PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering
Department of Mechanical Engineering

Project Folder

ASSE 4311: Learning Outcome Assessment III

Title of Project: **Design and Development of a 3D printed mold for Patternless Metal Casting**

Team #19

Group Members

Student					
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SECTION 112

FALL 2019 - 2020

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ABSTRACT & OBJECTIVES

Abstract

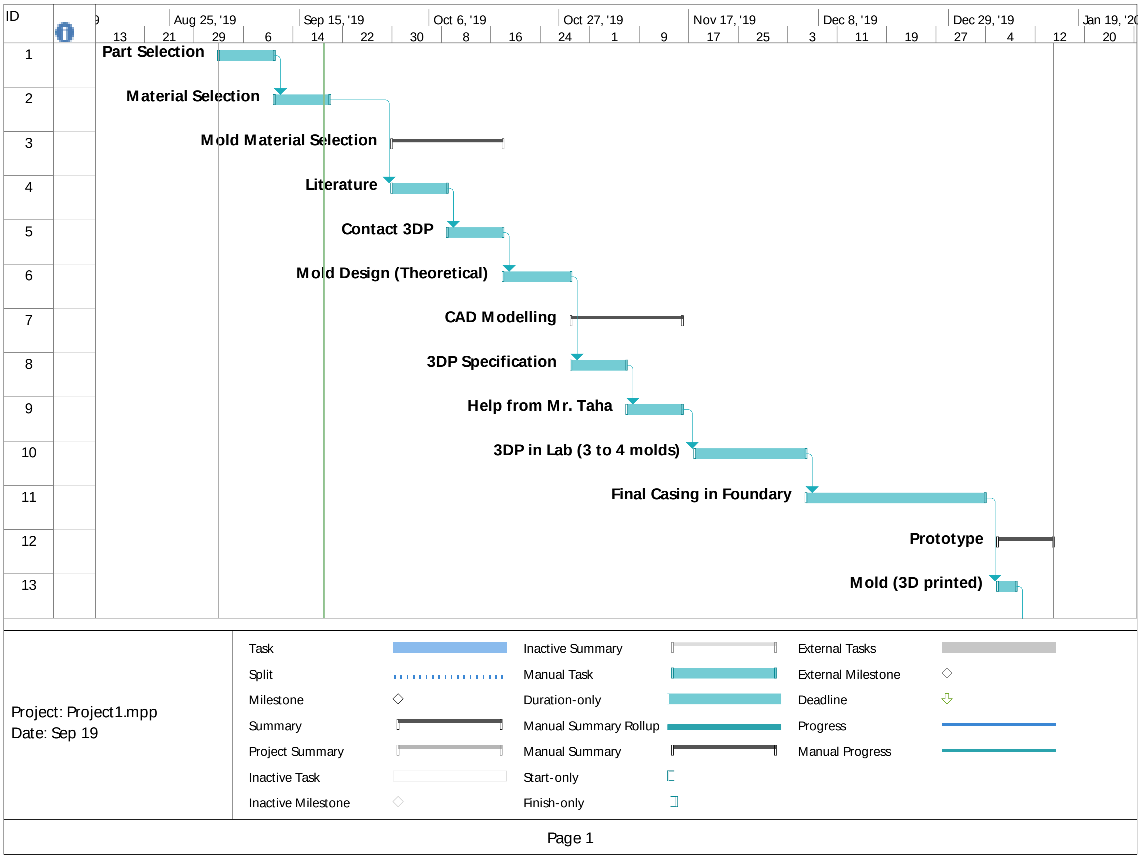
Over the period of the past decade, 3D printing has emerged as a very efficient tool in the field of manufacturing as it has reduced the time required for manufacturing and it is very economical from the point of view of cost. Industries are growing at a very fast pace and they are eagerly developing methods that can reduce the manufacturing time as well as the cost of manufacturing. To serve this cause, 3D printing has achieved a significant value and it has emerged as a very successful way of developing products in a shorter period. 3D printing is categorized as an additive manufacturing process because the material is being added to develop the component. Patternless casting is the latest technique, which is being used in the industry and it involved the casting of products through the mold manufactured from the process of 3D printing. In this project, the goal is to design and develop a 3D printed mold for the low-temperature alloys. An averagely complex part will be chosen and it will be cast through a mold, which is manufactured through 3D printing. Mold will be designed according to the standards and expertise of foundrymen will be considered while designing the mold. After locking the design, mold of that component will be designed in the SolidWorks and powder-based 3D printing will be used for the development of mold. Then the part will be cast in the foundry with the help of the developed mold.

Objectives

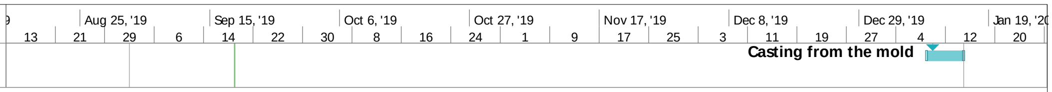
1. To develop a technique for the design and development of mold, which does not even require a pattern.
2. To design a mold, which can help in reducing the total time required for the manufacturing of any component through casting.
3. Another main objective of this project is to reduce the cost of the manufacturing of a component by developing a cheap mold through the 3D printing process.
4. To design a technique for the development of mold, which allows the casting of components, which is beyond the scope of conventional molds.
5. This project is aimed to assist the manufacturing of components through casting with geometric freedom.

6. The goal of this project is to increase the accuracy of molds by developing them through 3D printing because manufacturing in layers allows to uniquely integrate the vents and sprues in the mold.
7. To develop a method of developing mold, which can produce larger molds in less time and boosts the casting process.
8. This project will help in the development of multiple molds together, which can assist in the parallel casting of different components.
9. This project will aid in the developing of complex molds, which is impossible through the conventional methods of mold development.

GANTT CHART


ID
Aug 25, '19
Sep 15, '19
Oct 6, '19
Oct 27, '19
Nov 17, '19
Dec 8, '19
Dec 29, '19
Jan 19, '20
13 21 29 6 14 22 30 8 16 24 1 9 17 25 3 11 19 27 4 12 20
1 Part Selection
2 Material Selection
3 Mold Material Selection
4 Literature
5 Contact 3DP
6 Mold Design (Theoretical)
7 CAD Modelling
8 3DP Specification
9 Help from Mr. Taha
10 3DP in Lab (3 to 4 molds)
11 Final Casing in Foundary
12 Prototype
13 Mold (3D printed)
Project: Project1.mpp
Date: Sep 19
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress
Page 1

ID		
14		



Project: Project1.mpp
Date: Sep 19

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

PROGRESS REPORTS

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Fall**	**ACADEMIC YEAR:**	**2019-2020**
PROJECT TITLE	**Design and Development of a 3D printed mold for paternless Metal Casting**		
SUPERVISORS	**Dr.Muhammed Azhar Khan – Mr. Taha Waqar**		

Month 2: March

Members Name	**ID Number**
Abdullah Al-Askar	**201501266**
Turki Al-Ghamdi	**201502772**
Fahad Al-Shuabi	**201500623**
Faisal Al-Humaidi	**201400644**
Iftikhar Islam	**201102432**

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member Assigned	Progress 0%-100%	Delivery proof

	Managing the team and prsntation	Humaidi	80%	
	Report	Shuaibi	85%	
	Theory Calculations and Design	Al-Askar	100%	
	Prototype	AL-Ghamdi	100%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
	Designing the mold	Abdullah Al-Askar
	Theory And calculation	Abdullah Al-Askar
	Presentation and report	Faisal Al-Humaidi Fahad Al-Shuaibi
	Protoype	Turki Al-Ghamdi
	Testing	All

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	**Name**	**Criteria (d1)**	**Criteria (d2)**	**Criteria (d3)**	**Criteria (f1)**
1	Turki Al-Ghamdi	4	4	4	4
2	Faisal Al-Humaidi	4	4	4	4
3	Fahad Al-shuaibi	4	4	4	4
4	Iftikhar	4	3	4	3

FORMS

3.1 Design Constraints and Design Methodology

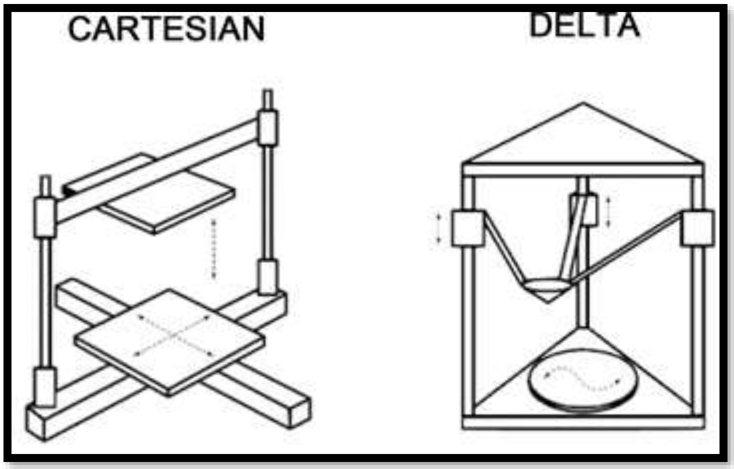
FDM (Fuel Deposition Molding) additive manufacturing technology that is used to make parts using heating and extruding filaments through a small nozzle is called fused deposition molding. This method can be used for the manufacturing of thermoplastics and composite materials. CNC (Computer Numerically Controlled) controls the path of movement of the nozzle and part is created by drawing layers on top of another by extruding the material.

This is rapid manufacturing technology. Additive Manufacturing techniques mostly used do not that much advantage compared to traditional manufacturing methods. According to the analysis made in recent times, it was concluded that the fused deposition molding technique can also be used for designing on the household level under feasible circumstances.

Albeit fused deposition molding technique has been used since the recent past for both increasing the flexibility and averting the dimensions, the knowledge available for a designer to design state of the art model has been used keeping requisite consideration in mind.

Geometric constraints

The methods of AM and FDM put some constraints regarding dimensions of the designed part. It does not allow us to make big parts. FDM printers available for the manufacturing allows sizes to be less than 30 cm X 30 cm X 30 cm. The cartesian coordinate system is used in most FDM printers but Delta coordinate system is also employed for manufacturing. One thing which distinguishes these two printers is the distribution of building volume. The larger bed is used in Cartesian based printers but not much height dimension. Contrary to this, Delta has a greater height dimension but a smaller bed size.



