ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
*A Peer Reviewed Open Access International Journal*

# Design and Analysis on Cast Mould Cavity with Cooling Channels for Titanium Flange

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## Abstract:

With increasingly usage of titanium flange in various shuttles and crafts which are necessary for high transportation systems. Casting is one of the main method for manufacturing the integrated components. But for the material which having high melting temperature it is an ineffective means of manufacturing process. The main phases involved in the casting are filling, cooling shrinkage and ejection. The main purpose of carrying out this project is to find out the thermal conditions on the mold and to understand the parameters like material, geometry, cooling medium etc. This work presents the design of the mold for casting and to produce less warping effect to the casted component during solidification.

Thermal analysis is performed on the mold by varying the parameters under the machines limits (Casting Machine). Thermal residual stress are also evaluated for understanding the mold design criteria. The objective of this project is to find how to modify the mold design based on the mold parameters, and to find out whether casting is a reliable manufacturing method for material like high melting points. The mold design is extracted from the CREO parametric 2.0 software, where the flange is first model and then the core cavity is extracted. Thermal analysis is performed on the mold for improving the mold design for better performance. The FEA analysis is carried out in ANSYS 15.0. The Analysis provides the information of thermal destitution of the mold ant the time of the molten metal is poured in to the mold cavity.

For every mold there will be a cycle time, here the analysis is done on its first stage. The results shows the shrinkage is observed near the cooling position. This uneven shrinkage will provides a wrapping effect in the mold. This project studied how to solve the wrapping problem by changing the material and its properties. Material like molybdenum, tungsten, and tantalum are used and finally it is proposed that tantalum Carbides is the best material among them all. The cooling time and shrinkage defects were the two factors contribute mostly on the cycle time and which the cost efficiency is reliant on it. Analysis of various models showed that with cooling channels location at a certain distance and temperature predicted the efficient cycle time and also the improvement in quality of product when compared to the machining process. The outcome of this project is where to place the cooling channels and how the thermal conductivity to be considered for the mold material will effects the cooling channels location.

## I. INTRODUCTION:

Among the manufacturing process casting is one of the oldest method for manufacturing components with integrated shapes and complex geometry. In casting molten metal such as metal or plastic is pore in to the mould, allowed it to solidify with in the mould for a certain time and eject from mould either by pulling or backing the mould to make out the product. Casting is one of the cheapest method for manufacturing the complex shapes, many geometrical shapes are able to manufacture by casting which are not that much of economical wile comparing to the other manufacturing methods [Campbell, 2003]. In casting mouldcavity are usually made sand, metal, plastic and other material which have hood surface finish properties and which have optimal thermal conductivity. The mould or the patter has the shape of the component that to be fabricated.When the mould is allowed for solidification there will be some shrinkage in the volume of the molten metal volume will reduced which will leads to an unequal size or shape of the product. So the patterns are usually made with an extra dimensions to compensating this phenomena. In casting this called as the allowance for the mould, these over side dimensions were depend on the molten metal properties. Usually by providing a raiser it will compensate the shrinkage volume problem. Developing a pattern in metal mould is very complicated thing and it required high skill and precision tools, because of this casting is lacking its effective position in the manufacturing tree.

But because of improvement in computers and modern mathematical logics given a solution and open the door for new type of manufacturing process. Now a days we can extract the complete mould for a component from software’s including the cooing channels, core and cavity, parting lines, splitting surfaces, runner, raiser, undercuts and many other features. In some software’s we can even get the NC codes for manufacturing the mould through CNC machinery. Numerous of these, countingcore, cavity, splitting curve, pattern, box derived from the part geometry, trailed by alteration to incorporate various allowances.

