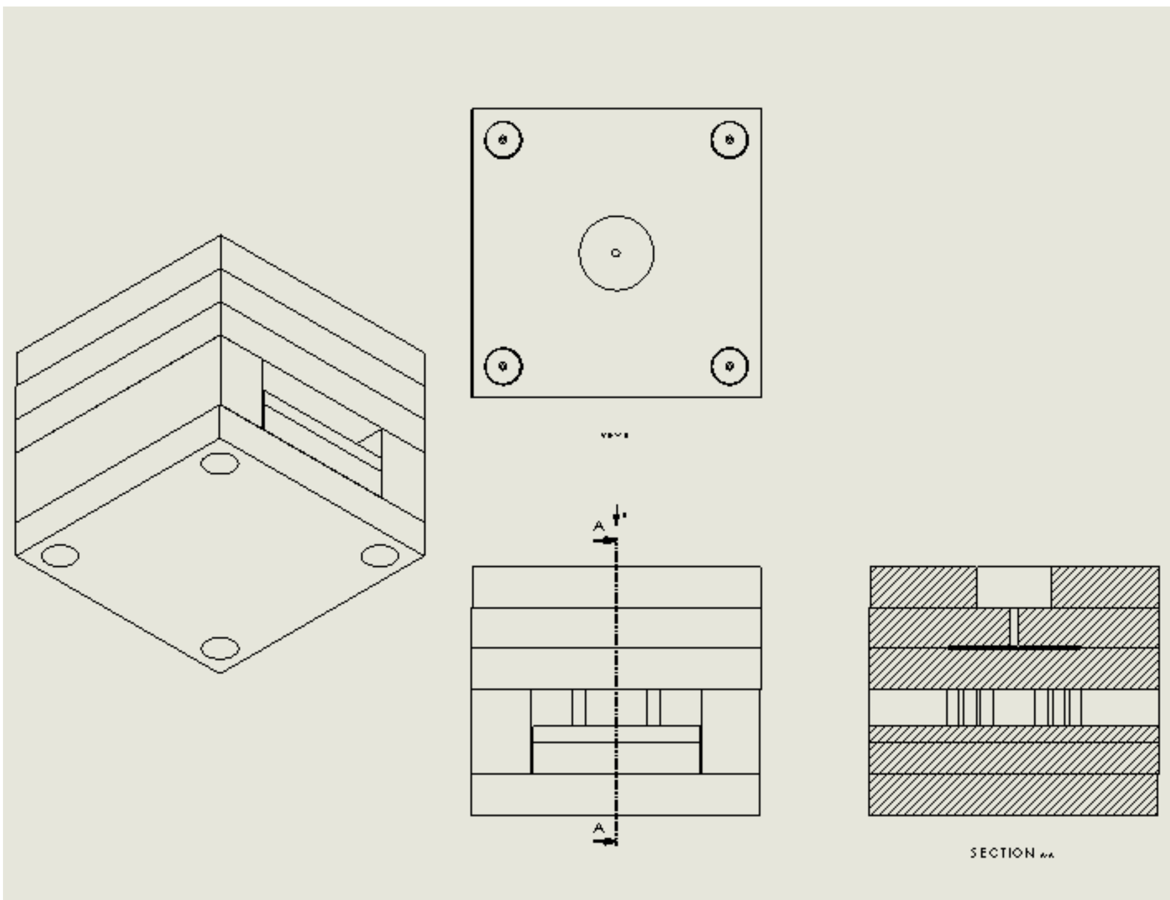


Figure 48: Draft view of assembly

4.3 **ASSEMBLING THE PARTS OF THE MOULD.**

All the plates are aligned in a linear manner with each other. At first, the back plate was taken, then according to it the support blocks, ejector plates and gradually the core cavity and top plates are added linearly. After doing this, the guide pins, locating sleeve and ejector pins are added. All the pins should go straight in the holes and are not supposed to be overlapping with any of the plates. This way, it is confirmed that all the parts are assembled correctly. In assembly, we use mate feature to join all the parts together. The parts can be moved and rotated according to the need of the assembly.