3.2 Design Standards

Engineering design standards

1- Venting
   The diameter of the runner has to be equal to the diameter of the vent to keep balance. Specification of the depth is based on materials used for making parts. Vents of the runner can be on either cavity or core side of the mold.
2- Welding
   Due to the completion of processes of die and texturing, every engineering change that happens in the welding of mold has to be addressed individually by tool source.
3- Die Parting Line
   Shutoff area must be in full contact for parting line and should be at least 1 inch around the cavity and at every corner of mold in the vicinity of guide pins and at all die locks. Other areas should be relieved by 0.030 inches.
4- Clamp slots
   Mold base should be held completely with the platens after clamping into its position. That’s why clamp slots must have large depth.
5- Eyebolts
   A suitable number of eyebolts holes must be on the four sides of every mold. And also on two halves which include an ejector box and any extra planes.
6- Core and cavity requirements
   Identification of all cavity, core blocks and inserts must be decided on the basis of the type of material and hardness.
7- Core pins
   The identification of all slides and lifters must be decided on the basis of the type of material and hardness.
   The core size of ¼ inch has to inserted to form holes.
8- Slide and lifter requirements

Labeling of all slides and lifters should be done using numbers that correspond to the cavity number.
The fastening of all lifters to the lifter bar has to be with steel pins.

9- Hydraulic cylinders
On the bottom of the mold, all tools having hydraulic cylinders should have support legs to clear the cylinders when setting on the floor.

10- Runner and gate requirements
The requirement is to have a system of runners that is in balance.
Runners have to be round.
The design of gates must be detailed on final tool designs. View of gate and dimension having four times the size must be shown.

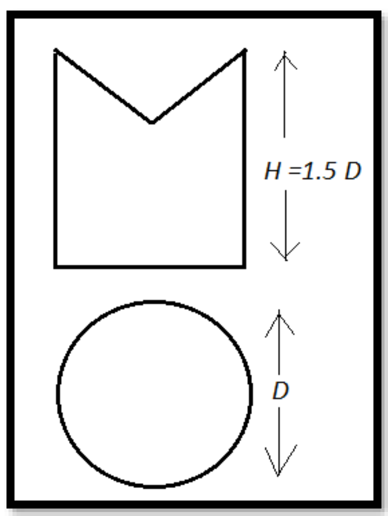
3.3 Theory and Theoretical Calculations

Theoretical calculations

- Riser

It is needed to provide feed metal in the right amount, at the right place, at the right time. The cylinder will have a diameter to height ratio as 1.0. Two ratios are important.

$\frac{V}{A}$ the ratio is known as modulus and it depends on solidification time. $\frac{H}{D}$ the ratio should be $1:1 - 1:1.5$.



For dimensions of $7.5cm \times 12.5cm \times 2cm$, $\frac{V}{A}$ the ratio comes out to be 0.7.

$$\frac{V}{A} = \frac{abc}{2(ab + bc + ca)}$$

Where $a = 7.5, b = 12.5, c = 2$.

Solidification time $t_s = k\left(\frac{V}{SA}\right)^2$, where SA is surface area, V is casting volume, k is mold constant

Take $t_s = 1.6\ sec$. Then $\gamma = \frac{t_s}{\left(V/_A\right)^2} = 3.26\ {}^{min}/_{cm^2}$.

Dimensions are dependent upon solidification time.

$$\text{If } \frac{D}{H} = 1, t_s = 2\ mm,$$

$$V = \frac{\pi}{4}D^2H\ ,\ A = \pi DH + 2\frac{\pi}{4}D^2$$

As D=H,

$$\frac{V}{A} = \frac{D}{6}$$

By Chvorinov's rule,

$$t_s = \gamma\left(\frac{V}{A}\right)^2$$

Riser dimensions came out to be $D = 4.7\ cm, H = 4.7\ cm.$

Choke area is another important consideration. It is the control area that meters the metal flow into a mold cavity.

As $Q = AV\ and\ W = \rho AV$, so choke area $A = \frac{W}{\rho V} = \frac{W}{\rho\sqrt{2gH}} = \frac{W}{\rho + c\sqrt{2gH}}$ where W is casting mass, c is efficiency factor, his the effective head.

- Sprue Height

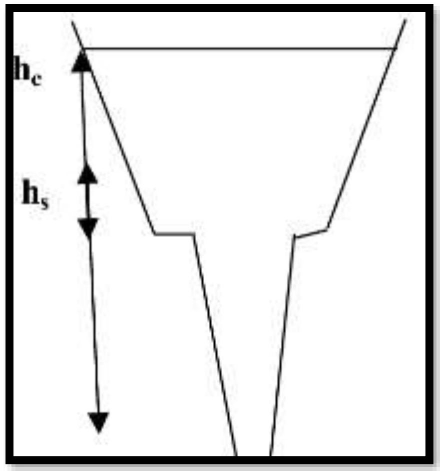
It is a function of the gating system and can be calculated as,

For top gate, H=h

For bottom gate, $H = h - \frac{c}{2}$

For parting gate, $H = h - \frac{p^2}{2c}$

Where H is effective sprue height, his sprue height, c is the height of the mold cavity, p is the total height of the cavity in cope.



- Runner

The diameter of a runner can be calculated as

$$D = \frac{W^{1/2} \times L^{1/4}}{3.7}$$

Where D is runner diameter, W is part weight, L is runner length.

For a runner, following relation works

$$W = 1.25D$$

- Gates

For the cylindrical gate ((sprue gate) following calculations are applied.

$$d = d_v + 1\, mm$$

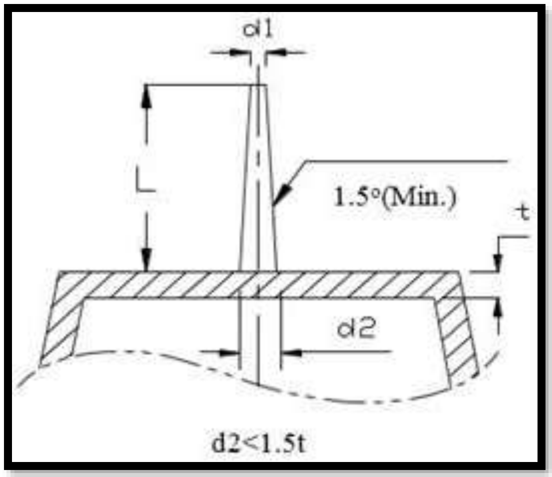
Where d_r is nozzle exit diameter, d is a diameter of sprue orifices.

The diameter of the sprue gate depends on the location of the molded part.

$$D = t + 1.5\, mm$$

Where t is the thickness of the product, D is the diameter of the sprue gate. The thickness should not be large because it would then increase the cooling time.

To de-mold the sprue without trouble, it should be tapered towards the orifice on the side of the nozzle. The taper angle is $\alpha \geq 1 - 4°$.



- Pouring basin

It is just like a reservoir with any appropriate dimensions according to space.

3.4 Product Subsystem and Component Selection

Components of mold

- Pouring basin

It is a cavity on the top side of the mold into which molten metal is poured.

- Sprue

It is the path through which molten metal goes from the pouring basin to the mold cavity.

- Runners

It is the path in the parting plane through which molten metal flow is controlled and regulated before it reaches the mold cavity.

- Gates

These are a kind of entry of passages into the mold cavity. It connects runner to the mold cavity.

- Riser

It is a type of reservoir into which molten metal is collected. Molten metal will go into the mold cavity from the reservoir when the volume of metal is reduced due to solidification in the mold cavity.

3.5 Manufacturing and Assembly

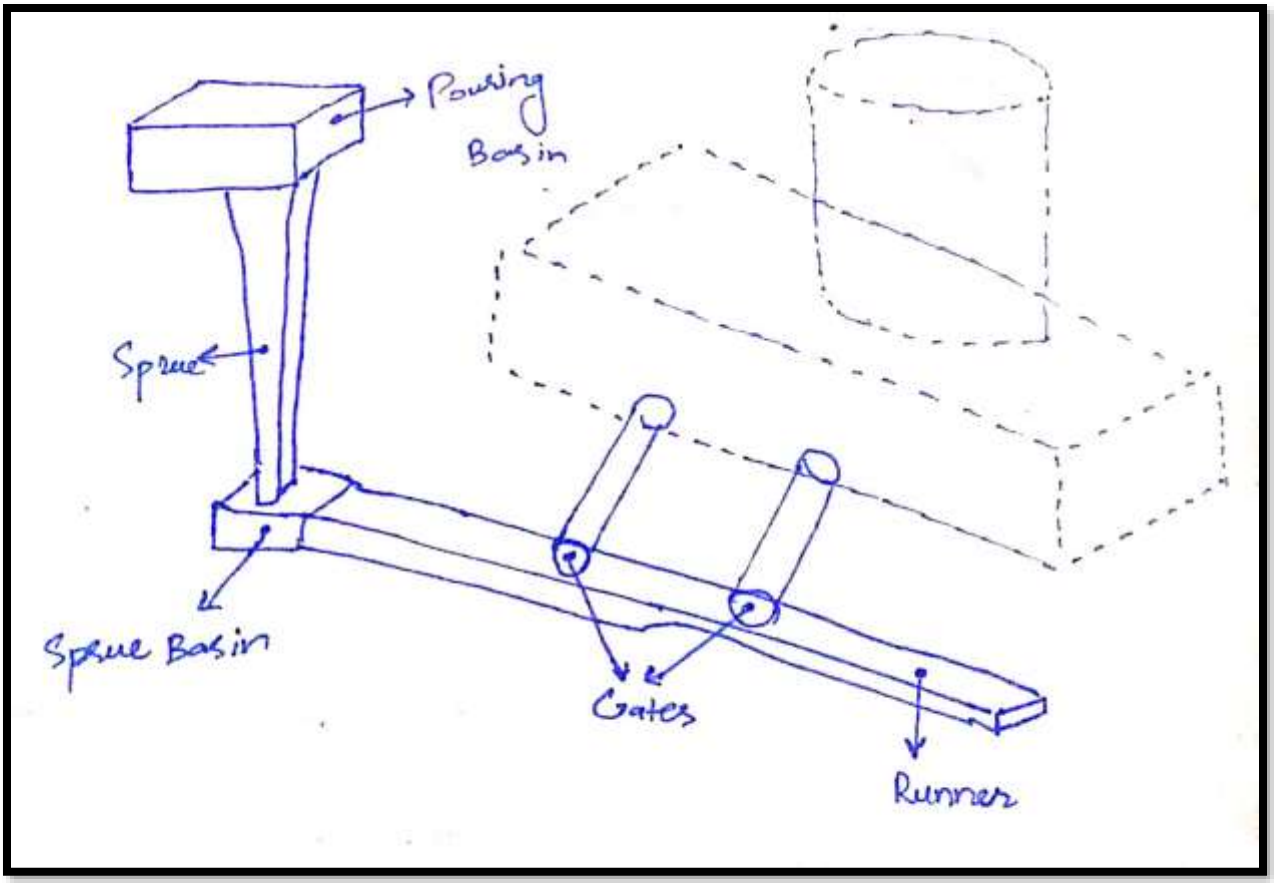
Mold Assembly

One of the most important steps in the process of mold making is the assembly of mold. All types of machined parts need to be assembled properly so that it could perform its function well. To do this job, knowledge about the process of injection molding and how the structure of mold is designed is necessary. This is to ensure the quality of assembly to obtain and precision in the manufacturing of mold and to get maximum productivity. Things to consider for the assembly are

