Flow pattern analysis of melted aluminum in shot sleeve of pressure dies casting and minimizing the defect

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Abstract— Cold chamber high pressure die casting, (HPDC), is a vital business process for the production of complex near net shape aluminum and magnesium alloy castings. The investigations were carried out mainly using the aluminum alloy. High Pressure Die Casting (HPDC) is a complex process that results in casting defects if organized inappropriately. Though, finding out the optimum construct is a quite uphill task as eliminating one of the casting defects (for example, porosity) can result in occurrence of other casting defects. The purpose of the project is to improve current modeling and understanding of defects formation in HPDC machines. An attempt has been made to analysis the flow behavior of metal (Aluminum) in HPDC injection chamber. The flow in the injection chamber of pressure die casting machines is analyzed using a model based on the shallow-water approximation which takes into account the effects of wave reflection against the end wall of the chamber.The results of the model for wave profiles, volume of air remaining in the injection chamber at the instant at which the molten metal reaches the gate to the die cavity, and optimum values of the parameters characterizing the law of plunger motion are observed to reduce the porosity defect.We found that, although the shallow water model does not provide a very accurate estimation of the mass of entrapped air in the injection chamber for certain ranges of working conditions, it does describe reasonably well the influence of the acceleration parameters and the initial filling fraction on the entrapped air mass, and can be of help in selecting operating conditions that reduce air entrapment while keeping the injection chamber filling time as low as possible.

Keywords—. CFD, Fluent, Gambit, Simulation, HPDC machine etc.

INTRODUCTION

Many researchs have been done in various domains like technology development, material development, etc to improve the pressure die casting process. Now a days, HPDC process is finding its application in numerous fields, consequently majority of researchers are paying attention towards utilizing the HPDC process in the areas like casting complex shapes, casting light weight components etc.

Sulaiman, Shamsuddin et al. (1997) [1] explain the Simulation of the molten metal flow along runner and gating system of pressure die casting is carried out to determine the pressure applied by the plunger of the injection system through the casting process and how angle of the runner and gating system influence it. The result shows that smaller branch angle will require less pressure to fill the runner and gating system. The time required to fill the runner and gating system takes longer when smaller branch angle is used.

X.P. Niu et al. (1999) [2] studied that High pressure die casting usually contain gas porosity due to the entrapment of air or gas in the melt during the very high speed injection . The benefit of with evacuated die cavity through mould filling was assessed. It was establish that volume of gas porosity in the casting were considerably diminished by applying vacuum aid during die casting. As a consequence, the density and mechanical properties, mainly tensile strength and ductility were improved. The result of vacuum support on the porosity distribution and mechanical strength of the castings were deliberated. An optimum injection speed was also identified for producing high performance castings. After heat treatment, vacuum assisted die cast parts showed much less surface blistering when compared to conventional die cast parts

K. H. Lee et al. (2000) [3] studied that a feasibility study of the partial squeeze and vacuum die casting process was performed to make defect free casting product with excellent mechanical properties. The mixture of vacuum effect before injection and the squeezing effect after injection results in exceptional flaw free die casting . In the die casting procedure the injection stroke can originate a jet of liquid to strike the far end of the mold cavity and then spatter back. This creates extreme turbulence which generates a plenty of air, and results flawed castings.

J. Lopez et al. (2001) [4] studied on the optimum plunger acceleration law in the slow shot phase of pressure die casting machine. The purpose is to examine a plunger acceleration that is supposed to diminish air trap in the slow shot stage of the pressure die casting to decrease porosity in parts. The results of the model for wave profiles, volume of air remaining in the injection chamber at the instant at which the molten metal reaches the gate to the die cavity, and optimum values of the parameters characterizing the law of plunger motion, are evaluated with the mathematical results obtained.

Haijing Mao (2004) [5] studied that externally solidify product (ECP) in the cold chamber die casting process has been done. The fraction of melt which solidifies in the shot sleeve before the metal is injected into the die cavity is referred to as externally solidified product.The objectives of this research is to examine what amount of ESP will travel into die cavity and final location of ESP in the casting.

Kallien, Lothar H (2009) [6] studies that Gas injection is a special technique which allows the production of hollow structure. The advantage of gas injection are free design of thick and thin wall in one part.In this process the cavity is filled with molten metal and after the partial solidificationwy the gas is injected in to the cavity. After total freezing the gas pressure is released.The result shows that the injection is applicable for relative complex geometries. Further release will deal with the optimization of the process with respect to later application in production and optimization of the internal surface structure that depends on the pressure and the alloy.

M. Sahu et al. (2009) [7] studied a CFD model of fully developed of laminar flow in a pipe is derived. Fluent is CFD software package to simulate fluid flow problem. Geometry and grid generation is done is GAMBIT which is further analyse in FLUENT. A solution can be obtain by following nine steps

1. Create geometry in GAMBIT.
2. Mesh geometry in GAMBIT
3. Set boundary type in GAMBIT
4. Set up problem in FLUENT
5. Solve
6. Analyze result
7. Refine mesh

Yoshifumi kuriyama et al. (2011) [8] studied an optimum velocity control of Die casting plunger accounting for air entrapment has been done. Die casting has the disadvantage, however, of air entrapment reducing product strength because it forces molten metal at high speed into a mold using a plunger. A multistage velocity control pressure die casting machine is used. Projection velocity is in between 0.02 to 5.0 m/s and acceleration between 4.23 and 4.61 m/s^2 .We set the Die temperature in between 110 to 150 degree celcius and molten metal temperature is 660 to 680 degree celcius. Evaluation of air entrapment amount - Using FLOW-3D to determine the air entrapment amount in the molten metal caused by plunger movement. Using casting CAE, we analyzed fluidity behavior, the amount of air trapped, and the amount of air shutting caused by a plunger moving to evaluate their effect on product quality.

Matti sirvio et al. (2012) [9] studied the simulation of the wave formation in the shot sleeve and all of its effects , such as air entrapment. By including the parameters and attributes of the die casting machine in simulation model, it is achievable to simulate the filling perfectly.
The present research explains the benefits of the Shot Sleeve simulations to achieve improved casting system design in HPDC castings. Investigation of filling is utilized to decide upon the size, location of the gate and runner design to make certain complete filling of the mould. Shot sleeve simulations in High Pressure Die Casting process ensures the minimum air entrapment during the pre-filling phase. The low velocity of the plunger enables the air to escape via parting line or vents.