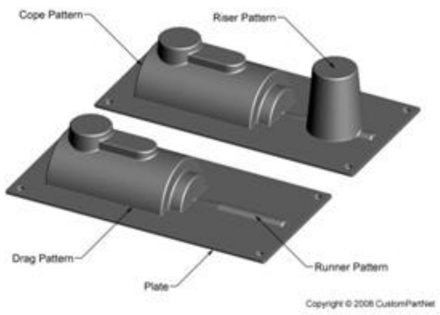

Figure 1: Pattern, core and core boxes

CREO-Parametric 2.0 is a potential tool that be useful for a product throughout its life cycle. With the help of this tool first the titanium flange is modeled in the part modeling interface and the model is imported to manufacturing workbench where the core and cavity are extracted. The generated core and cavity are generated by two piece split pattern method. After extracting the mould from the module it is saved as a part file for further analysis. After modeling the component is imported in to the ANSYS 15.0 of thermal analysis. This analysis is performed on the mold body to optimize the shape and size of the body. Since the objective of this project is finding out a better model and material for mould. In this thesis molybdenum, tungsten, tantalum and Tantalum Carbides are used as the mold material because of its high temperature melting point. The material properties are taken from the book High temperature material and mechanics by Yoseph Bar-Cohen.

## II. PREVIOUS WORKS:

A number of projects has been studied and analysis how to model the core and cavity and it effects on the overall cost of manufacturing and the productivity. A cost estimation analysis approach is available nowadays, Camargo and Rabenasolo had done there research on Application of the Parametric Cost Estimation in the Textile Supply Chain and Management, they developed a cost estimation logic for optimizing the casting process and they compared both conventional manufactured cost and CAD-CAM cost. D.E. Dimla a, M. Camilotto and F. Miani are contributed there research on Design and optimization of conformal cooling channels in injection mounding tools, in this paper they had studied the warping effect on the mould cavity. S.H. Tang and Y.M. Kong done there research on Design and thermal analysis of plastic injection mould, design of a plastic injection mould for producing warpage testing specimen and performing thermal analysis for the mould to access on the effect of thermal residual stress in the mould. S. Pipleya, D. Joshi had done there thesis entitled as Computer Aided Casting Simulation, Analysis and Pattern Cost Estimation, in which they explain how the

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tool can be used as the manufacturing level. Mo hdJamsheeda and MdAaqibRahmanb done their research on Design and Analysis of Plastic Injection Mould for CAM BUSHwith Submarine Gate.

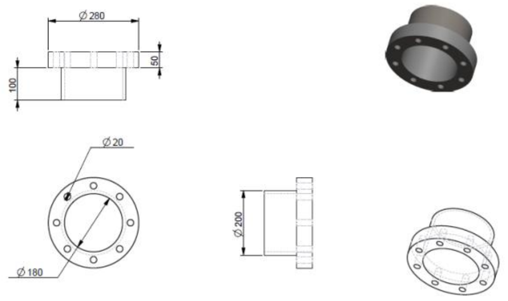
## III. Problem Definition:

Mostly casting process are applicable for the items which have a melting temperature around 1200°C to 1500°C, it is because of the mould metal. The main property of the mould material should be its melting temperature. It should be higher than that of molten material. Basically if we take steel as the molten material, them the pouring temperature will be around 1400°C, so the mould material should not show any plastic deformation at that temperature. The melting temperature of the both metals should in differ about 500°C. The problem is identified here, what kind of the material are to be used for high temperature materials like titanium. Titanium is one of the rear and costly material, manufacturing of titanium components are usually optimized. Flanges are one of the most commonly used item in piping industry, sometime flanges are manufactured by titanium, but is done by machining approach. In machining a lot of material is chipped out form the billet, converting those chips in to a billet is really a costly process and there is a lot scrap in it. So if we can manufacture the flanges by casting it will optimize the overall cost and productive. So to find out the better material and to improve the shape and size of the mould.

## IV. Mould Die Design:

To develop core and cavity of any component firstly the component to be model and then by using core cavity extrusion module, cavities can be extruded for the model. Here flange joint is used as the component and then core cavities are extracted. The procedural steps are given below

Step-1 Open the creo-2.0 parametric and select the part for part modelling.
Step-2 Now select the top view of the stranded datum planes and sketch the top view profile.
Step-3 By using extrude command extrude the sketch.
Step-4 Now select the bottom surface of the extruded body and then sketch the remaining portion of the body.
Step-5 Now apply the fillets and surface commends to model the component to realistic manner. The final model is shown below.