- The surfaces of mild must be polished properly. Especially the deep rib should be polished otherwise de-molding problems can occur.
- At all places where there are pointed or sharp edges in the cavity or in the core that places need to be rounded by giving it a radius if there isn't any special requirement for edges to be sharp.
- The size of the runner and that of the mold gate must be according to the design requirements and has to be checked if that's the case or not. The polishing of a runner is also very important.
- The base of the mold must be properly marked, slots are to be made between parting lines and clamp plates, support plates and ejector. Every lifting plate must have holes in inappropriate places. Dimensions of the thread must be correctly marked.
- The size of the sprue and nozzle must be accurate along with the location ring.
- The line through which water is coming must be made correctly in and out. And the interference of the water tube line with the clamp slots has to be monitored.
- All of the pins, cores, and sleeves are to be marked. Dimensions and clearances of fitting must be of the dimensions of length and head.
- Also look if dimensions of knock out holes, layout and clamping slots are correct or not.
- Cavity and core inserts must be on a high level compared to the level of the parting line.
- To inspect if there is any clearance left, close the mold and see if there is any space between the cavity and core retainer plates.
- Proper orientation of limit switches is necessary for wiring.
- Also, verify that insulator plates are installed and slide locks and parting line locks work correctly.
- Try to move ejector plates to check its working and if it produces back and forth motion.
- All the mechanism needs to be checked for working smoothly.

These steps and processes depend upon the type of mold structure and the components it includes.

Assembly can be shown as:



REPORT DRAFTS

Chapter 1: Introduction

1.1 Project Objectives

The objectives behind this project are listed below:

10. To develop a technique for the design and development of mold, which does not even require a pattern.
11. To design a mold, which can help in reducing the total time required for the manufacturing of any component through casting.

12. Another main objective of this project is to reduce the cost of the manufacturing of a component by developing a cheap mold through the 3D printing process.
13. To design a technique for the development of mold, which allows the casting of components, which is beyond the scope of conventional molds.
14. This project is aimed to assist the manufacturing of components through casting with geometric freedom.
15. The goal of this project is to increase the accuracy of molds by developing them through 3D printing because manufacturing in layers allows to uniquely integrate the vents and sprues in the mold.
16. To develop a method of developing mold, which can produce larger molds in less time and boosts the casting process.
17. This project will help in the development of multiple molds together, which can assist in the parallel casting of different components.
18. This project will aid in the developing of complex molds, which is impossible through the conventional methods of mold development.
19. The objective of this project is to eliminate the concept of the pattern from the mold development, as it will again save a lot of time and cost. It will also decrease the complexities in the development of mold.

Overall, it can be said that this project will help in the development of mold through 3D printing as 3D printing has many advantages over the conventional methods of mold development. Components manufactured through casting with the help of 3D printed mold will be manufactured in less time and there will be no geometric restriction in their manufacturing.

Chapter 2: Literature Review

2.1Project Background

Casting is a process of very high significance and it is used in the manufacturing of several components. The importance of casting cannot be denied in any way and there are no chances of ruling this process out. With the increase in the demand for the manufacturing of new components, the importance of casting process is significantly increasing. Demand of public for new products and design of new components and parts to improve the quality of life and to improve the industrial processes is being done on daily basis. At the same time, there are several restrictions and limitations to the casting process. These restrictions and limitations are slowing down the complete manufacturing process and it is forcing the designers and manufacturers to shift to other manufacturing processes, as many complex geometries cannot be made through casting process. Every casting process involves a mold that is the basic requirement of manufacturing of any part. Mold is first designed according to the specifications of part or component and designing of mold and specifications of mold play an important role in the quality of the component (Campbell, 2003).

3D printing is another manufacturing process that is introduced to the industry over a period of past few decades. Due to its efficiency and its accuracy, this process has been adopted at a very large scale and many ordinary and complex designs are being manufactured through this process. 3D printing is a material additive process and it just needs a proper CAD design of geometry. 3D printer takes the material in the powder form and then the binder binds that material into the required form. There are a lot of advantages of 3D printing as it is a very cost-efficient process and it takes very little time to manufacture a product as compared to the other manufacturing process. However, 3D printing has its own limitations and not every product can be manufactured through 3D printing. 3D printer can be used to manufacture products at high temperatures and its diversities are making it a very common option.

As far as our project is concerned, the aim of our project is to improve the casting process with the help of a 3D printer. Limitations of the casting process are because of the limitations of the mold design. If the method of development of mold can be changed, then there are possibilities that the casting process can be used for many other components and its restrictions and limitations can be reduced. The development of mold for the casting process involves the pattern, which is very necessary to develop a mold. Our aim is to develop mold with the help of a 3D printer without using the pattern. The development of mold through 3D printing is already being done in some industries. Nevertheless, if it is taken to a larger scale, then there can be a big revolution in the field of casting.

The use of a 3D printer for the development of mold is getting very popular because it takes very little time to develop mold on the 3D printer. Moreover, it is a very economical process and it does not cost as much as the conventional methods of development of mold. The main reason behind shifting to the 3D printing process for the development of mold is that it goes beyond the geometrical restrictions. The casting of any component is possible if its mold can be prepared. 3D printer is very efficient in developing the complex molds. Adding more to it, 3D printing is more efficient as the mold is developed in layers and designer can set the vents and sprues more easily and more accurately. Thus, the involvement of 3D printing process is very efficient from the point of design complexity. One of the basic reasons for shifting to the 3D printed mold in the patternless metal casting. Every conventional method of developing mold requires a pattern but 3D printed mold does not need a pattern. Because the mold is printed from the CAD model of the mold. Therefore, the deletion of pattern from the process of mold development is very efficient in time and it saves a lot of costs. In our project, an ordinary complex part will be taken and its mold will be designed on the SolidWorks. From the CAD file of the mold, the command of manufacturing will be given to the 3D printer. The powder-based 3D printer will be used for this purpose. The component will be chosen according to the expertise of the foundrymen. The developed mold will be taken to the foundry and casting of the component will be done through this mold. We will choose a low-temperature alloy for this purpose.

(Snelling)

2.2Previous Work

The already done work on the 3D printed molds for the metal casting is not enough to cover the low-temperature alloys. Still, the molds of low-temperature alloys are being developed through conventional methods. The literature available on the 3D printed molds is very limited and it does not cover the effects of 3D printed mold on the casting. Most of the literature just provides the advantages of using the 3D printer for the development of mold or they just highlight the type of 3D printer that can be used for mold development. The concern of our project is with the real mold development and then doing casting with the developed mold to understand and study the effects of this mold on metal casting. Literature available on the comparison of 3D printed mold for metal casting versus the conventional mold for metal casting is also very limited.

Either it is sand casting or investment casting; authors have worked on the strengths of 3D printed mold. Previous literature tells about the composition of the molds and different advantages and disadvantages of 3D printed mold as the 3D printed molds. According to McKenna et al., there are possibilities that the 3D printed mold produces numerous gases while being used and it can affect the shape and geometry of the final product. So that a new curing cycle must be devised that has a higher temperature range and a lower time duration. This can efficiently reduce the gas defects in the final output of the casting. Adding more to the work of McKenna et al., Kaplas and Gill worked on the comparison of 3D printed molds and conventional molds. They studied the difference in the mechanical properties of two molds under consideration. The mechanical properties such as surface roughness, hardness values, shrinkage, dimensional tolerances, etc. were majorly considered by Kaplas and Gill. They also made a comparison on the economy of both molds and produced the results that the 3D printed mold is more economical and cheap, and have enhanced mechanical properties. Kaplas and Gill also investigated different parameters that are involved in the calculations of cost and found out that there are some optimal values at which the mold can be developed economically (METAL).

2.3Comparative Study

This section of the literature review will highlight the other projects related to the 3D printed molds. In the form of our project, this section will also highlight the addition of new literature to the field of 3D printed molds.

Following is the list of some other projects, which have been completed on the 3D printed molds or being completed:

1. “Use of 3D Printed Models to Create Molds for Shaping Implants for Surgical Repair of Orbital Fractures” (William J. Weadock, 2019).

In this project, the author used the 3D printed molds to repair the fractures of surgical instruments as the conventional molds were producing defective pieces. The author used 3D printed molds and got positive results.

2. “Fabricating smooth PDMS microfluidic channels from low-resolution 3D printed molds using an omniphobic lubricant-infused coating” by Martin Villegas and Amid Shakeri. (Shakeri, 2018)

In this project, the author worked on improving the quality of 3D printed mold using lubricant-infused fluids. He developed a cheap mold from 3D printing with a rough surface and then improved its quality through lubricant-infused coating. It was a project on reducing the cost of molds.

3. “3D printed elastic mold granulation” by Clint Okeyo and Dewan F. Chowdhury. (Chowdhury, 2019)

In the project, the author devised a way for the pharmaceutical companies in which they can prepare the bottled-packing of their medicine through 3D printed elastic molds. It can increase the rate of production and lowers the cost. It is significant because it increased the elasticity of packing and reduced the possibility of breaking.

Why Our Project is Significant?

In all the projects mentioned above, and in the literature reviews, it has become obvious that the work on 3D printed molds for metal casting is very limited. Authors have written about the 3D printed molds but the use of 3D printed molds for patternless metal casting has not been done. The development of mold for the patternless metal casting is of great importance as it eliminates the most difficult concept of the pattern from the whole casting process. Our project distinguishes us from other projects because we are working on a new idea of patternless metal casting. It can reduce cost because there will be no effort and cost involved in the manufacturing of mold as we do not need any mold for our casting purposes. Moreover, it will reduce a lot of time in the whole process. To produce a quality product in less time and with less cost is the main objective of our project and it distinguishes our project from the other projects.

References

Campbell, J. (2003). Casting. Butterworth-Heinemann Limited.

Snelling, D. (n.d.). THE EFFECTS OF 3D PRINTED MOLDS ON METAL.