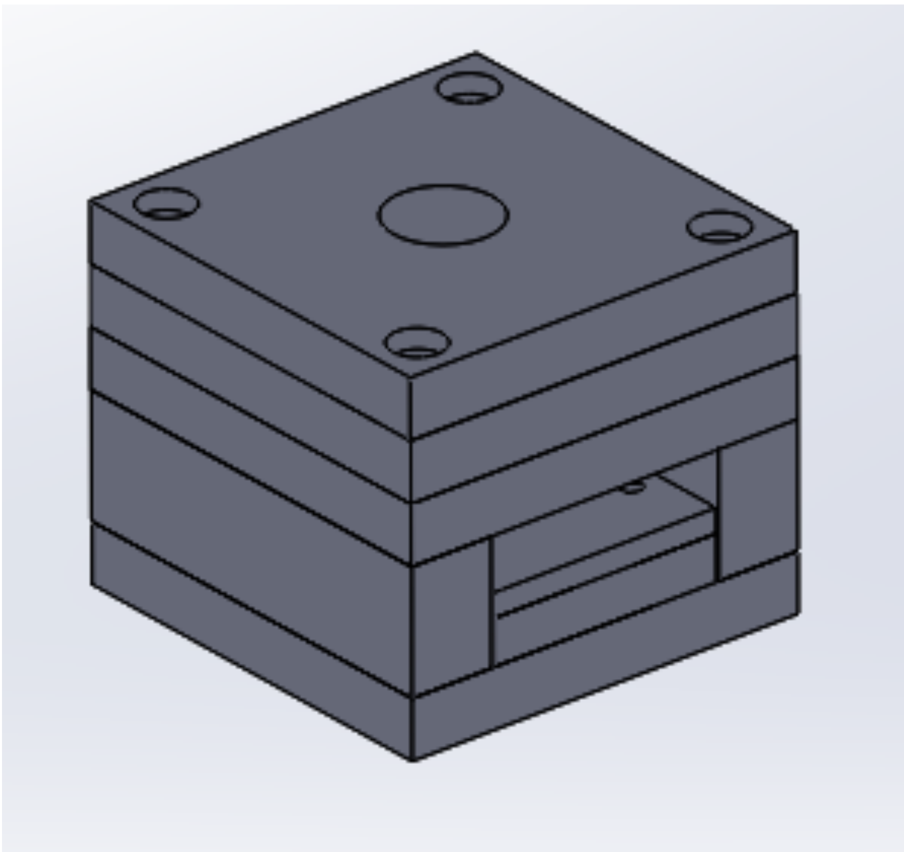


Figure 49: Assembly of the mould

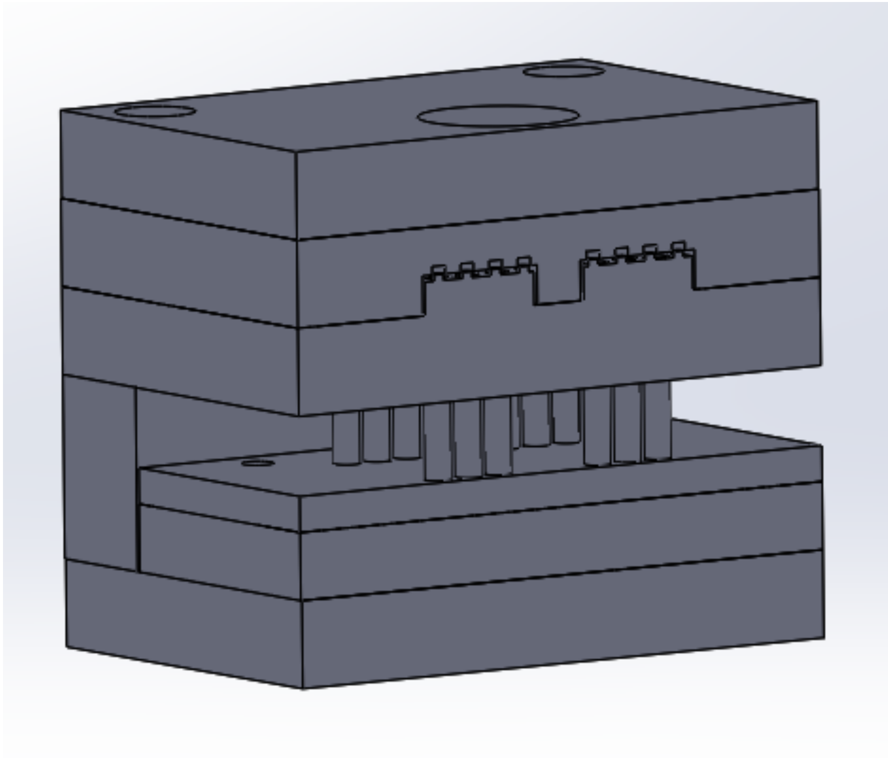