Kuo, T.H et al. (1993) [10] studied the simulation in high pressure die casting by computer aided engineering (CAE). The filling and solidification behaviour related to product quality and defect forming mechanism. It reduce trial and error in workshop as the process is virtually realized and verified by computer. CAE simulation of the entire casting system reveals filling and solidification behavior in the casting process and identifies the necessary information related to product quality and defect formation.

Paul Robbins (2012) [11] studied the vacuumed assisted casting. The benefit of vacuum assisted die casting are many such as rejections due to porosity are virtually eliminated, excellent surface quality is practically ensured, product density and strength are increased, less casting pressure is required. The gap between the plunger and the wall of the shot sleeve is necessarily very small- only 0.004 in. If at any time during the slow part of the shot, the gap becomes much greater than this, air is likely to be sucked through gap.

Brevick, J. R et al. (1994) [12] studied the effect of entrapped gas in porosity of Aluminum Horizontal Cold Chamber Die Casting. Duran. M et al. (1991) [13] in their research tried to minimize air entrapment in the shot sleeve of a die casting to reduce porosity. Thome, M. C et al. (1993) [14] modelled fluid flow in horizontal cold chamber die casting shot sleeves. Sekhar, J. A et al. (1979) [15] studied the effect of pressure on metal die heat transfer coefficient during solidification.

METHODOLOGY

Shot sleeve related parameter

The parameters like

- Acceleration
- Stage velocities
- Diameter

The above parameters determining the formation of wave patterns which can be a crucial factor in deciding whether air becomes entrapped in molten metal. Shot command delay in the first process parameter is to be selected carefully. Another process parameter to be optimized is the first stage velocity. The vents should be big enough to let the air escape and also the runner should not have sharp corners.

CFD Software

- Commercial: Fluent, Comsol, CFX, Star-CD
- In-house codes: Edge (FOI), DLR-Tau (German Aerospace Center), Fun3D (NASA), Sierra/Premo (American Aerospace)
- Open Source: Open FOAM, FEniCS, OpenFlower

What is FLUENT?

FLUENT is a state-of-the-art computer program for modeling fluid flow and heat transfer in complex geometries. FLUENT gives total mesh exibility as well as the capability to explain your own problems applying unstructured meshes which can be create intricate geometries with comparative simplicity. FLUENT also allows you to refine or coarsen your grid based on the flow solution. FLUENT is written in the C computer language and makes full use of the exibility and power offered by the language. As a result, accurate dynamic memory distribution, efficient data structures, and supple solver run are all feasible. FLUENT also utilizes a client/server architecture, which permits it to run different concurrent processes on client desktop workstations. This architecture permits capable execution, interactive control, and complete flexibility between diverse types of operating systems. All functions required to compute a solution and display the results are accessible in FLUENT through an interactive, menu-driven interface.

Explaining how to use FLUENT cannot be done without discussing GAMBIT first. GAMBIT is an application that is distributed along with FLUENT. As of this writing, it is owned and distributed by ANSYS, Inc. GAMBIT is used as a tool to generate or import geometry so that it can be used as a basis for simulations run in FLUENT. It can either build a model or import existing geometries from various other CAD applications. With a geometry in place it generates a mesh for the surface and volume of the geometry allowing it to be used for computational fluid dynamics. FLUENT is able to read geometries generated in GAMBIT and model fluid flow within the. It can be modeled using CFD.

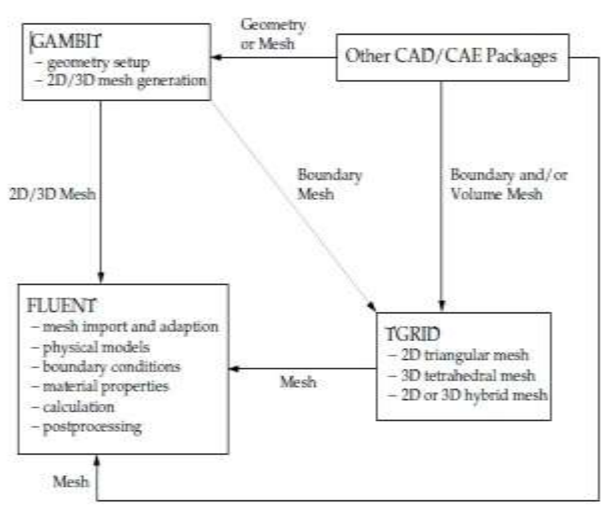

Fig 1. Basic fluent structure

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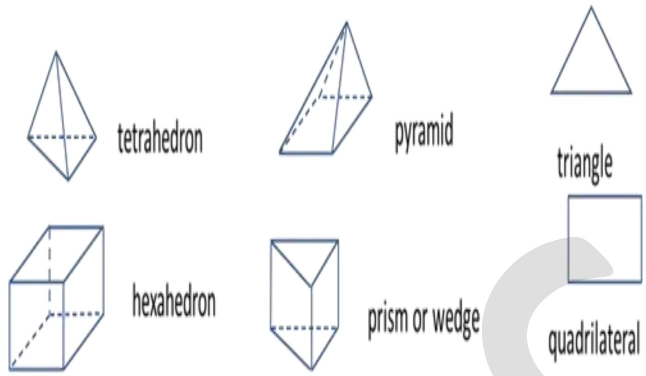

Fig 2 Types of grid

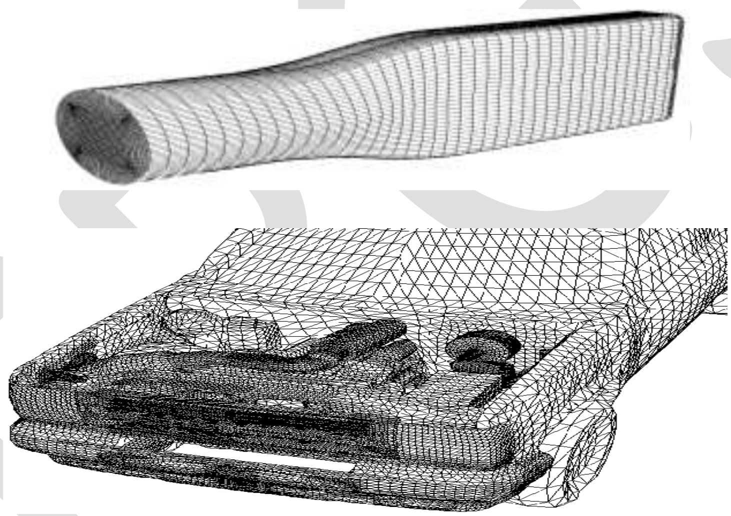

Fig 3. Grid shape in simple and complex geometry

Terminology-

- Cell – Control volume into which the domain is broken up.
- Node – Grid point
- Cell center – Center of cell
- Edge – Boundary of face
- Face – Boundary of cell
- Domain - Group of nodes, cells and faces