METAL, T. E. (n.d.). THE EFFECTS OF 3D PRINTED MOLDS ON METAL. 19. Retrieved October 2019, from https://sffsymposium.engr.utexas.edu/Manuscripts/2013/2013-66-Snelling.pdf

William J. Weadock, C. J. (2019). 1. Use of 3D Printed Models to Create Molds for Shaping Implants for Surgical Repair of Orbital Fractures. Retrieved 2019, from https://www.sciencedirect.com/science/article/pii/S1076633219303733

Shakeri, b. M. (2018). 2. Fabricating smooth PDMS microfluidic channels from low-resolution 3D printed molds using an omniphobic lubricant-infused coating . Retrieved from https://www.sciencedirect.com/science/article/pii/S0003267017313417

Chowdhury, C. O. (2019, Febraury 15). 3D printed elastic mold granulation by. *344*. Retrieved 2019, from https://www.sciencedirect.com/science/article/pii/S0032591018310465

3.1 Design Constraints and Design Methodology

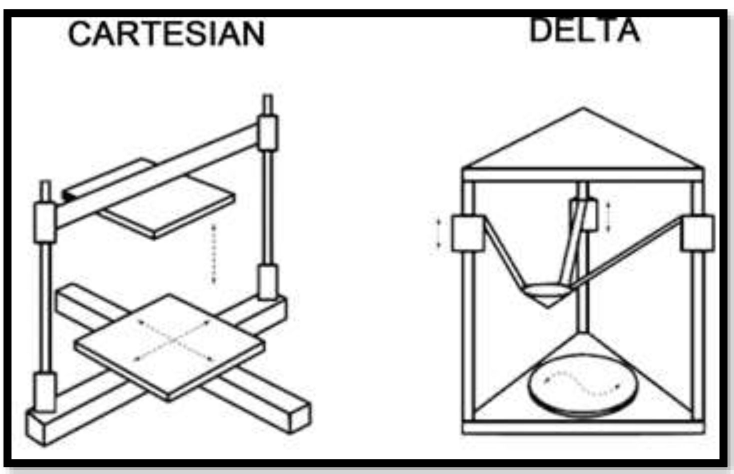
FDM (Fuel Deposition Molding) additive manufacturing technology that is used to make parts using heating and extruding filaments through a small nozzle is called fused deposition molding. This method can be used for the manufacturing of thermoplastics and composite materials. CNC (Computer Numerically Controlled) controls the path of movement of the nozzle and part is created by drawing layers on top of another by extruding the material.

This is rapid manufacturing technology. Additive Manufacturing techniques mostly used do not that much advantage compared to traditional manufacturing methods. According to the analysis made in recent times, it was concluded that the fused deposition molding technique can also be used for designing on the household level under feasible circumstances.

Albeit fused deposition molding technique has been used since the recent past for both increasing the flexibility and averting the dimensions, the knowledge available for a designer to design state of the art model has been used keeping requisite consideration in mind.

Geometric constraints

The methods of AM and FDM put some constraints regarding dimensions of the designed part. It does not allow us to make big parts. FDM printers available for the manufacturing allows sizes to be less than 30 cm X 30 cm X 30 cm. The cartesian coordinate system is used in most FDM printers but Delta coordinate system is also employed for manufacturing. One thing which distinguishes these two printers is the distribution of building volume. The larger bed is used in Cartesian based printers but not much height dimension. Contrary to this, Delta has a greater height dimension but a smaller bed size.



3.2 Design Standards

Engineering design standards

11- Venting
The diameter of the runner has to be equal to the diameter of the vent to keep balance. Specification of the depth is based on materials used for making parts. Vents of the runner can be on either cavity or core side of the mold.

12- Welding
Due to the completion of processes of die and texturing, every engineering change that happens in the welding of mold has to be addressed individually by tool source.

13- Die Parting Line

Shutoff area must be in full contact for parting line and should be at least 1 inch around the cavity and at every corner of mold in the vicinity of guide pins and at all die locks. Other areas should be relieved by 0.030 inches.

14- Clamp slots

Mold base should be held completely with the platens after clamping into its position. That's why clamp slots must have large depth.

15- Eyebolts

A suitable number of eyebolts holes must be on the four sides of every mold. And also on two halves which include an ejector box and any extra planes.

16- Core and cavity requirements

Identification of all cavity, core blocks and inserts must be decided on the basis of the type of material and hardness.

17- Core pins

The identification of all slides and lifters must be decided on the basis of the type of material and hardness. The core size of ¼ inch has to inserted to form holes.

18- Slide and lifter requirements

Labeling of all slides and lifters should be done using numbers that correspond to the cavity number. The fastening of all lifters to the lifter bar has to be with steel pins.

19- Hydraulic cylinders

On the bottom of the mold, all tools having hydraulic cylinders should have support legs to clear the cylinders when setting on the floor.

20- Runner and gate requirements

The requirement is to have a system of runners that is in balance.
Runners have to be round.
The design of gates must be detailed on final tool designs. View of gate and dimension having four times the size must be shown.

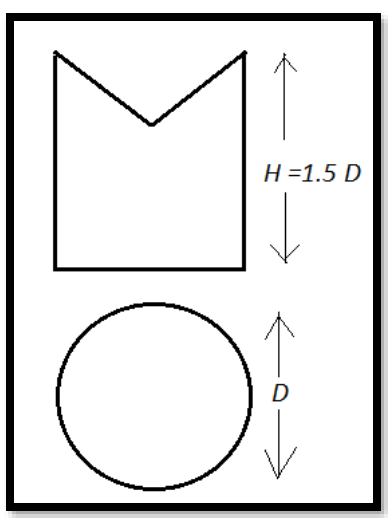
3.3 Theory and Theoretical Calculations

Theoretical calculations

- Riser

It is needed to provide feed metal in the right amount, at the right place, at the right time. The cylinder will have a diameter to height ratio as 1.0. Two ratios are important.

$\frac{V}{A}$ the ratio is known as modulus and it depends on solidification time. $\frac{H}{D}$ the ratio should be $1:1 - 1:1.5$.



For dimensions of $7.5cm \times 12.5cm \times 2cm$, $\frac{V}{A}$ the ratio comes out to be 0.7.

$$\frac{V}{A} = \frac{abc}{2(ab + bc + ca)}$$

Where $a = 7.5, b = 12.5, c = 2$.

Solidification time $t_s = k\left(\frac{V}{SA}\right)^2$, where SA is surface area, V is casting volume, k is mold constant

Take $t_s = 1.6\ sec$. Then $\gamma = \frac{t_s}{\left({}^{V}/_{A}\right)^2} = 3.26\ {}^{min}/_{cm^2}$.

Dimensions are dependent upon solidification time.

$$\text{If } \frac{D}{H} = 1, t_s = 2\ mm,$$

$$V = \frac{\pi}{4}D^2H\ , A = \pi DH + 2\frac{\pi}{4}D^2$$

As D=H,

$$\frac{V}{A} = \frac{D}{6}$$

By Chvorinov's rule,

$$t_s = \gamma\left(\frac{V}{A}\right)^2$$

Riser dimensions came out to be $D = 4.7\ cm, H = 4.7\ cm$.

Choke area is another important consideration. It is the control area that meters the metal flow into a mold cavity.

As $Q = AV\ and\ W = \rho AV$, so choke area $A = \frac{W}{\rho V} = \frac{W}{\rho\sqrt{2gH}} = \frac{W}{\rho + c\sqrt{2gH}}$ where W is casting mass, c is efficiency factor, his the effective head.

- Sprue Height

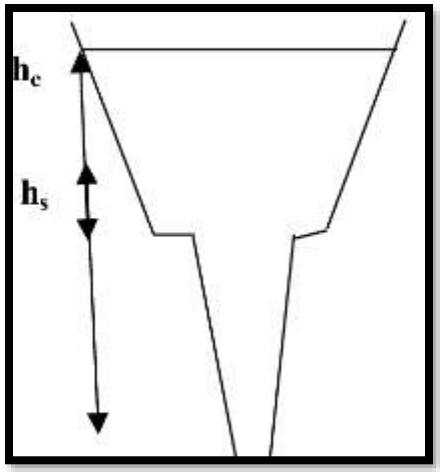
It is a function of the gating system and can be calculated as,

For top gate, H=h

For bottom gate, $H = h - \frac{c}{2}$

For parting gate, $H = h - \frac{p^2}{2c}$

Where H is effective sprue height, his sprue height, c is the height of the mold cavity, p is the total height of the cavity in cope.



- Runner

The diameter of a runner can be calculated as

$$D = \frac{W^{1/2} \times L^{1/4}}{3.7}$$

Where D is runner diameter, W is part weight, L is runner length.

For a runner, following relation works

$$W = 1.25D$$

- Gates

For the cylindrical gate ((sprue gate) following calculations are applied.

$$d = d_v + 1\ mm$$

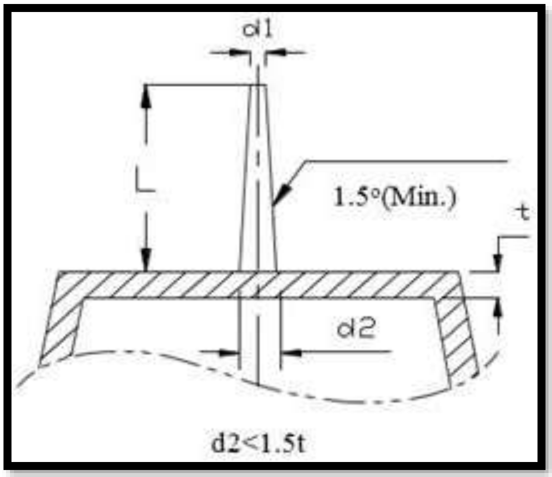
Where d_r is nozzle exit diameter, d is a diameter of sprue orifices.

The diameter of the sprue gate depends on the location of the molded part.

$$D = t + 1.5\ mm$$

Where t is the thickness of the product, D is the diameter of the sprue gate. The thickness should not be large because it would then increase the cooling time.

To de-mold the sprue without trouble, it should be tapered towards the orifice on the side of the nozzle. The taper angle is $\alpha \geq 1 - 4°$.



- Pouring basin

It is just like a reservoir with any appropriate dimensions according to space.

3.4 Product Subsystem and Component Selection

Components of mold

- Pouring basin

It is a cavity on the top side of the mold into which molten metal is poured.

- Sprue

It is the path through which molten metal goes from the pouring basin to the mold cavity.

- Runners

It is the path in the parting plane through which molten metal flow is controlled and regulated before it reaches the mold cavity.

- Gates

These are a kind of entry of passages into the mold cavity. It connects runner to the mold cavity.

- Riser

It is a type of reservoir into which molten metal is collected. Molten metal will go into the mold cavity from the reservoir when the volume of metal is reduced due to solidification in the mold cavity.