Figure 50: Section view of mould

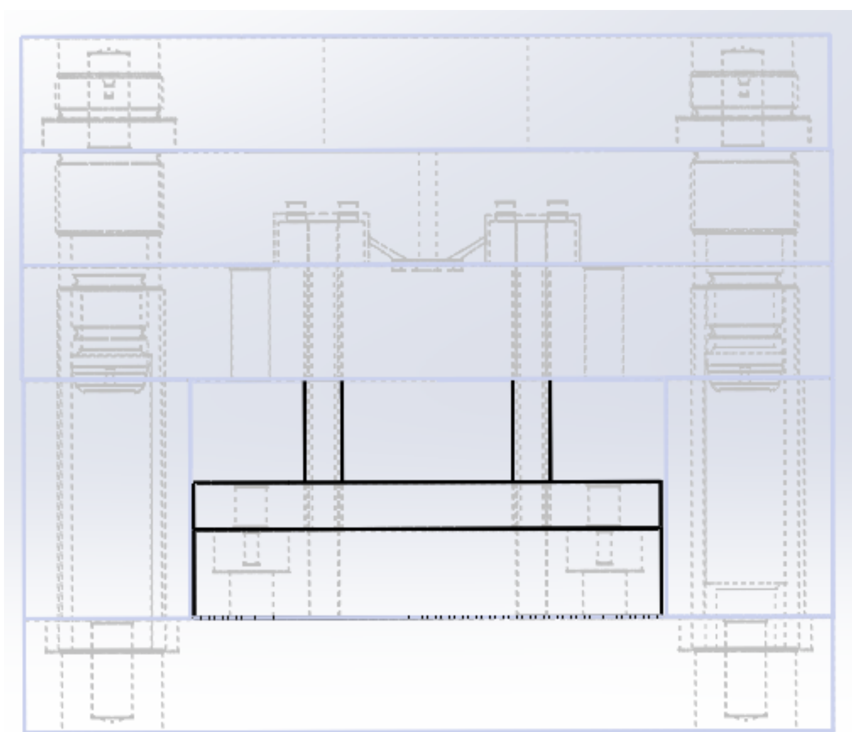