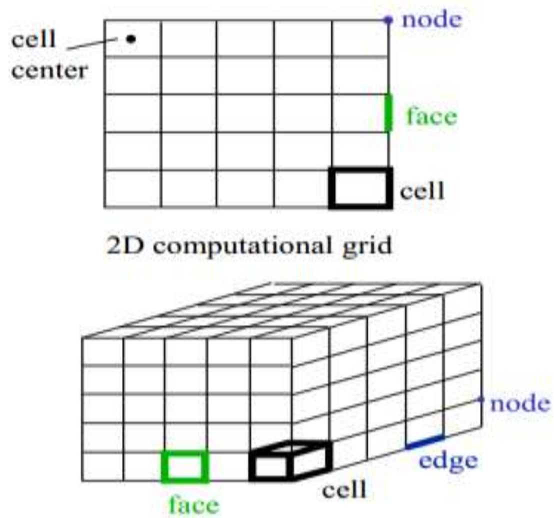

Fig 4. Domain type

CFD Procedure

I. Formulate the Flow Problem

The initial step is to generate the flow problem by answering to the questions as follows:

- What is the objective of the analysis?
- What geometry should be included?
- What are the freestream and/or operating conditions?
- What dimensionality of the spatial model is required? (1D, quasi-1D, 2D, axisymmetric, 3D)
- How the flow domain should look resemble to?
- What sequential modeling is suitable? (steady or unsteady)
- What is the nature of the viscous flow? (inviscid, laminar, turbulent)
- How should the gas be modeled?

II. Model the Geometry and Flow Domain

The body about which flow is to be analyzed requires modeling. This usually done using CAD. Rough estimates of the geometry and some simplifications may be involved to permit analysis with relative ease. Simultaneously, decisions are made as to the extent of the finite flow domain in which the flow is to be simulated. The geometry and flow domain are modeled in such a manner as to provide input for the grid generation. Thus, the modeling often takes into account the structure and topology of the grid generation.

III. Establish the Boundary and Initial Conditions

Since a finite flow domain is specified, physical conditions are required on the boundaries of the flow domain. The simulation usually begins from an initial solution and subsequent iterative results in final solution.

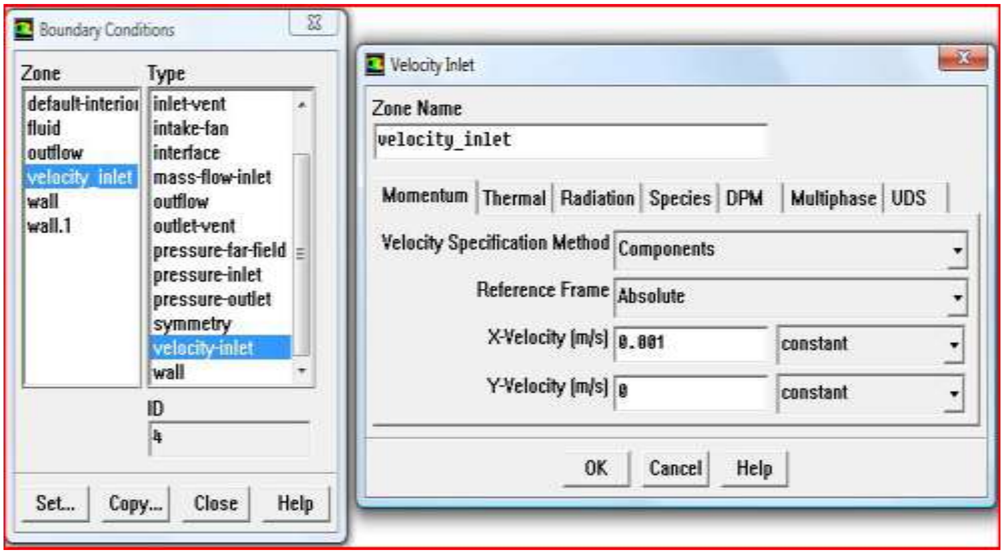

Fig 5. Boundary condition and velocity inlet window

IV. Generate the Grid

The grid creation defines the structure and topology. At present the entire cases under consideration are multi-block, structured grids; though, the grid blocks may be abbuting, contiguous, non-contiguous, and overlapping. The grid should exhibit some minimal grid quality as defined by measures of orthogonality (especially at the boundaries), relative grid spacing (15% to 20% stretching is considered a maximum value), grid skewness, etc.

V. Establish the Simulation Strategy

The strategy for performing the simulation involves determining such things as the use of space-marching or time-marching, the choice of turbulence or chemistry model, and the choice of algorithms.

VI. Establish the Input Parameters and Files

A CFD codes generally requires that an input data file be created listing the values of the input parameters consisted with the desired strategy. Further the a grid file containing the grid and boundary condition information is generally required. The files for the grid and initial flow solution need to be generated.

VII. Perform the Simulation

The simulation is carryout with a variety of possible alternatives for interactive or batch processing and distributed processing.

VIII. Monitor the Simulation for Completion

The solution is examined to find out whether "converged" solution has been achieved or not.

IX. Post-Processing involves extracting the desired flow properties (thrust, lift, drag, etc...) from the computed flowfield.

X. Make Comparisons of the Results

The computed flow properties are judge against the experimental studies to ascertain the legitimacy of the calculated results.

XI. Sensitivity Analysis

The sensitivity of the results is investigated with respect to the following parameters:

- Dimensionality
- Flow conditions
- Initial conditions
- Marching strategy
- Algorithms
- Grid topology and density
- Turbulence model
- Chemistry model
- Flux model
- Artificial viscosity
- Boundary conditions
- Computer system

XII. Document

Documenting the findings of an analysis involves describing each of these steps in the process.