3.5 Manufacturing and Assembly

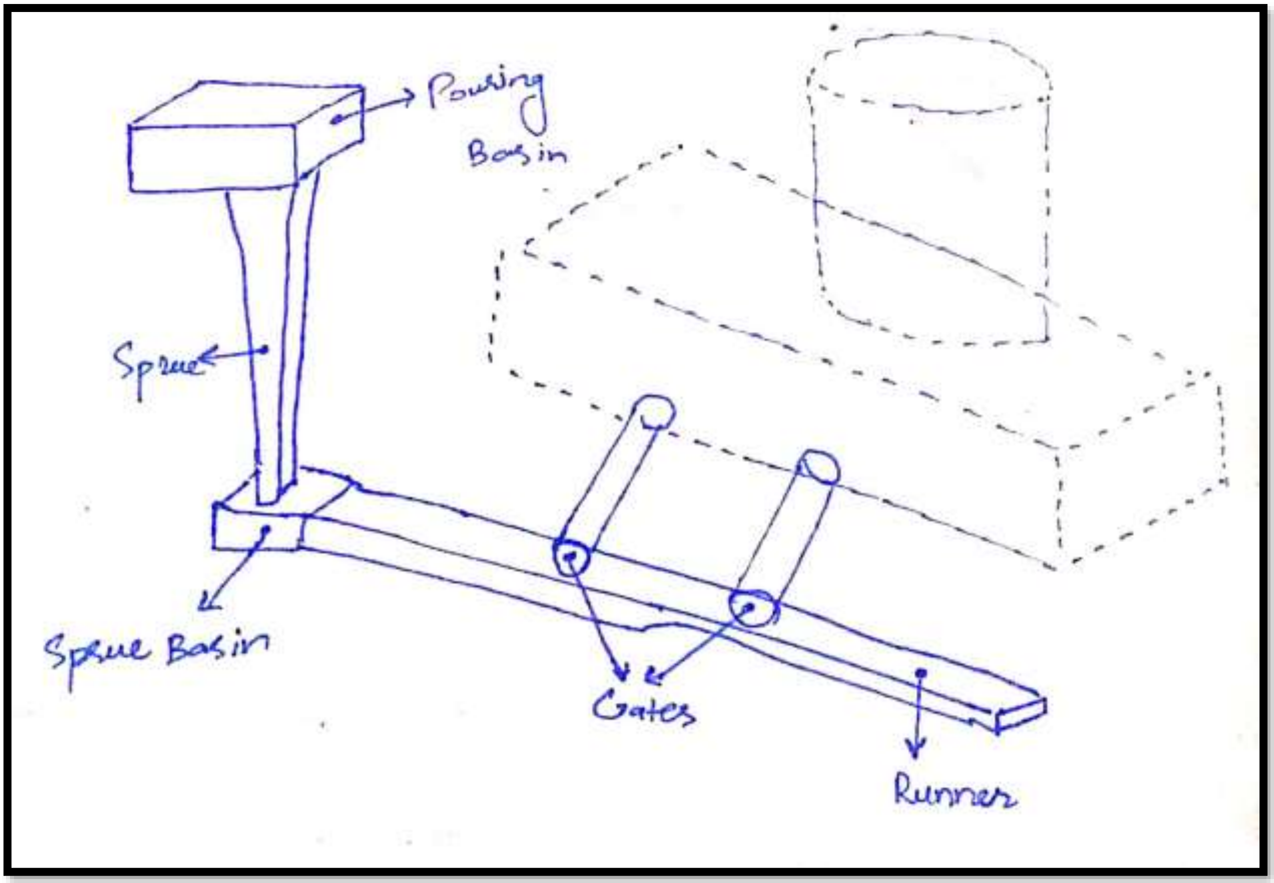
Mold Assembly

One of the most important steps in the process of mold making is the assembly of mold. All types of machined parts need to be assembled properly so that it could perform its function well. To do this job, knowledge about the process of injection molding and how the structure of mold is designed is necessary. This is to ensure the quality of assembly to obtain and precision in the manufacturing of mold and to get maximum productivity. Things to consider for the assembly are

- The surfaces of mild must be polished properly. Especially the deep rib should be polished otherwise de-molding problems can occur.
- At all places where there are pointed or sharp edges in the cavity or in the core that places need to be rounded by giving it a radius if there isn't any special requirement for edges to be sharp.
- The size of the runner and that of the mold gate must be according to the design requirements and has to be checked if that's the case or not. The polishing of a runner is also very important.
- The base of the mold must be properly marked, slots are to be made between parting lines and clamp plates, support plates and ejector. Every lifting plate must have holes in inappropriate places. Dimensions of the thread must be correctly marked.
- The size of the sprue and nozzle must be accurate along with the location ring.
- The line through which water is coming must be made correctly in and out. And the interference of the water tube line with the clamp slots has to be monitored.
- All of the pins, cores, and sleeves are to be marked. Dimensions and clearances of fitting must be of the dimensions of length and head.
- Also look if dimensions of knock out holes, layout and clamping slots are correct or not.
- Cavity and core inserts must be on a high level compared to the level of the parting line.
- To inspect if there is any clearance left, close the mold and see if there is any space between the cavity and core retainer plates.
- Proper orientation of limit switches is necessary for wiring.
- Also, verify that insulator plates are installed and slide locks and parting line locks work correctly.
- Try to move ejector plates to check its working and if it produces back and forth motion.
- All the mechanism needs to be checked for working smoothly.

These steps and processes depend upon the type of mold structure and the components it includes.

Assembly can be shown as:


Pouring Basin
Sprue
Sprue Basin
Gates
Runner

4.1. Experimental Setup, Sensors and data acquisition system

Gaining popularity in manufacturing world since 1980s, 3D Printing is now one of the pioneer manufacturing techniques in this era. The most famous of the 3D printing techniques, the Fused Deposition Modelling Technique is immensely used in almost every technological field.

4.1.1 Working of an FDM 3D Printer:

The principle is of FDM is simple. A thermoplastic filament is used by heating it upto its melting temperature and then comes out of a nozzle to produce a 3D product. The forming layers can be viewed as a flat cross section. After completion of one layer, the nozzle lows down to create the next adjacent layer. As the layering process completes, the 3D model is developed.

The design fed into the 3d Printer is a digital one which is first formed on some CAD Software. The materials used mostly for FDM Technique are ABS, Polyethyleneimine, and PEEK & Polyethylene terephthalate. These polymers in the form of a filament are fed through a nozzle and after melting, lay on the build platform, cool down eventually and form solid layers. This platform and the nozzle, both are computer controlled. The computer works according to the design instructions provided by the CAD file of the final product.

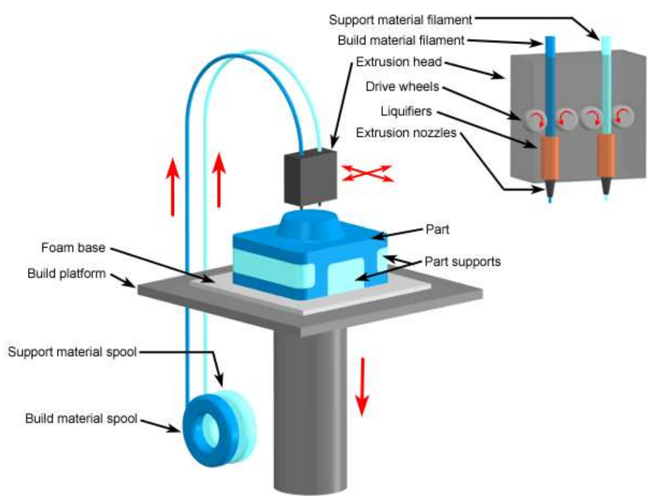


Figure 1: Schematic of FDM Printing

4.1.2 Advantages of FDM Technique:

For the development of our mold, we chose FDM technique because it has the following advantages over the other 3D printing techniques:

Easy to handle:

The easy handling comes through the simplicity of the manufacturing technique, easy prototype testing, easy alteration in the test prototype and then faster & better production of the finalized object.

Cost Effectiveness:

The FDM technique is cheaper & effective than the other printing techniques for the production of our mold. The reason is, through FDM, we get an overall lower prototype development, test and & product manufacturing cost.

Wider Range of Material Choice:

One of the major reasons to use FDM as our production method was that, the materials used in this technique are easily accessible & relatively cheaper. This technique also enables us to use multiple materials at the production time which enables to develop complex objects and multiple colors become available for the print thus giving a flexibility of choice of materials.

Lesser Post-Processing:

Through this technique, time for production is optimized, money saved & a better product developed. The best part is that readily available products are developed with less processing needed to carry out after the printing process thus creating less fuss.**.تم تحديد مصدر غير صحيح**

4.1.3 Selection of the suitable FDM Printer:

For the development of our product, the choice of the right FDM Printer was essentially important. Three major factors that were kept in mind while selecting the printer were build volume, technical printer specifications & the printable materials.

1. Build Volume:

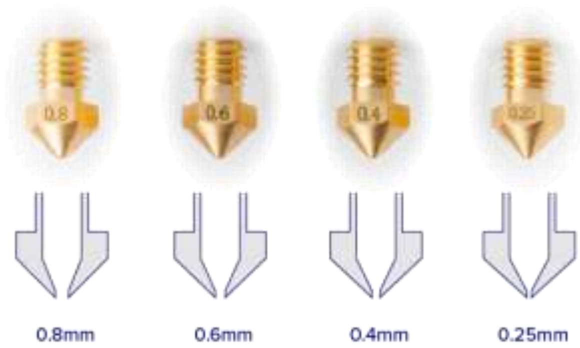
The design size is a major factor in the selection of the suitable 3d printer. Also, batch printing of the product (optional) decides the build volume of the production. Hence these two aspects were duly kept in mind while choosing our FDM printer.

2. Printer Technical Specifications:

The printers available for the purpose are mostly specific to the purpose of use. For this reason, the technical specifications of the printer is the foremost deciding factor in the 3D printing processes. Other than build volume discussed above, the following specifications are also checked while selecting our specific printer;

- Extruder/Nozzle:

Every polymer material used for the product manufacturing through FDM printing has its own unique melting temperature. Hence, an extruder able enough to handle the molten material used should be applied for the printing purpose.**.تم تحديد مصدر غير صحيح**



- Resolution:

The resolution is related to the thickness of the layer. A higher resolution means a thinner layer. Resolution if often taken in micron units. As per calculations, a 10-micron resolution means the layer has an average thickness of about 0.01mm. So, the optimum resolution for the development of our mold was required because a faulty layer size can lead to issues in strength of the final mold developed.