Figure 51a: Mould front view

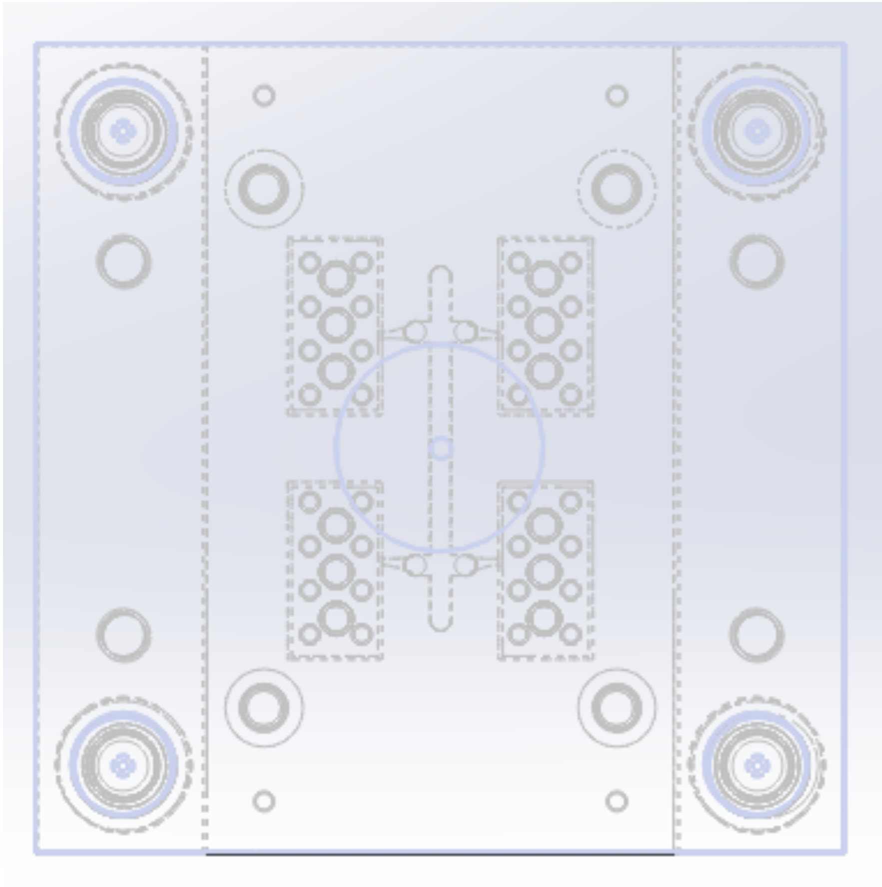
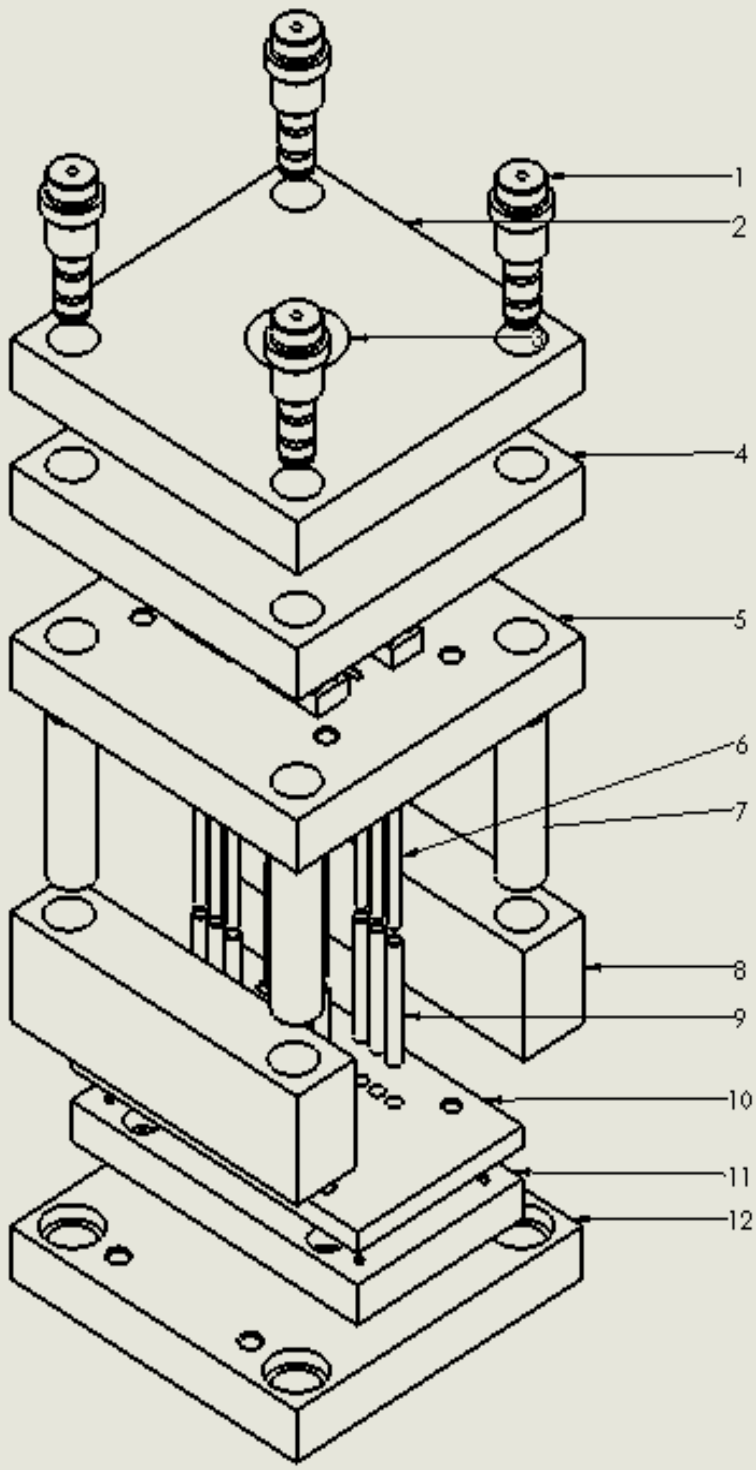