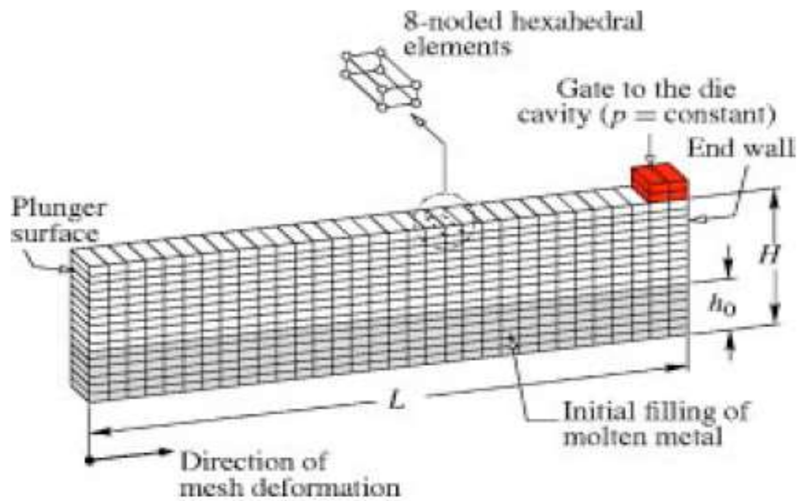

Fig 6. Grid formation in domain

EXPERIMENT

In order to achive the goal of this experiment work. , i.e. to establish the correlation between software analysis and real time condition, high pressure die casting machine is used. For the practical work Indore based industry " Triyami Tools" provide the HPDC machine. Two parts have been prepared , Engine cover and the automotive foot rests. The material used for this experiment is aluminium. It should be pointed out that the cast plates were also subjected to thermal treatments, i.e. Solution Treatment (T4: 2 hr at 470oC), Aging (Stress-Relief) (T5: 2 hr at 200oC), and Solution Treatment +Aging (T6).

Fig 7. HPDC Machine

- **For engine cover**
  60 tonnes machine is used.
  80000 KPa pressure is required.
  Shot sleeve diameter 40 mm
  Locking force 60 tonnes
- **For Foot rests**
  60 tonnes machine is used.
  100000 KPa pressure is required.
  Shot sleeve diameter 40 mm
  Locking force 60 tonnes

Fig 8. Engine cover and footrests

Specification

Die cast parts can vary greatly in size and therefore require these measures to cover a very large range. As a result, die casting machines are designed to each accommodate a small range of this larger spectrum of values. Sample specifications for several different hot chamber and cold chamber die casting machines are given below.

Machine	DC60	DC120	H-160D	H-250D	H-400D	H-660D
Locking force	60	120	160	250	400	660

Injection force (adjustable)	10	13	20	35	38.5	65
Hydraulic ejection force	4	6	10	15	22	43
Initial plunjer stroke(mm)	250	275	300	350	400	600
Plunjer dia (mm)	30-45	50-65	40-80	50-85	60-110	50-120
Max injection pressur (kg/cm^2)	800	1035	1600	1780	2600	3310

Table 1. Specification of HPDC machine

Both hot chamber and cold chamber die casting machines are typically characterized by the tonnage of the clamp force they provide. The required clamp force is determined by the projected area of the parts in the die and the pressure with which the molten metal is injected. Therefore, a larger part will require a larger clamping force. Also, certain materials that require high injection pressures may require higher tonnage machines. The size of the part must also comply with other machine specifications, such as maximum shot volume, clamp stroke, minimum mold thickness, and platen size.

HPDC machine and setup

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies. The die casting process involves the use of a furnace, metal, die casting machine, and die. The metal, typically a non-ferrous alloy such as aluminum or zinc, is melted in the furnace and then injected into the dies in the die casting machine. There are two main types of die casting machines - hot chamber machines (used for alloys with low melting temperatures, such as zinc) and cold chamber machines (used for alloys with high melting temperatures, such as aluminum). The differences between these machines will be detailed in the sections on equipment and tooling. However, in both machines, after the molten metal is injected into the dies, it rapidly cools and solidifies into the final part, called the casting. The steps in this process are described in greater detail in the next section.

RESULTS

ANALYSIS OF FLOW

- Material used- Aluminium
  Inlet Velocity- 1 m/s
  Software used- Gambit and Fluent
  Gambit is used for mesh generation and Fluent for flow Analysis.