Step-6 Now save this model as flange and open the new part file and model nut and bolt arrangement for fastening purpose. Nut and bolts are to be models separately by using extrude command.
Step-7 Open assembly module for assembling the flange and fasteners to form a fitting assembly.
Step-8 Import the flange and make it as the default part. Assembling any model basic frame or part are necessary for working bottom up approach. Now call all parts and assemble them based on contains. The final assembled model is showed below.

**Fig-2. Assembled Flange joint**

Modelling the component is completed, now by using core cavity extrusion module cavity is generated from CREO- for above component for casting. The procedural steps are given below.

Step-1 Open the new window and select the casting cavity module.

Step-2 import the component from the local directory and create the outer rectangular cube where the cavity to be generated.

Step-3 After creating the work object shrink curve is to be define and the split patter to be generate.

Step-4 after click on generate two piece pattern cavity.

Step-5 now save the cavity separately for further modelling. The generated cavity is shown below.

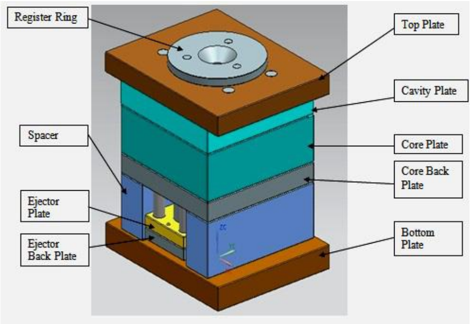


Fig 3 Solid Model of Mould Die.

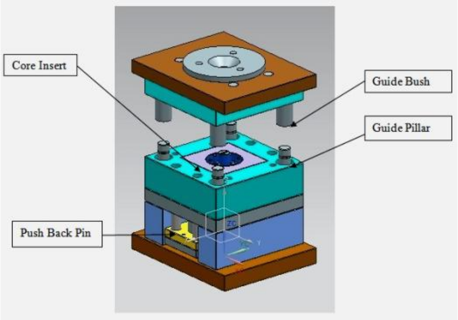


Fig 3.1 Solid Model Exploded View

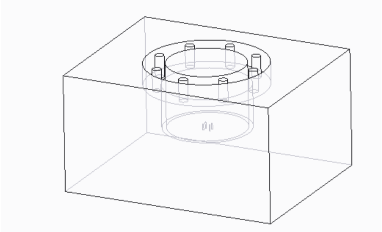


Fig-3.Pattern of the mould cavity.

## V. Thermal Analysis on Mould cavity:

a. Firstly material properties of the mold are to be inputted in to the ansys material library. The material used in this study is Tantalum Carbides and its thermal properties are taken from a book entitled as High Temperature Materials and Mechanisms by Yoseph Bar-Cohen

b. After completion of defining materials in ansys library it have to save and the return to the previse window by clicking on return to the project. Make sure that module is turn with a green tick mark at the right side of the tree, if u missed any essential information it will definitely won’t allow to solve the problem.

c. For importing the geometry in to the ansys, click on geometry module in the tree and then it will enter in to the ansys geometry work space. Make sure that the part is saved in .IGS format, otherwise it won’t read properly. After importing the geometry click on generate to generate the body.

d. After developing the geometry in the ansys geometry module, meshing to be done for solving the problem. For defining the mesh geometry window should be closed and then open the model module for defining the meshing and boundary conditions.

e. Open the model module from tree and then define the type of mesh and its refinement for getting better results. The small the mesh the better the results but if the mesh size is too small then the computational time will increases. So optimal mesh to be selected and check for convergence and then apply the same meshing conditions for the rest of the project.

f. By clicking on the mesh, a new window will open at the left bottom Corner of the screen by selecting the mesh refinement to fine and defining the spam angle to medial and smoothness to high. After fill the values in the mesh updated the project in ansys to generate the mesh body.