Figure 51b: Mould top view



Number	Part
1	Guide pins
2	Top Plate
3	Sprue bushing
4	Cavity Plate
5	Core Plate
6	Ejector pin
7	Locating pin
8	Support Block
9	Ejector Pin Sleeve
10	Ejector Plate
11	Ejection Retainer Plate
12	Back Plate

Figure 52: Exploded view of the mould

4.4 3D PRINTING CORE AND CAVITY

After designing and analyzing the mould, next step is to make a prototype of the mould. Prototyping helps in detail analyzation and knowing the strengths and weakness of the model. For prototyping 3D printer was chosen. 3D printer is easy and convenient for prototyping any product. The 3D printer in Arcada's laboratory is Makerbot and uses PLA plastic. The 3D Printing of the core and cavity was done.

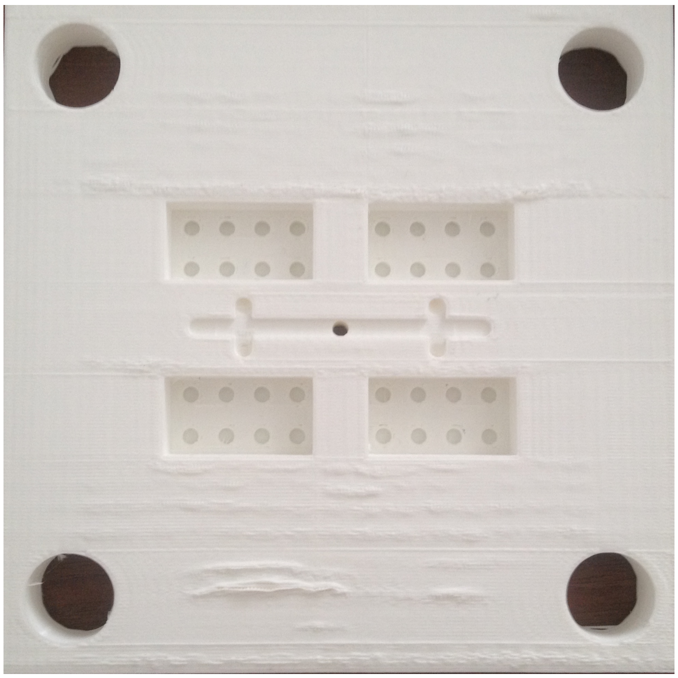


Figure 53: Prototype of the cavity of Lego bricks

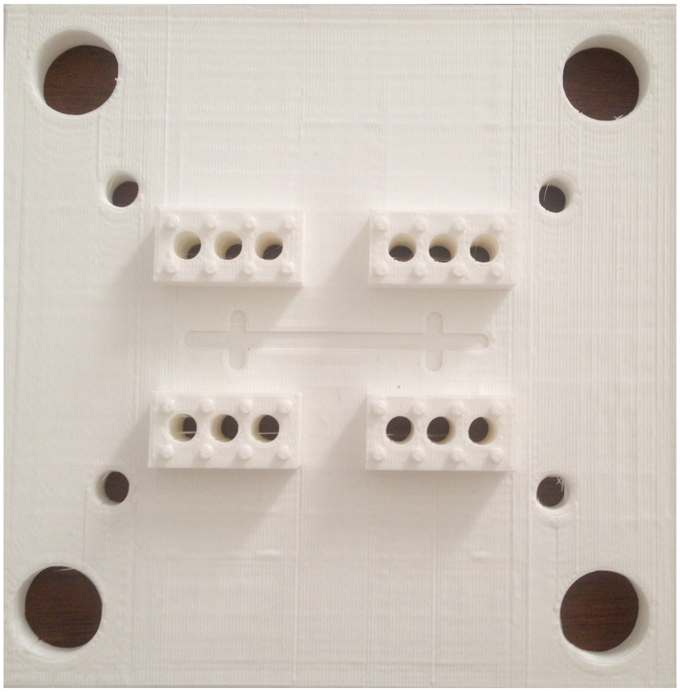


Figure 54: Prototype of the core of Lego bricks

5 DISCUSSION

As a further study and elaboration of this thesis work, the designed part and its mould can be manufactured in the laboratory after mould flow analysis. Also customization of the part and different parts of Lego bricks can be created in one mould. Further analysis and alternatives of production of the Lego bricks can be discussed for more feasible and practical ways. An additional study of clamp force, cooling system and venting can be done for better economy and production line. The mould cooling, cooling time and designing of the cooling channel plays a vital role in production of the product. Since the product is small, it needs higher speed injection pressure and faster cooling system. A 3D printed prototype allowed seeing how the mould actually looks.

Furthermore, the core and cavity plate can be designed more industrially; a better way to design the plates would also be making separate parts for the cavity and core instead of carving them on the plate. For example, if the core and cavity of the product is separate from the mould and not attached in the plates as done in the thesis, then it gives us a leverage to change the parts without changing the whole plate. If the parts are damaged because of some reasons, it can just be removed and changed using the same plate. It costs less and is more convenient to work with.

This product is a rectangle shaped part and while in injection moulding process, the products with sharp corners tend to have shrinkage, discoloration or deformations. But the demand of the product is sharpness and changing it would not reach its need. So, to keep the sharp edges and produce it without any deformations, the mould plates has to be very shiny and smooth so that it does not stick to the core after injection. Similar to the design made in the thesis, other design of the Lego bricks can be made with similar process.

6 CONCLUSION

Concluding the thesis work, a comprehensive study of the software SolidWorks, product designing and its mould designing is completed. The use of mould tools and its procedure is clearly stated. The product Lego brick as simple as it is does not hold a simple procedure to be produced. The ridges inside the Lego brick is not possible to be made in normal laboratory conditions since it is too small and it will take a lot of pressure to inject into that small gap. Other than that, the Lego brick can be produced.