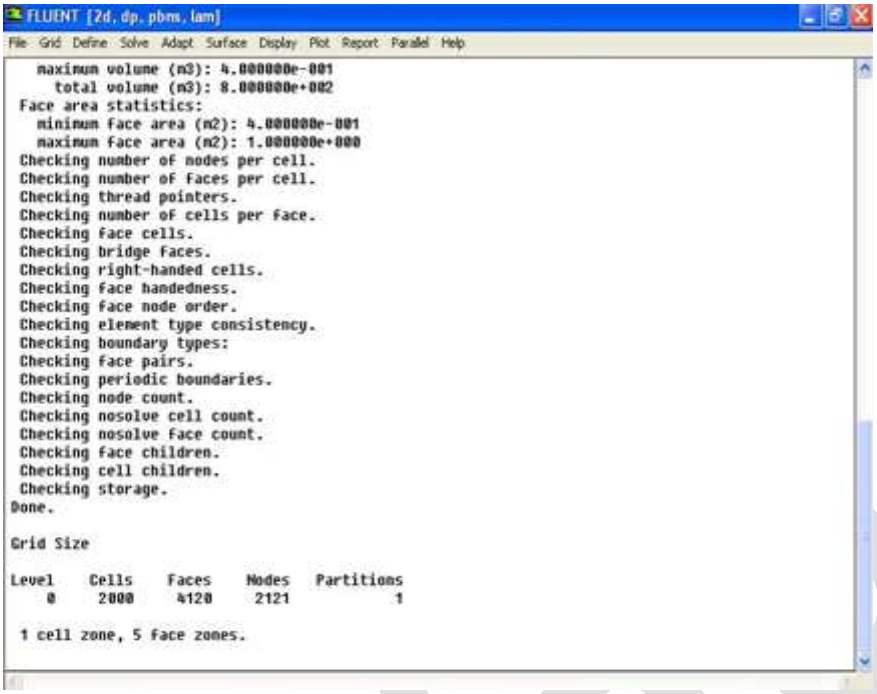

Fig 9. Grid size details

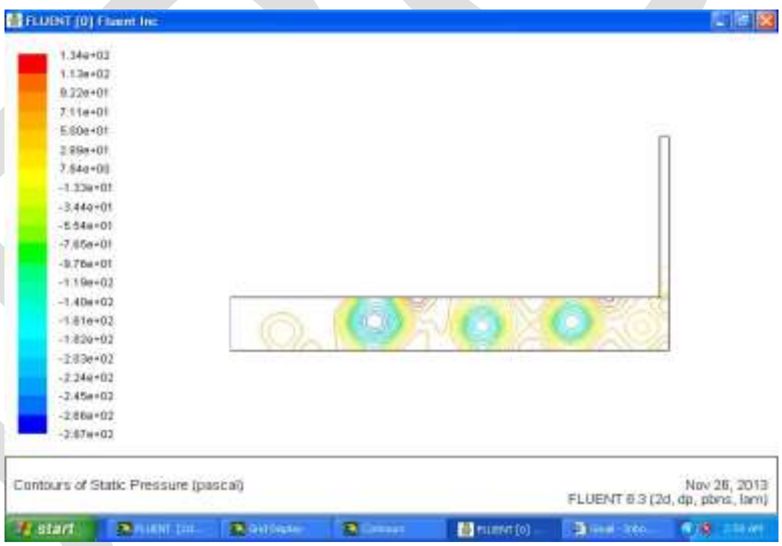

Fig 10. Pressure plot at velocity 1m/s

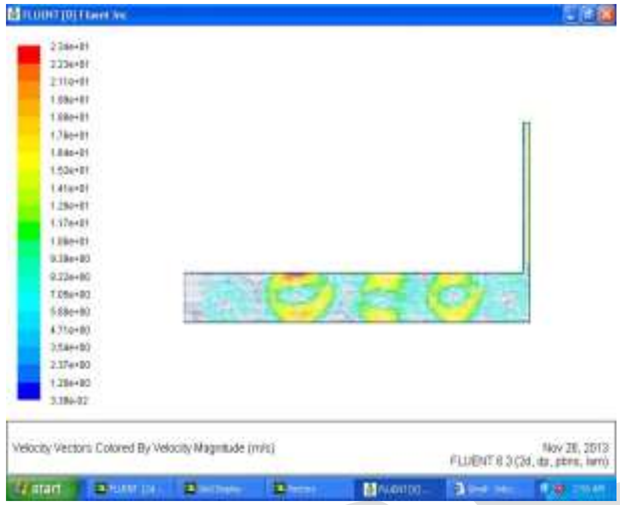

Fig 11. Velocity plot to 1m/s

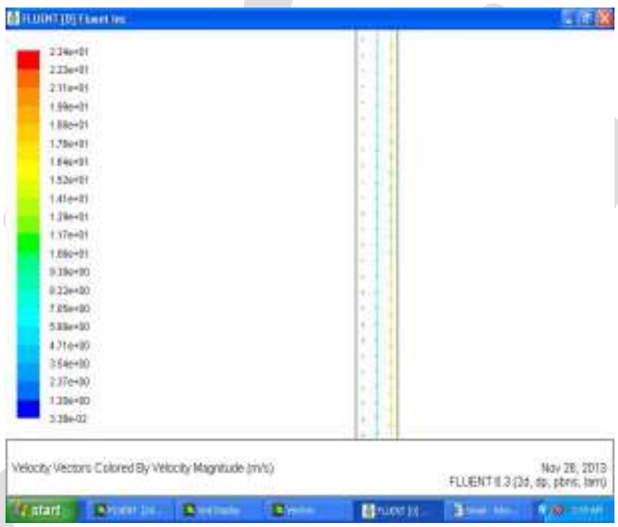

Fig 12. Zoom to runner

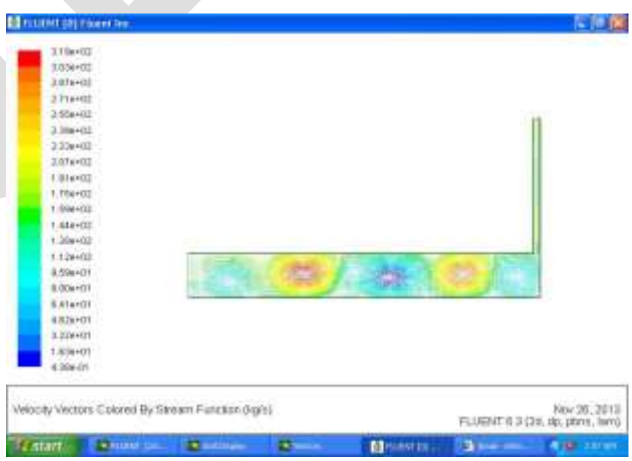

Fig 13. Stream function plot

- Increasing the velocity to 3 m/s for the same model

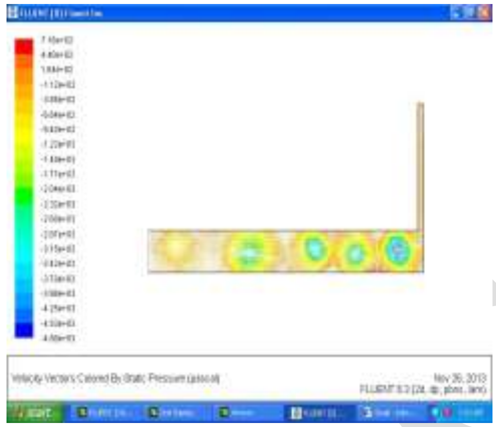

Fig 14. Pressure plot 3 m/s

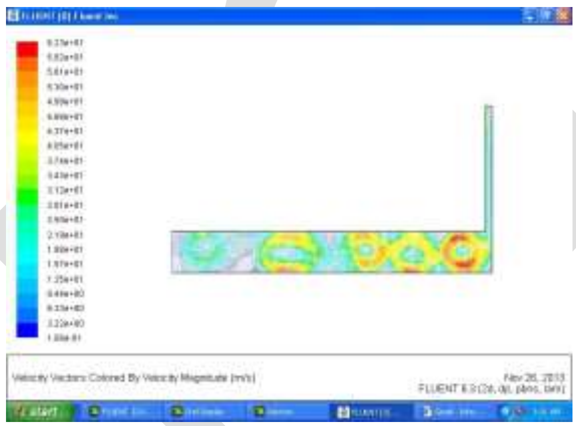

Fig 15. Velocity plot at 3 m/s

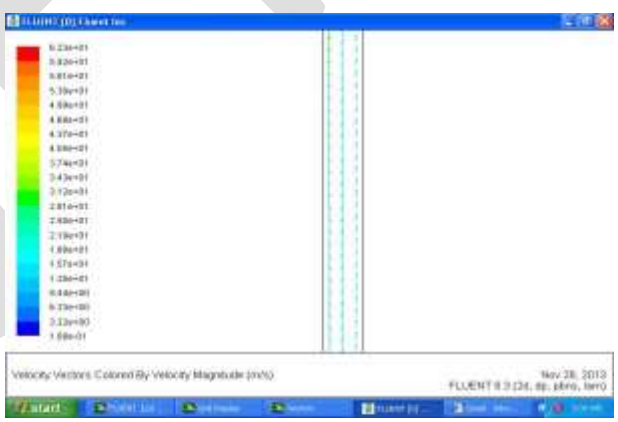

Fig 16. Velocity plot (zoom to runner)