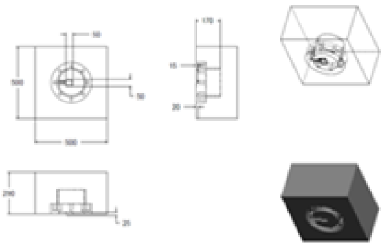
g. After updating the project meshed body will be shown in the window, total number of nodes generated in this analysis is 61631and the number of elements are 36849. Type of element used in this analysis is Solid-87

h. Now boundary conditions are to be defined, boundary conditions are classified as loading conditions and support conditions. In loading conditions temperature are to be defined and in support condition convection surfaces are to be define for solving the problem.

i. The red collected area is the area that contacts with the molten metal and the yellow surfaces are where the convection takes place through air. The molten temperature is considered as 1800oC, and convective co-efficient is calculated heat and transfer data book as 8 W/m2 K.
j. Now select the solution and define the output parameters such as temperature heat flux etc.
k. If coolant is used as the cooling medium there will be a slight change in the boundary conditions. In addition to the existing condition convection due to the coolant is also taken in to account and convective heat transfer co-efficient to be calculated.

In this project there are many parameters that to be studied, among them material is the one of the best parameter. There are total four different type of materials are used in this work they are listed below.

### VI. Design and Analysis:



The objective of this project is to find out a better mold cavity for high temperatures castings, there are few parameters which will affect the overall efficiency of the mold cavity they are listed below.

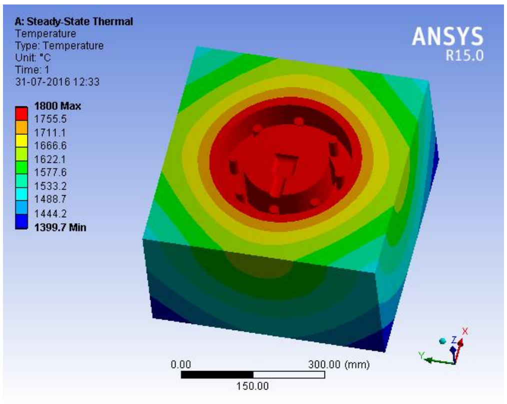
A. Mold Geometry.
B. Mold Material.
C. Cooling method.
D. Collet properties.
E. Time duration of cooling.

In this project, study is conducted on parameters Geometry, material and cooling method only. Because the remaining parameters are can only studied by experimentation.

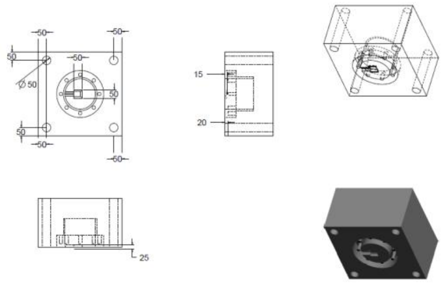
### Mold Geometry:

The Geometry of the mold will affect the overall heat transfer coefficient, surface area of the mold will directly effects the heat dissipation factor, so by modifying the geometry of the mold under varies cases and analyzing how it effects the overall efficiency. Firstly the geometry is developed from the Creo-2.0, the dimensions of the mold are taken from the existing machine. There are two limits for the mold poring machine, one is the minimum size of the mold and other one is maximum size of the mold. These two limes are the maximum and minimum sizes of the mold that can be accommodate in the machine. So firstly the minimum size is considered and the analyzed it with different modifications. Then the results and observations are carried out for the maximum lime mold.