The designing of the product is a modern Lego brick but the mould does not consist of the ridges that are in the inner side of the Lego brick. The first aim was to create a core and cavity for the modern Lego brick but the ridges inside as removed for easier approach. The cavity and core of the product were made and all the parts of the mould are assembled. Along the designing process, there were some changes made from the first thought design, such as at first there was only one cavity in the plate but later while designing, it was found that putting more cavity and core was a better idea since the product is so small. The best gate idea for the product was a tunnel gate with the sprue puller in it. The size of the runner, gating system and ejection system is thoroughly discussed in the thesis. Another change in design made was the core. At first the core did not consist of the studs. Those 8 studs were just seen in the cavity and the core was not supplied with it. This made the studs bulky with plastic melt in it. It is a better idea to also make the studs in the core so that the plastic melt is entering just around the cavity and is not bulky anywhere. The part has only lining of the plastic and not extra accumulation of plastic anywhere.

There is no draft in the Lego brick. But the argument of having no draft can lead to deformed pieces and the problem of sticking of plastic to the core can be resolved. The plastic itself is very slippery and shiny also the mould that is manufactured has to be very shiny and smooth so that the plastic does not stick onto it. To make the mould plates shiny extra capital and effort should be taken.

Then the Mastercam simulation of the mould was done and is ready to be fed in the CNC mill. The prototype of the core, cavity and products were printed to see how the mould would work and what kind of improvements does it need. The prototyping helped a lot to see what kind of small dimensional mistake can occur and how to revise it again.

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8 APPENDIX

Shell Mill = ShM Not In Use = NIU HSS or CARBIDE

Spherical = SPEnd Mill = EM Slot Mill = u s d T ┘ └

Table2. List of installed tools in Arcada's laboratory

T	D (Mm)	Type Long Short	Material	Number of teeth (n)	Machining in Z axis	r/min	Z -offset
1	80	ShM	HM	5	No		-78,878
2	50	ShM	HM	5	No		-93,560
3	25	ShM	HM	2	No		-29,223
4	20	ShM	HSS for Al	2 +1	Y	3000	-69,007
5	20	SP	HM	2	Y		-62,419
6	6	SP	HM	2	Y		-73,469
7	4	EM/HS	HM	2	Y		-0,602
8	10	E M	HSS	2	Y		-67,954
9	4/30°	E M	HSS	4	(50) Y		-52,029
10	12	SP	HSS	3	Y		-44,517
11	16	EM/AL	HSS	2	(48) Y		-52,340
12	3 / 8	Center drill	HSS	2	Y		-96,305
13	10/15	TEM/ 15 °	HSS	4	Y	3000	11,68

14	10	EM	HM	3	(Short) Y		-90,090
15	2	EM	HM	2	Y		-87,458
16	16	SP	HSS	2	(Long) Y		38,531
17	8	EM	HSS	3	Y		-76,622
18	20	EM	HSS	3	LONG		2,006
19	22 x R3	EM	HM	3	(Very long Y)	2500	57,80
20	20	SP	HM	2	(Very long) Y		43,960
21	16	EM	HSS	2	Y	1800/Al	-48,205
22	4,5/3°	EM		3			
23	9,5 R2	EM 3°	HM	3	Y		-50,848
24	4	EM		4	Y		-79,379
25	3/3°	EM		2	Y		-64,018
26	4	SP	HM	1	Y (lean in 0,5)		-73,398
27	68,5	ShM	HM	3	Y (lean in 0,5)		-89,320
28	20	SP	HM	3	Y		-42,117
29	6	EM	HM	2	Y		-78,083
30	3	Drill	Mild steel 30m/min	2	Y	2120	-52,80

31	3,5	Drill	Stainless steel 15m/min	2	Y	1800	-44,94
32	4	Drill	=>20m/min	2	Y	1600	-40,16
33	4,5	Drill		2	Y	1400	-35,56
34	5	Drill		2	Y	1270	-31,285
35	5,5	Drill		2	Y	1160	-24,56
36	6	Drill		2	Y	1060	-25,36
37	6,5	Drill		2	Y	980	-17,83
38	7	Drill		2	Y	900	-11,06
39	7,5	Drill		2	Y	850	-11,06
40	8	Drill		2	Y	790	-3,904
41	8,5	Drill		2	Y	750	-4,06
42	9	Drill		2	Y	700	1,903
43	9,5	Drill		2	Y	670	2,23
44	10	Drill		2	Y	630	9,72
45	10,5	Drill		2	Y		
46	11	Drill		2	Y	550	16,939
47	11,5	Drill		2	Y	500	17,459
48	12	Drill		2	Y		17,373
49	20	Drill		2	Y	477	34,395