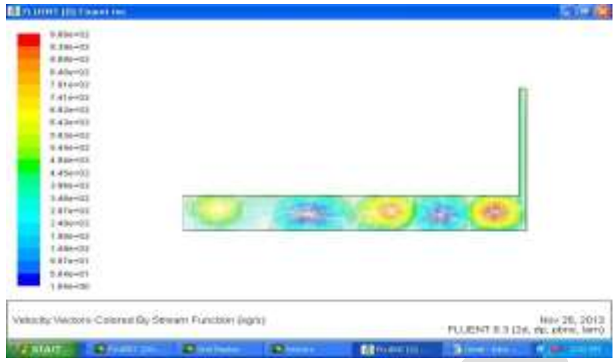

Fig 17. Stream function plot

The stream function can be used to plot streamlines, which represent the trajectories of particles. Since streamlines are tangent to the velocity vector of the flow, the value of the stream function must be constant along a streamline

- When the velocity is increased by 5m/s for the same model

Fig 18. Flow behavior at 5 m/s

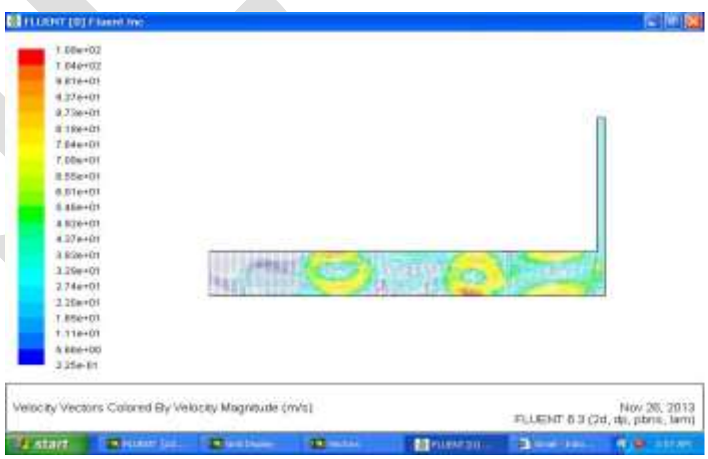

Fig 19. Velocity plot

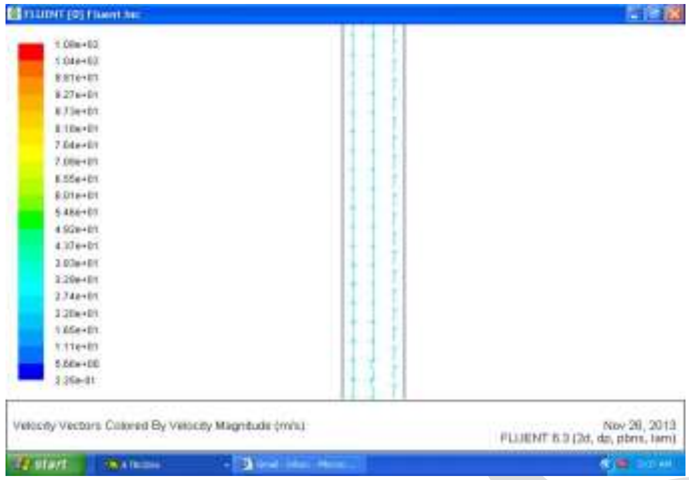

Fig 20. Zoom to runner

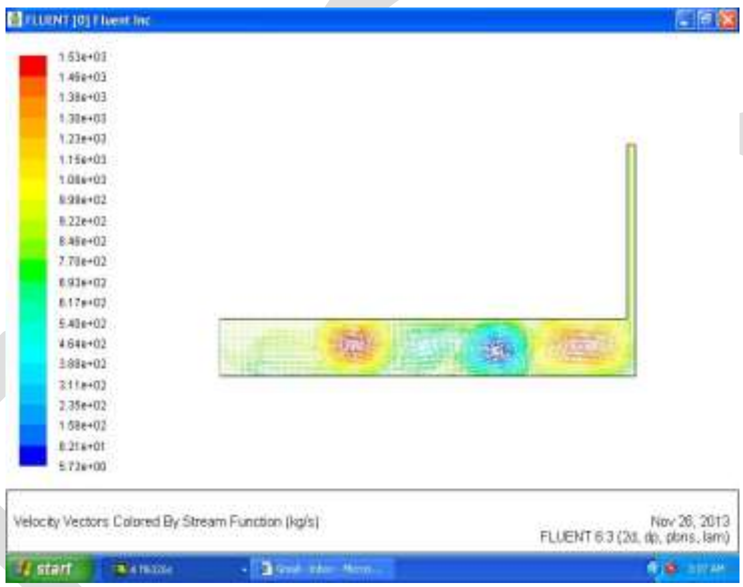

Fig 21. Stream function plot

- Preparation of Engine cover in 3-D visualize the grid structure

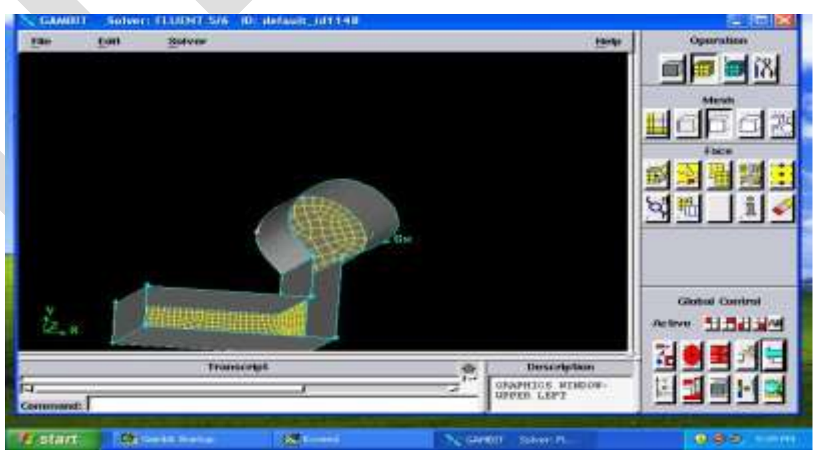

Fig 22. Model of engine cover

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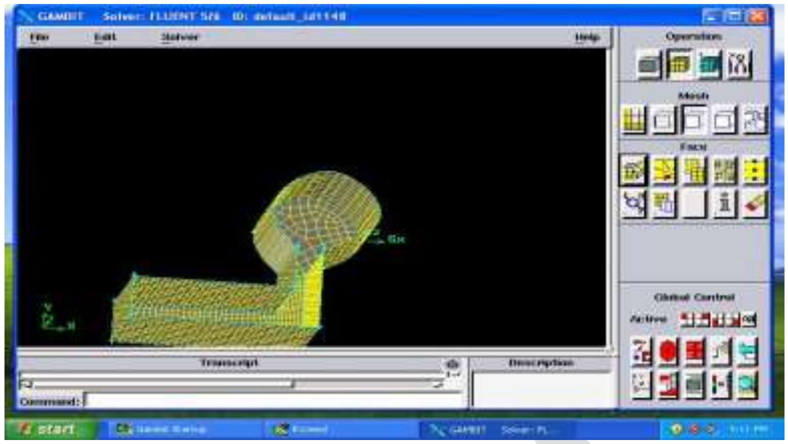