**Case-1 model**



**Temperature distribution of case-1 model**



**Case-2 model**

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International Journal & Magazine of Engineering, Technology, Management and Research
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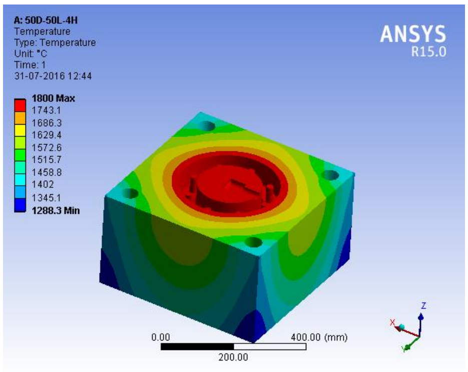
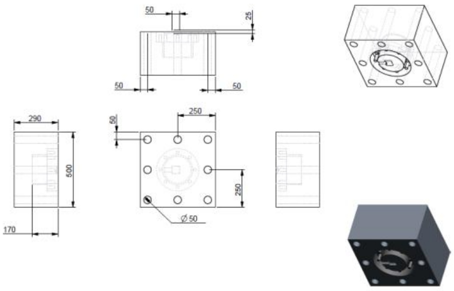
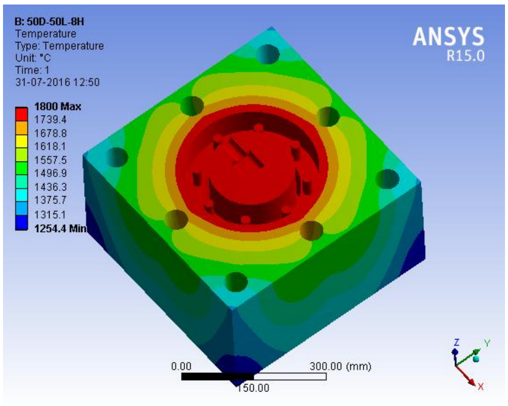


**Temperature distribution of case-2 model**

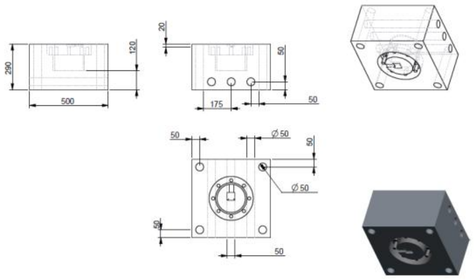
| Metal | Melting Point |  | Thermal conductivity (W/$m^2$ k) | Thermal expansion co-efficient (10-6 m/(m K))) |
|---|---|---|---|---|
|  | (°C) | (°F) |  |  |
| Molybdenum | 2620 | 4750 | 140 | 5 |
| Tantalum | 2980 | 5400 | 54 | 6.5 |
| Tungsten | 3400 | 6150 | 163 | 4.3 |
| Tantalum Carbides | 3800 | 6872 | 21 | 4.6 |



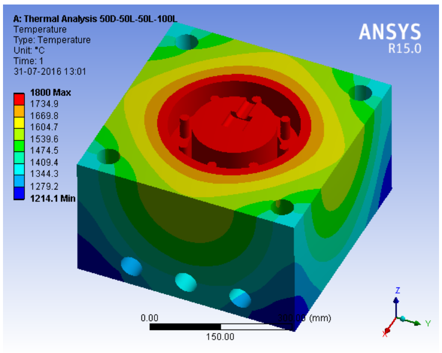
**Case-3 model**



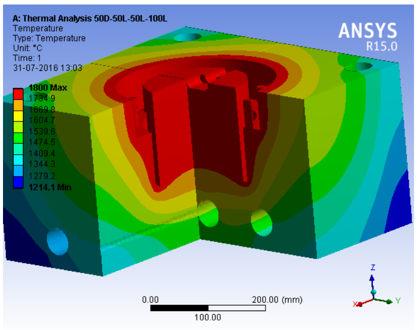
**Temperature distribution of case-3 model**