- Speeds:

While selecting the best suited FDM printer, two speeds were considered. These are travel and printing speeds. The travel speed corresponds to the speed of the nozzle movement between different points over the print bed in non-printing stage. Whereas, the print speed corresponds to the speed at which printing of a single layer is carried out.

3. Printable Materials:

The choice of print materials largely affects the choice of FDM printer used. Every material has its own characteristics. For instance, the melting temperature of PEEK polymer is extremely high and not all FDM printers are able to withstand this temperature. Thus, a specific printer is required according to the polymer material used. Also, a choice has to be made between the closed & open filament systems. Closed filament system means that certain companies manufacture FDM printers that can only work with a specific work material while in open filament system, the choice of material is open to the user.

Thermoplastic Materials	**Acrylonitrile Butadiene Styrene (ABS)**	**Polylactic Acid (PLA)**	**Polyether Ether Ketone (PEEK)**	**Polyether Imide (PEI)**
Printing temperature (°C)	220–250	190–220	350–400	355–390
Properties	High strength, flexibility and durability	Biodegradable, biocompatible, brittle	High mechanical strength, toughness, flexibility, chemical and radiation resistance, self-extinguishing properties	High specific strength (strength-to-weight ratio), flame resistance, chemical resistance
Applications	Pipe systems, automotive, toys, electronic casing	Biomedical, drug delivery systems, food packaging	Electronics, aerospace, automotive, mechanical and medical parts	Medical, chemical instruments, aerospace, automotive, electronics

Figure 2: Materials used for FDM Printing

All of these factors were kept in mind and then the printer required for the purpose was selected.

References:

References

Campbell, J. (2003). Casting. Butterworth-Heinemann Limited.

Snelling, D. (n.d.). THE EFFECTS OF 3D PRINTED MOLDS ON METAL.

METAL, T. E. (n.d.). THE EFFECTS OF 3D PRINTED MOLDS ON METAL. 19. Retrieved October 2019, from https://sffsymposium.engr.utexas.edu/Manuscripts/2013/2013-66-Snelling.pdf

William J. Weadock, C. J. (2019). 1. Use of 3D Printed Models to Create Molds for Shaping Implants for Surgical Repair of Orbital Fractures. Retrieved 2019, from https://www.sciencedirect.com/science/article/pii/S1076633219303733

Shakeri, b. M. (2018). 2. Fabricating smooth PDMS microfluidic channels from low-resolution 3D printed molds using an omniphobic lubricant-infused coating . Retrieved from https://www.sciencedirect.com/science/article/pii/S0003267017313417

Chowdhury, C. O. (2019, Febraury 15). 3D printed elastic mold granulation by. *344*. Retrieved 2019, from https://www.sciencedirect.com/science/article/pii/S0032591018310465

Chapter 5: Project Management

5.1: Project Plan

There were a number of tasks to be done for the project completion. All the members of the group were assigned different tasks. A general view regarding the project tasks, the group mates, & the completion period of each task is drawn in the form of the table below:

<table>
<tr><th>#</th><th colspan="2">Tasks</th><th>Start</th><th>End</th><th>Duration</th></tr>
<tr><td>1</td><td colspan="2">Chapter 1: Introduction</td><td>Sep2</td><td>Sep 7</td><td>5</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Chapter 2 : Literature Review</td><td>Project Background</td><td rowspan="3">Sep8</td><td rowspan="3">Sep 13</td><td rowspan="3">5</td></tr>
<tr><td>Previous Work</td></tr>
<tr><td>Comparative Study</td></tr>
<tr><td></td><td></td><td>Design Constraints & Design Methodology</td><td></td><td></td><td></td></tr>
</table>

3	Chapter 3: System Design	Engineering Design Standards	Sep 14	Oct 11	25
		Theory & Theoretical Calculations			
		Project Subsystems & Selection of Components			
		Manufacturing & Assembly			
4	Chapter 4: System Testing & Analysis	Experimental Setup, Sensors & Data	Oct 14	Oct 19	5
		Results, Analysis & Discussion			
5	Chapter 5 : Project Management	Project Plan			
		Contribution of Team Members	Oct 21	Oct 29	7
		Project Execution Monitoring			
		Challenges & Decision			
		Making			
		Project Bill of Material & Budget			
6	Chapter 6: Project Analysis	Life Long Learning	Oct 30	Nov 5	6
		Impact of Engineering Solutions			
		Contemporary Issues Addressed			
7	Chapter 7: Conclusions & Recommendations	Conclusions	Nov 6	Nov 11	4
		Future Recommendations			

8	Design of Prototype				
		Initial CAD Design	Nov 12	Nov 17	5
		Amended CAD Design	Nov 18	Nov 24	6
9	Manufacturing	Manufacturing of 1st Prototype	Nov 24	Nov 30	6
		Manufacturing of 2nd prototype			
10	Testing	Testing of Apparatus	Dec 1	Dec 12	12
		Testing of the Initial & Final Prototypes			

No	Tasks	Assigned Members
1	Chapter 1: introduction	All
2	Chapter 2: Literature Review	Abdullah Al-Askar
		Faisal Al-Humaidi
		Fahad Al-Shuaibi
3	Chapter 3: System Design	All
4	Chapter 4: System Testing & Analysis	All
5	Chapter 5: Project Management	Abdullah Al-Askar
		Turki alghamdi

		Faisal Al-Humaidi
6	Chapter 6: Project Analysis	Abdullah Al-Askar
		Faisal Al-Humaidi
		Turki alghamdi
7	Chapter 7: Conclusions & Recommendations	Abdullah Al-Askar
		Fahad Al-Shuaibi
		Iftikhar Islam
8	Design of Prototype	Abdullah Al-Askar
		With Mr. Taha's help
9	Parts Purchase	All
10	Manufacturing	Abdullah Al-Askar
		Turki alghamdi
11	Testing	All

5.2: Contribution of Team Members:

All the tasks to be completed for the project were allocated to one or more than one group members. The dependence of this relied on the capability to efficiently do the task & furthermore, the time period that the task would require. The percentage contribution of members along with the task division among the project members is provided here below in tabular form.

No	Tasks		Assigned	Percentage Cont.
1	Chapter 1: Introduction		All	
		Project Background	Askar	33.3%
			Ghamdi	33.3%
			humaidi	33.3%
			Ghamdi	33.3%

	Chapter 2: Literature Review	Previous Work	Humaidi	33.3%
			Askar	33.3%
		Comparative Study	Askar	50%
			Iftikhar	25%
			shuaibi	25%
	Chapter 3: System Design	Design Constraints & Design Methodology	Turki	25%
			Fahad	15%
			Askar	50%
			Iftikhar	10%
		Engineering Design Standards	Askar	100%
			Askar	100%
		Theory & Theoretical Calculations	Askar	100%
			Askar	100%
			Askar	100%
		Product Subsystems & Selection of Components	Ghamdi	50%
			Humaidi	10%
			Askar	40%
		Manufacturing & Assembly	Turki ghamdi	70%
			Askar	30%
	Chapter 4: System Testing & Analysis	Experimental Setup, Sensors & Data	humaidi	65%
		Results, Analysis & Discussion	shuaibi	35%
		Project Plan	Askar	20%
		Contribution of Team Members	askar	20%

	Chapter 5: Project Management	Project Execution Monitoring	T ghamdi	20%
		Challenges & Decision Making	Askar	20%
		Project Bill of Material & Budget	T ghamdi	20%
6	Chapter 6: Project Analysis	Life Long Learning	Iftikhar	10%
		Impact of Engineering Solutions	askar	60%
		Contemporary Issues Addressed	humaidi	30%
	Chapter 7: Conclusions & Recommendations	Conclusions	Shuaibi	80%
		Future Recommendations	Askar	
	Design of Prototype	CAD Design	Askar	100%
		Amended CAD design		
	Manufacturing	1st prototype Manufacturing	Ghamdi	70%
		2nd prototype manufacturing	askar	
	Testing	Testing of Apparatus	All	100%
		Testing of the Initial & Final Prototypes		

5.3: Monitoring of the Project Execution:

The progress and enhancement of our project work was dependent upon many factors and activities. These factors included the meetings, the project presentations, the preparation of the prototypes, etc. Below provided is the outline of the important activities, meetings and events concerning out project during the semester.

Time & Date	Important Activities & Events

Once a week	Assessment Class
Weekly	Meeting between group mates
Biweekly	Meet up with Advisor/Co-Advisor
Nov 28	Finishing First Prototype
Nov 12	Mid Term Presentations
Dec 1	First Test of the System
Dec 6	Finishing Final Prototype
Dec 8	Test the system
Dec 10	Final Submission of the report
Dec 13	Final Presentation

5.4: Challenges & Decision Making

As the project activities and tasks progressed, we had to go through some issues & problems that affected the project pace.

Listed below are the main issues that we went through in the project duration:

1. Equipment & Design related Issues
2. Testing & Safety related Issues.
3. Design related issues

5.4.1: Equipment & Design related Issues:

Use of a number of tools and numerous devices was made during the project. These tools were used in both, the manufacturing stage of the project and then the testing phase of the project. But there were various technical issues related to these tools and devices. But these issues were successfully tackled and it was assured that everything worked just fine.

- FDM 3D Printer:

The FDM 3D Printer used for the development of the mold was checked before the project start and it worked fine. But during the printing of the mold, it presented various issues. The sensors that directed the movement of the nozzle according to the CAD design of the part sometimes stopped. Thus, we had to troubleshoot the machine and restart it. Also, there were some issue in the connection lead of the 3D Printer because the machine sometimes turned off on its own. Thus we had to replace the lead. All these issues were addressed in time, therefore preventing them to cause any delay in the project duration.

- Nozzles:

The nozzles used were of different sizes. We brought the best quality nozzles from our point of view. But still, there were a number of issues faced with these nozzles. The first issue was that some of the nozzles did not fit easily into the printer and we had to struggle with such nozzles. Also one of the nozzles was not ejecting the molten polymer correctly. An issue regarding the temperature of the nozzles was also faced. The temperature resisting ability of one of the nozzles was not good and it was overheating. Thus, we had to replace it. This issue needed some time and it affected the progress of the project. But in the end, we tackled this problem and finished the project in time.

5.4.2: Testing & Safety Issues:

In the testing phase, we first tested that the whether the apparatus was working correctly or not. And the problems of the apparatus were presented in the above section with their solutions. After that, the testing of the prepared mold was also conducted. Firstly, the initial prototype of the mold presented some issues. The riser and the gates were not of proper dimensions. Also the gates presented blockage for the molten metal to pass into the mold. The dimensions of the knockout and layout holes were also not correct in the first prototype. We had to address all these issues and produce a 2nd prototype. The safety of the apparatus in the operation phase and the safety of the students operating the apparatus was our utmost priority. But the unavailability of the safety equipment was a major problem and we had to write an application to the department to provide the proper safety equipment for the efficient performance of the experiment.