Fig 23. Fully meshed model

- Flow behaviour at 40000 KPa

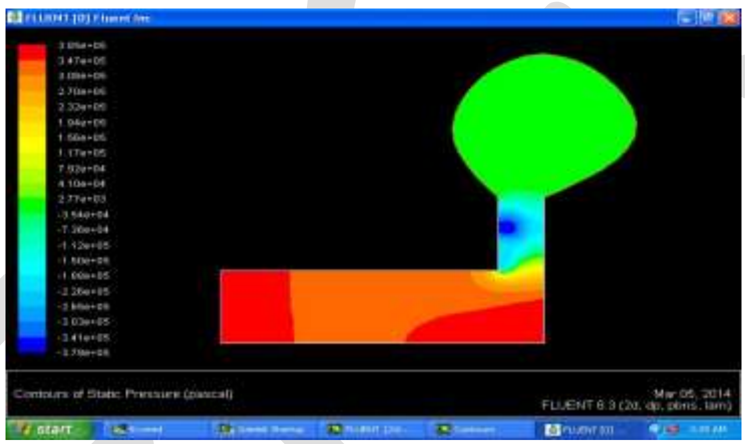

Fig 24. Pressure graph when the pressure is 40000 Kpa

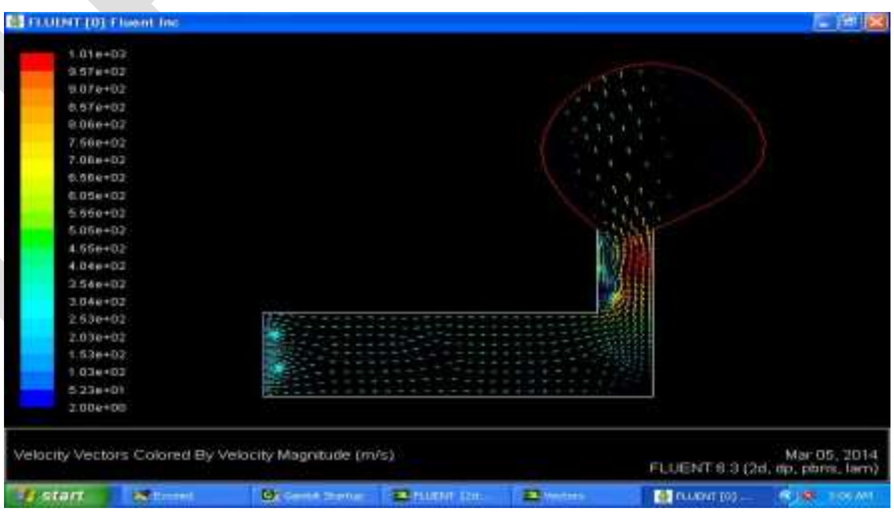

Fig 25. Velocity plot

- Flow behaviour at 60000 KPa

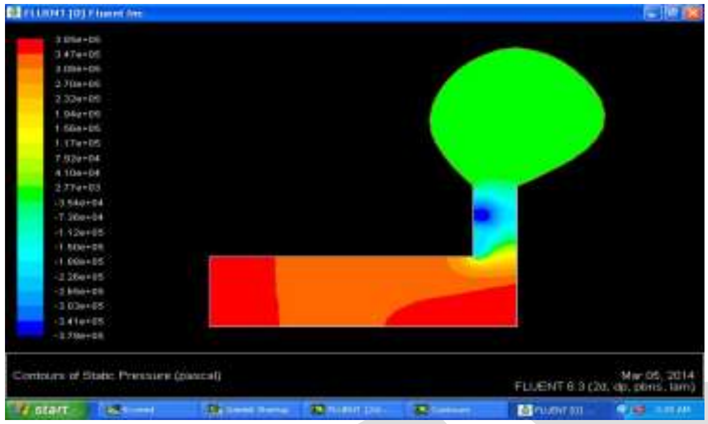

Fig 26. Pressure based plot at 60000 Kpa

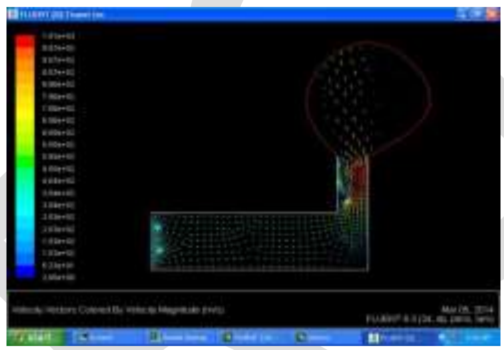

Fig 27. Velocity plot

Flow behaviour at 80000 KPa

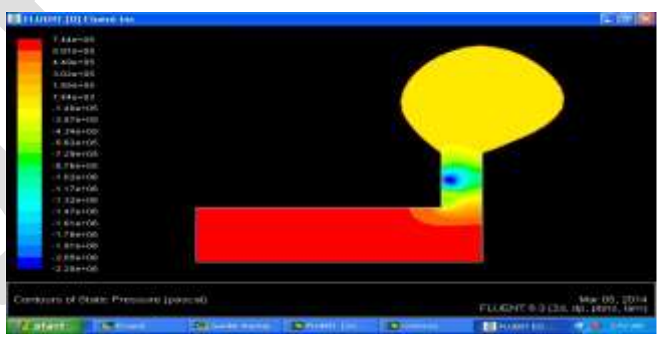