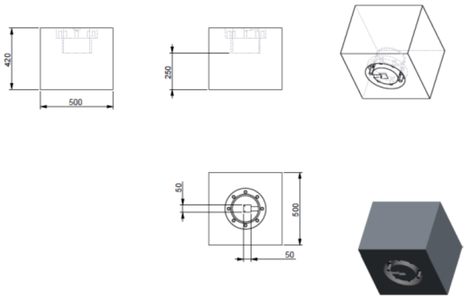
**Case-4 model**



**Temperature distribution of case-4 model**



**Temperature distribution of case-4 model**



**Case-5 model**

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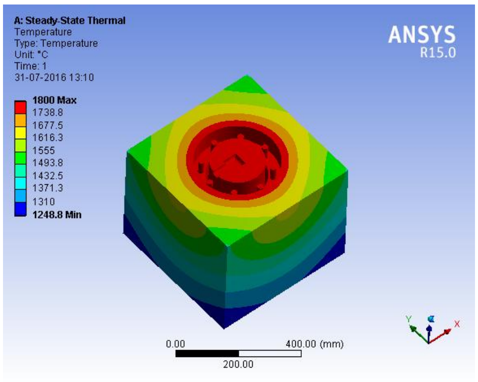
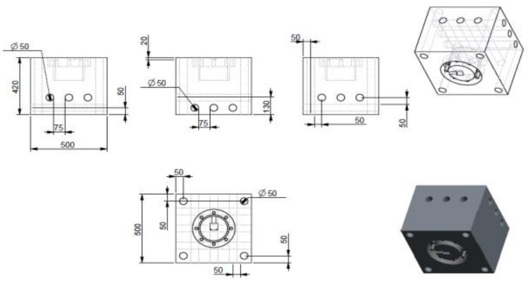
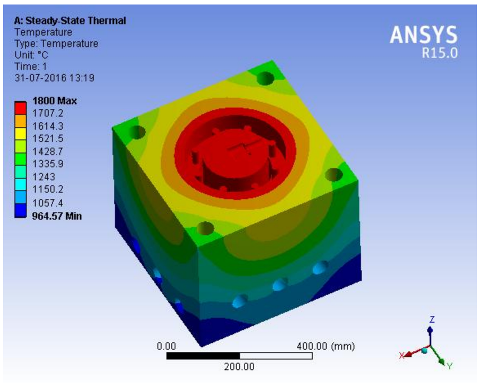


**Temperature distribution of case-5 model**

### Case-6 model



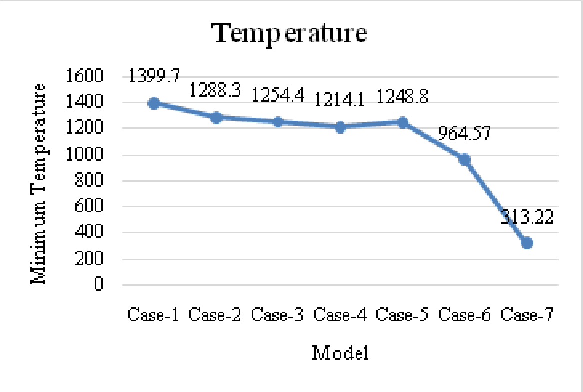


**Temperature distribution of case-6 model**

The list of all results are shown below and plotted in the graph.

| Model | Temperature |
|---|---|
| Case-1 | 1399.7 |
| Case-2 | 1288.3 |
| Case-3 | 1254.4 |
| Case-4 | 1214.1 |
| Case-5 | 1248.8 |
| Case-6 | 964.57 |
| Case-7 | 313.22 |

### Tabulated results of the minimum temperatures of all models

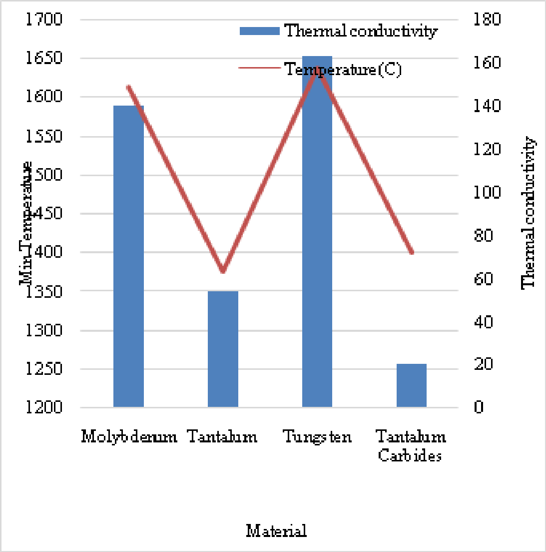


Graph of the temperature distribution.