TEM=tapered end mill = TM° High Spindle ratio 5 = HS HM = Hard Metal

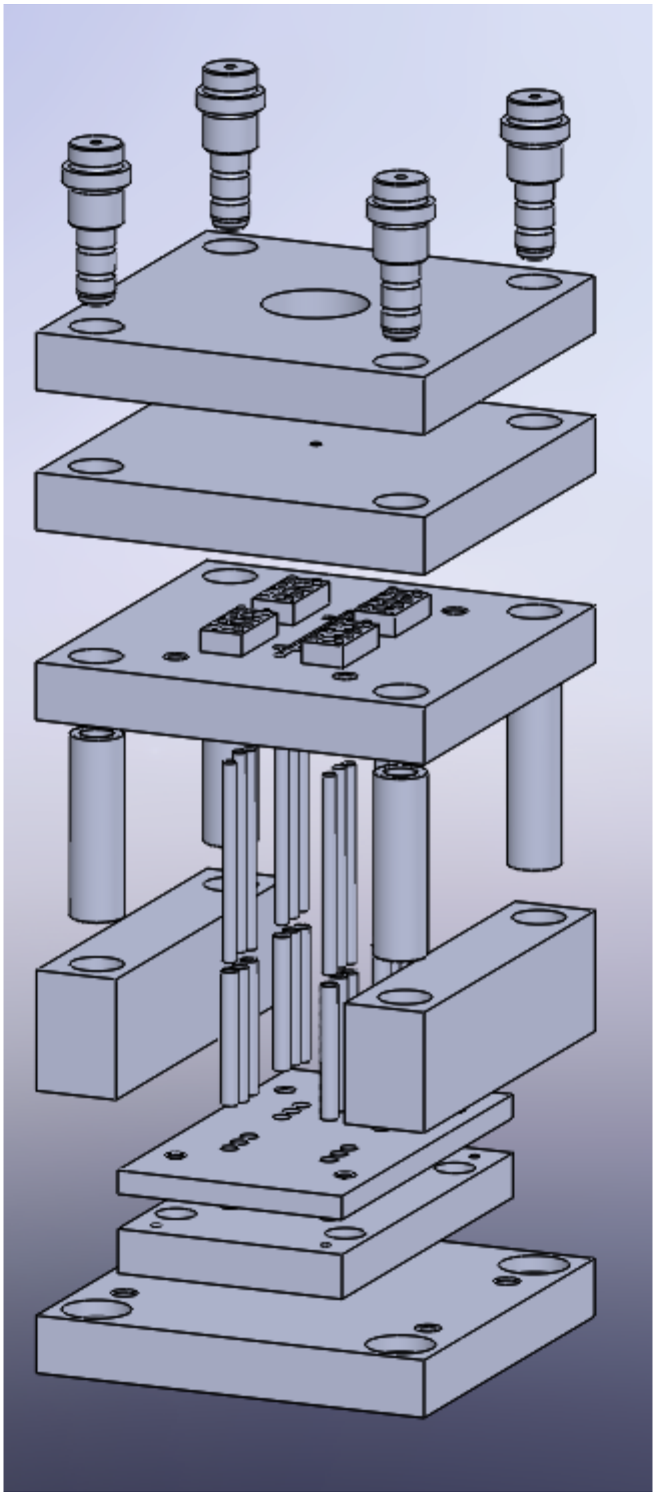

Figure 55: Exploded view of mould