5.4.3: Design related Issues:

The design initially presented to the 3D FDM Printer had some problems in the dimensions. Due to this issue, the dimensions of various parts of the 1st prototype were not according to the required design. The issue was then addressed by making amends in the CAD design of the mold and then printing a 2nd prototype with proper dimensions.

All these issues were addressed but some delay in the project duration was caused gradually. In the end, the all issues were resolved to bring the pace of the project back on the track.

5.5 Project Bills of Materials and Budget

The table below the budget of the project and the expenses that were made on every part purchased for the project.

Table 1: Bill of Materials

Materials	Costs (SR)

3D Printing Shop (Plastic Printing)	1995.5 SAR
Total	2000 SAR

Chapter 6: Project Analysis

6.1: Life Long Learning:

While working on this project, we developed a good skill set which a professional personal requires in his/her professional & personal career. The project taught us time & resource management capabilities, effective & brief communication skills along with the essential technical skills. This part of the report focuses on all these skills and experiences gained while working on this project:

6.1.1: Software Capabilities:

The project enabled us to thoroughly learn some important technical & analytical softwares. The basic softwares that we learned while doing the project were Microsoft Office & SolidWorks. As clarified in the prior sections of the report, SolidWorks was used to create the CAD model of the pattern to be developed through 3D Printing. This proved to be extremely beneficial for us as we learned the different aspects of computerized designing of a specimen with all its aspects. Microsoft Office was basically used for the overall documentation of the different stages of the project. For example, we developed a thorough budget sheet of the project and various required graphs using Microsoft Excel. Microsoft Word was used for thesis writing and we explored different tools of these softwares while performing these tasks.

6.1.2: Hardware Capabilities:

For the collection of the necessary data, the use of different equipment was made. The most important machine that we learned was the FDM 3D Printer. We went through different stages from selecting the optimum printer for our project to learning the specifications & technicalities of the working of the 3D Printer. This hence enabled us to gain enough knowledge to make a good choice & developing good 3D printed models according to the requirements. Also, we had to go through a number of thermoplastic polymers for the selection of the best material for our project. This provided us with a good knowledge about the mechanical & thermal properties of different materials.

6.1.3: Time & Resource Management Capabilities:

The most important skill that our project enabled us to learn was time & resource management. To meet the project deadlines timely, each member played its role by completing the given task in time for the successful completion. Also, we learned about resource management through our project. As we could only buy a limited amount required material like the thermoplastic polymer, different nozzles, etc., with the decided project budget, this pushed us to make optimum use of the materials available keeping the wastage low and thus the productivity high. An extremely helpful tool in this was the project's Gantt Chart.

6.1.4: Project Management:

For the effective performance of the team, the project partners were divided into different teams. For example, procurement team, documentation team, experimentation team, etc. Also to ensure that every member has a keen knowledge of the activities of the project, we switched the team members time to time. This helped us a lot not only to relieve the stress off from the group members but also enabled us to gain expertise in every aspect of the project. This was how the project management was done.

6.1: Impact of Engineering Solutions:

The project also contributed towards different aspects related to economy, environment & society. This segment of the report focuses on the various impacts made by the project in the terms as discussed above.

6.2.1: Economy

The development of the 3D Print Molds for the patternless metal casting will reduce the cost of the overall process of casting. More complex metal castings will be produced in lesser time and at a much less cost. Also, the usability of the 3D developed mold will be higher and it will save even more project costs because it will make us able to achieve small scale productions.

6.2.2: Environment

The project also contributes towards environmental sustainability because for the developments of the molds, the convectional processes like casting are hence excluded and thus the gases that escape during these conventional processes are hence controlled. The reason is that the development of 3D printed molds doesn't involve any escape of gases and its usability is also higher.

6.2.3: Society

The project we opted contributes positively towards the society in the sense that it eliminates any dangers involved in the conventional process because the 3D printing process is fully automated. Also, the health of the workers is not compromised because of the elimination of harmful gases.

6.1: Contemporary Issues Addressed:

There are a lot of controversies present about FDM 3D printing. Among these are laws related to encroachment of intellectual property, manufacturing of harmful drugs & ammunition for criminal purposes, complying with the international FDA standards and the ethical considerations. The finalized product of FDM printing still requires intense processes like friction weld, rivet, sand, painting, etc

Chapter 7: Conclusions & Future Recommendations:

6.1: Conclusions:

The projects that we opt in our academic life not only help us in industrial fields but in the various aspects of life as well. This project helped us a lot in gaining new & detailed experiences, enabled us to develop much better personal and professional communication capabilities, and we learned a lot of new aspects. The knowledge and the broader outlook that this project helped us to achieve will surely make us interested in different projects of the same approach in the future. We produced a 3D printed mold and then tested it for the patternless metal casting. The project had roots in manufacturing technology, material sciences, and mechanical systems. We learned how to develop a more society friendly, more economical and environmental friendly method to produce the metal castings that were casted early on with complex and dangerous methods. Also, we arrived to the conclusion that the use of FDM 3D printer for the production of mold was cost effective, included less post processing, was easy to handle and consisted of a wider material choice. We were also able to enhance our software capabilities by using different technical & analytical softwares, specially SolidWorks. The problems faced in the project were during the selection of the proper material and the most appropriate 3D printer, and the right operation of the 3D printer according to the CAD design of the mold. We selected the printer based on the factors of build volume, technical specifications & the printable materials. We found a number of compatible materials fit for use according to the purpose-specific molds produced.

7.2: Future Recommendations

There can be a number of possible schemes that can improve the project even further. The layer height should be selected very carefully. Usually, there exists a tradeoff between layer height, costs & build time. Putting thinner layer ultimately means that the build time is going to be increased & so is the cost. The optimum wall thickness of the mold to be printed should also be considered to save time & material. After that function of the part has been decided, the best technologies & materials should be used for the purpose. The weight of the mold should also be taken as a major consideration as this mold will be used to manufacture the castings in the future & it has to have a good value of strength itself. Functions like ID-Light or Sparse-Fill Options can be applied for the purpose. This customized function prints structures similar to lattices in the walled parts utilizing lesser material and decreasing the build time. Although, FDM 3D printed models require very less post processing, methods should be developed to get a more finalized part at the end of the printing process to eliminate the need of post processing. This too will save the labor cost & build time.

PRESENTATION

جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

Design and Development of a 3D printed mold for Patternless Metal Casting

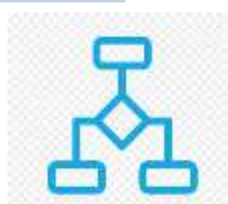
Turki Al-Ghamdi	201502772
Iftikhar Islam	201102432
Abdullah Al-Askar	201501266
Faisal Al-Humaidi	201400644
Fahad Al-Shuaibi	201500623

Advisor: Dr.Mohammed Azhar Khan
Co-Advisor: Mr.Taha Waqar

OUTLINE


Introductio


Objectives


Flow


Mold Design & Constraints

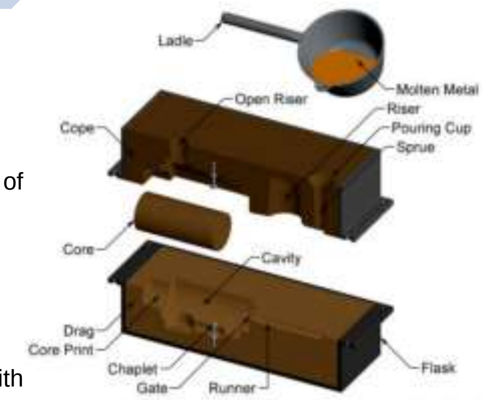

Timeline


Conclusion

INTRODUCTION

Metal casting

- Old Process
- Liquid Metal is poured into a mold containing a hollow cavity of required shape and allowed to solidify



Patternless Casting

- Doesn’t need a pattern and inside uses a CAD built design with required specific details.
- Utilizes CNC and advanced technologies like Selective laser sintering for development of parts with complex shapes and geometries

3D Printing

3D Printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers or material

3D printing begins with a CAD 3D design model which is then used to send specific instructions to the printer about the **amount, location** and **type** of material to use.

Using 3D digital CAD model as the **blueprint**, successive layers of materials are precisely deposited or fused by a computer controlled print head into the desired 3D shape.

No machining of the part is required, thus no raw material is wasted

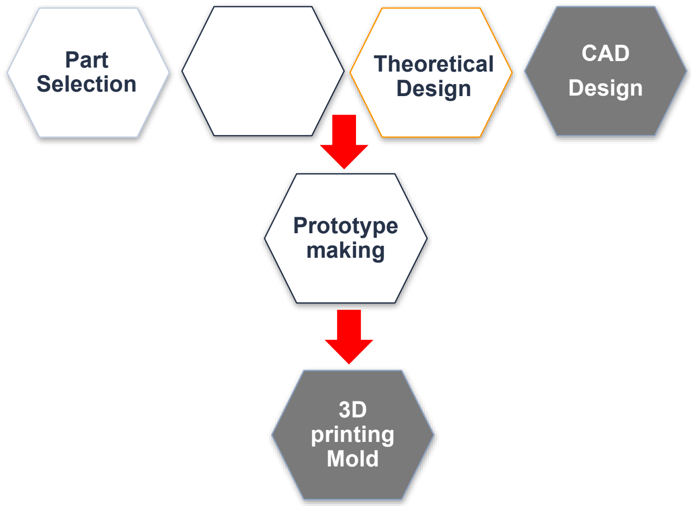
Motivation

- As 3D printing has emerged as a very efficient tool in the field of manufacturing, reducing time and it is economically better for large quantities, so we decided to use 3D printing for patternless metal casting.
- To develop a mold and a complex part using a low temperature alloy while considering all standards.

Objectives

- To develop a technique for the design and development of mold, which does not even require a pattern.
- To design a mold, which can help in reducing the total time required for the manufacturing of any component through casting.
- This project is aimed to assist the manufacturing of bulk components through casting with geometric freedom.