### Mold Material:

Mould material place very important role in the cooling process. Better the thermal conductivity better the cooling rate, but if the cooling rate is high then there will be an uneven cooling zones, which leads to an uneven shrinking effect. To find that four material are considered and studied, from that it is proposed material Tantalum Carbides is the better one based on its melting temperature and on its thermal conductivity. Where comparing to the other materials Tantalum Carbides as the less thermal conductivity but for provisions of the dimensional constrains those are not use full for present problem. Because of the cooling channel, if we use either of the materials the width of the mould to be increased which is not possible for the present situation.

| Material | Thermal conductivity | Temperature ($^{o}$C) |
|---|---|---|
| Molybdenum | 140 | 1614.6 |
| Tantalum | 54 | 1375.5 |
| Tungsten | 163 | 1638.8 |
| Tantalum Carbides | 21 | 1399.7 |



## Cooling Method:

Instead of using air water is used as the cooling medium, because it is the cheapest and it has best convective heat transfer co-efficient rate. Heat transfer rate are calculated by using Dittus-Boelter Equation.

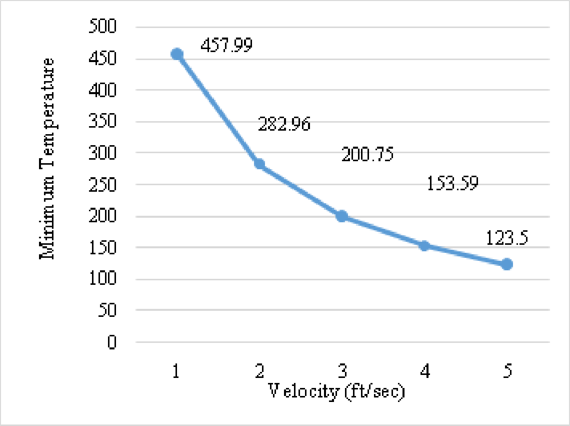
The convective heat transfer co-efficient is find out from mathematical approach. Five velocities are considered in this analysis, they are given below.

| S.no | Medium of coolant | Velocity (feet/sec) | Heat transfer coefficient ($W/m^2$-K) |
|---|---|---|---|
| 1 | Water | 1 | 44.65 |
| 2 | Water | 2 | 77.74 |
| 3 | Water | 3 | 107.54 |
| 4 | Water | 4 | 135.36 |
| 5 | Water | 5 | 161.82 |

Heat transfer coefficient of water at different temperature

| Velocity (ft/sec) | Minimum Temperature |
|---|---|
| 1 | 457.99 |
| 2 | 282.96 |
| 3 | 200.75 |
| 4 | 153.59 |
| 5 | 123.5 |

## Tabulated results of the temperature change with velocity



Graphical representation of temperature change with respective to velocity.

Mould ejection temperature should be 400°C so water at velocity 1 ft/sec is used as the final velocity. Since the thermal convective heat transfer co-efficient is used as the input, different type of coolant can used for this system and obtained same type of results while the heat transfer coefficient is constant.

## CONCLUSION:

Core and cavity creation for manufacturing procedure will changes from component to component, the process is not documented any ware because of it unstandardized approach for extraction of mould and patterns. Cooling channels, material, cooling medium etc. will depend on the particular problem and to a seatrain portion of materials, from this thesis it is concluded as fooling points.

1. Mould geometry to be optimism for the better cooling and strength factor, basically heat transfer in conduction process is much smoother than that of the convection process so cooling channels are to be placed where the mould temperatures are drop to the solicitation temperature. That means cooling channels are to be placed where the mould temperature is at its three forth of it melting temperature.

2. Mould material are to be selected based on the melting point and thermal conductivity, if thermal conductivity is increased then the distance between the cooling channels and the mould core increases.

3. Cooling material (cooling fluid) can be selected based on their boiling point and convective heat transfer co-efficient. General it can be selected any material and velocity which are equal to same heat transfer co-efficient then the results will be similar.

4. To reduce the warping effect there should not and abrupt change in the temperature in the system and cooling channels are to be placed properly to maintain this.

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