Flow Chart



Standards and Calculations

- **ASTM** standards were followed:

- **ISO / ASTM52910 – 18** – *Additive manufacturing design requirements.*
- **ASTM B86 - 18 -** *Standard Specification for Zinc and Zinc-Aluminum (ZA) Alloy Foundry and Die Castings.*
- **ASTM B949 - 18** - *Standard Specification for General Requirements for Zinc and Zinc Alloy Products*
- **ASTM E2349 - 19** - *Standard Practice for Safety Requirements in Metal Casting Operations*

Sprue Height

For top gate, H=h

For bottom gate, $= h - \frac{c}{2}$

For parting gate, $= h - \frac{p^2}{2c}$

Runner

$$= \frac{1/2 \times 1/4}{3.7}$$

$= 1.25$

Gates

$= \ _v + 1\square$

$= \ + 1.5\square$

Riser

$$- = \frac{}{2(\ +\ +\ )}$$

Solidification time $_s = \left(\frac{V}{SA}\right)^2$

Take $_s = 1.6\square$. Then $= \frac{t_s}{(V/A)^2}$

$= 3.26\square^{min}/_{cm^2}$.

By Chvorinov's rule,

$$_s = \left(-\right)^2$$

Riser dimensions came out to be $= 30\square$,$\square$

$= 142\square$

Mold Design

Part Selection

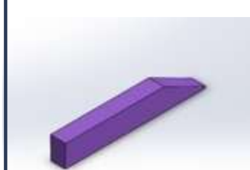
- Mounting Bracket
- Mass Production
- Produced by casting process normally
- Low temperature alloy
- Many application

Mold Design

Parts of Casting Layout

Pouring Basin and Sprue

Runner

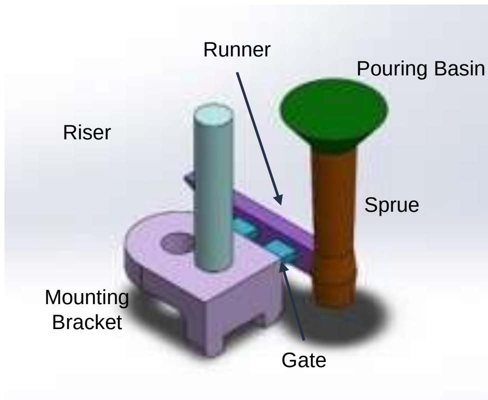


Gate

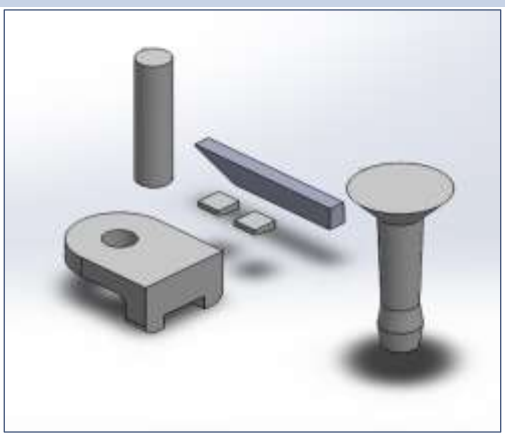
Riser

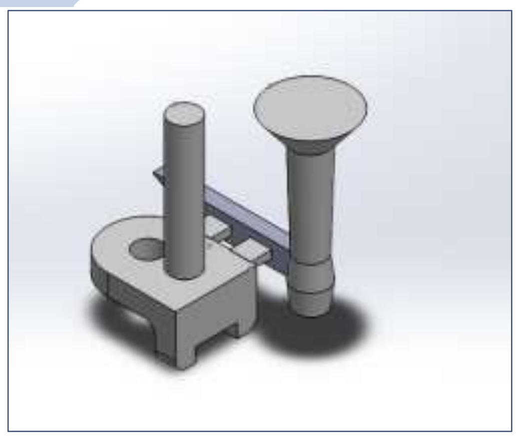
Mold Design

Casting Layout Assembly

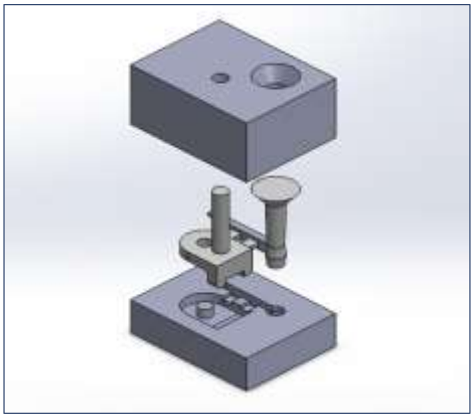


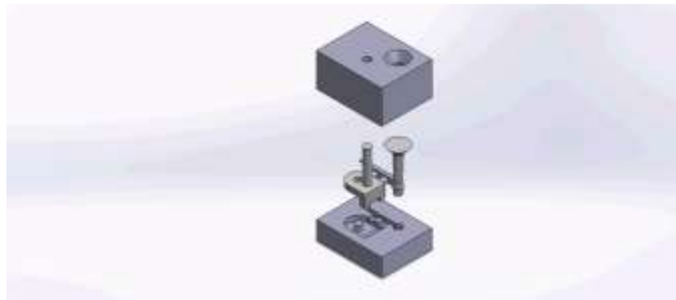
3D Modeling of MOLD in SOLIDWORKS





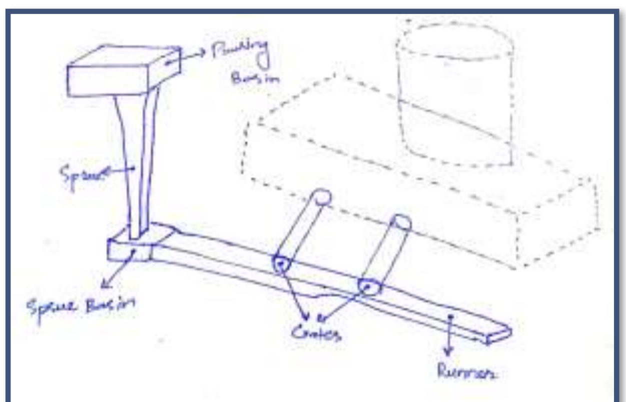
Assembly of MOLD





Design and Manufacturing Constraints

- The design which was made by hand is shown aside in the picture. It uses FDM and few changes were made in conventional geometry trends like cylindrical gates etc to gain manufacturing simplicity.
- For manufacturing, ceramic metrical was also an option but it was quite expensive.
- We selected PLA (Polylactic acid) for our prototype with following dimensions.
- Dimensions (cm): 15*15*5



Budget

Quote in case of Ceramic Material

Quotation

Date: 28/11/2019

To:
PRINCE MOHAMMED BIN FAHD UNIVERSITY
Dr Mohammed Azhar Khan
Mob +966 50 456 1806
mkhan6@pmu.edu.sa
KSA

Quotation # QT000011

Description	Qty	Unit price	Sub.Total
3D Printing Service			
Material Ceramic (Full color if texture available)			
Cope_v2 - Size (28cm x 14.1cm x 21.5cm)	1		944.000
Model in Cubic cm - 2360			
Drag_v2 - Size (28cm x 78.32cm x 21.5cm)	1		1,043.000
Model in Cubic cm - 2609			

Note : Unit price 400Fils/Cubic cm
Duration for print - 1 to 3 weeks
We can print in 2 to 3 working days but now one cartridge is out of stock and we placed the order that's why it may take up to 3 weeks to print.

Notes: Total **BD 1,987.000**

Budget

Quote in case of Plastic Material

We preferred this quote instead of the other because:

- **Plastic can work efficiently for low temperature alloys.**
- **It is cost effective.**
- **It is quite light in weight as compared to the ceramic.**

عرض سعر
Quote

نمذجة
namthaja

مؤسسة فيصل عدنان محمد العامر للصناعة
حي النهضة، شارع ابن الصاحب، الدمام
السعودية 34241- 966591727117+
الرقم الضريبي: 302255953200003

بيانات العميل
تركي الغامدي

رقم عرض السعر: 19136
تاريخ الإنشاء: 2019-12-04
تاريخ الانتهاء: 2019-12-18

#	المنتج Products	الكمية Qty	السعر Unit Price	الخصم % % .Dis	الضريبة VAT	الاجمالي Amount
1	002 - طباعة ثلاثية الأبعاد	1.0 وحدة	1900.0	0.0	95.00 ر.س	1,995.00 ر.س

الاجمالي قبل الضريبة: 1,900.00 ر.س
اجمالي الضريبة: 95.00 ر.س
المجموع: 1,995.00 ر.س

3D Printed Mold using FDM

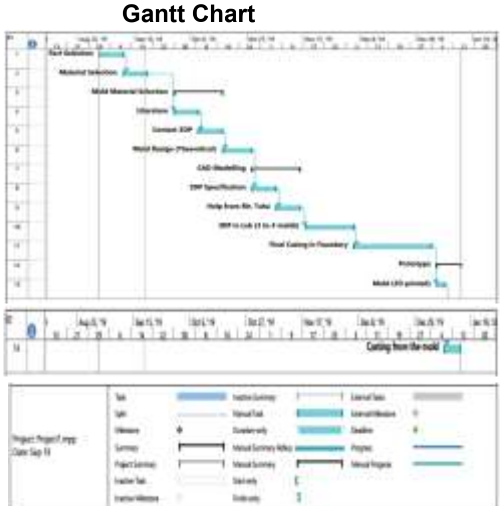
DRAG

COPE

3D Printed Mold

Timeline

Gantt Chart



WBS

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			Part Selection	7 days	Sep 2	Sep 10	
2			Material Selection	7 days	Sep 11	Sep 19	1
3			**Mold Material Selection**	**14 days**	**Sep 30**	**Oct 17**	
4			Literature	7 days	Sep 30	Oct 8	2
5			Contact 3DP	7 days	Oct 9	Oct 17	4
6			Mold Design (Theoretical)	7 days	Oct 18	Oct 28	5
7			**CAD Modelling**	**14 days**	**Oct 29**	**Nov 15**	
8			3DP Specification	7 days	Oct 29	Nov 6	6
9			Help from Mr. Taha	7 days	Nov 7	Nov 15	8
10			3DP in Lab (3 to 4 molds)	14 days	Nov 18	Dec 5	9
11			Final Casing in Foundary	21 days	Dec 6	Jan 3	10
12			**Prototype**	**7 days**	**Jan 6**	**Jan 14**	
13			Mold (3D printed)	3 days	Jan 6	Jan 8	11
14			Casting from the mold	4 days	Jan 9	Jan 14	13

CONCLUSION & FUTURE WORK

- A lot of work has been done on 3D printed molds but not for patternless metal casting.
- Patternless metal casting is relatively a new idea in metal casting.
- 3D printing of ceramics is relatively expensive
- This technique is cost effective and less time consuming only in case of mass production
- In future, a low temperature alloy can be cast to examine the defects in this mold
- Casting simulations can be done to predict the behavior of molten metal within the designed mold.

THANKS!

Any questions?

BROCHURE

BANNER

Prototype Pictures

Notes

&

Scratch Papers