Fig 28. Pressure based plot

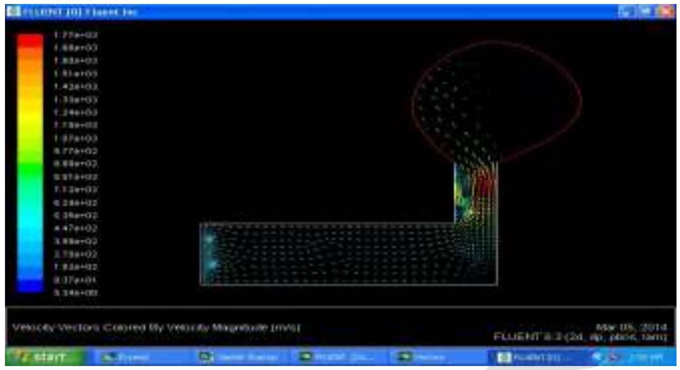

Fig 29. Velocity plot

- 3-D model of foot rests

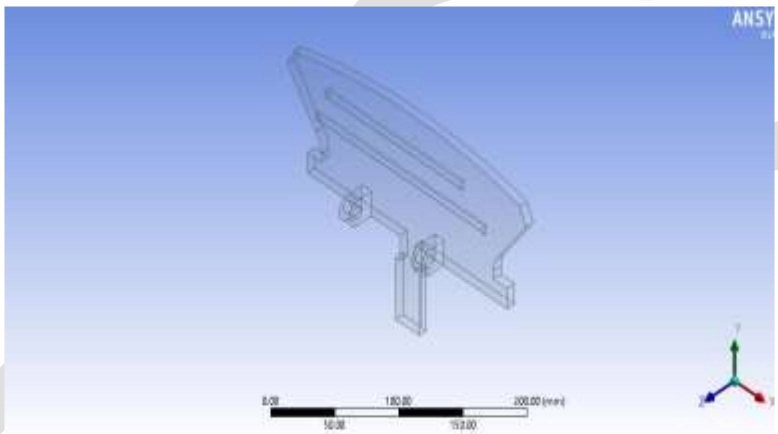

Fig 30. 3d model of footrest

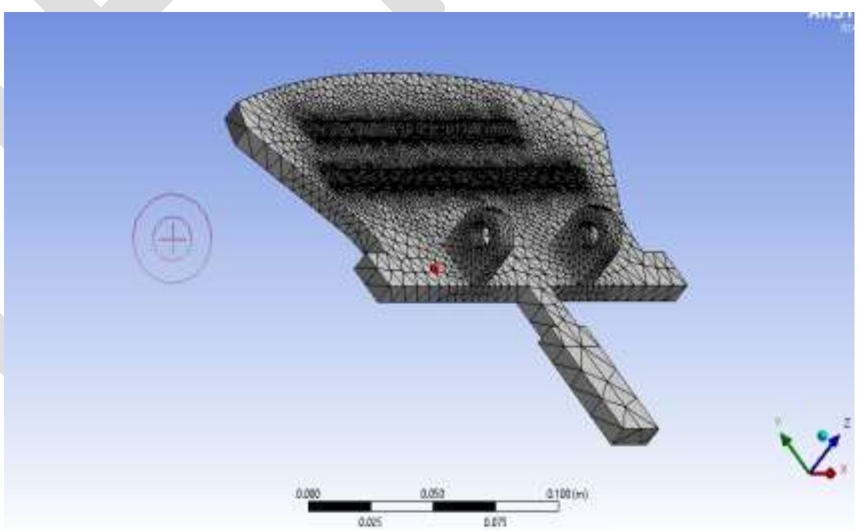

Fig 31. Meshing of structure

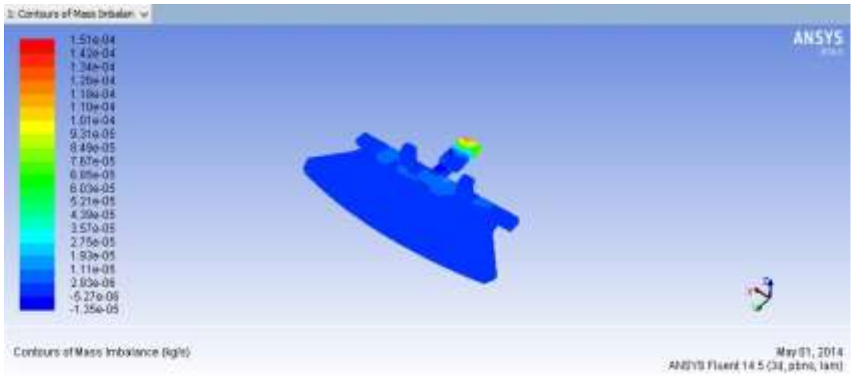

Fig 32. Contour of Residual

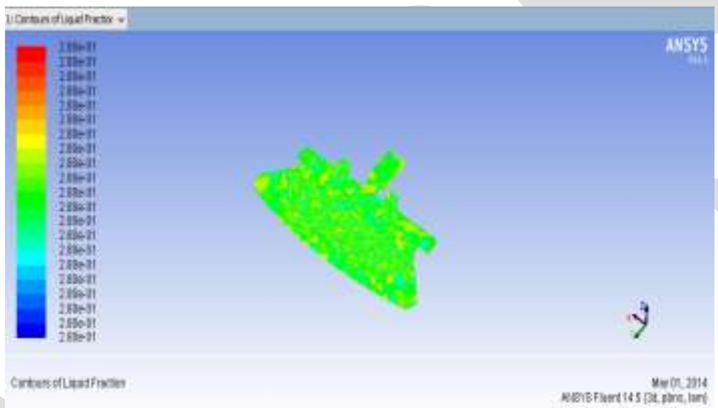

Fig 33. Solidification of casting

Result and Discussion

Graph plot between Pressure and Velocity.

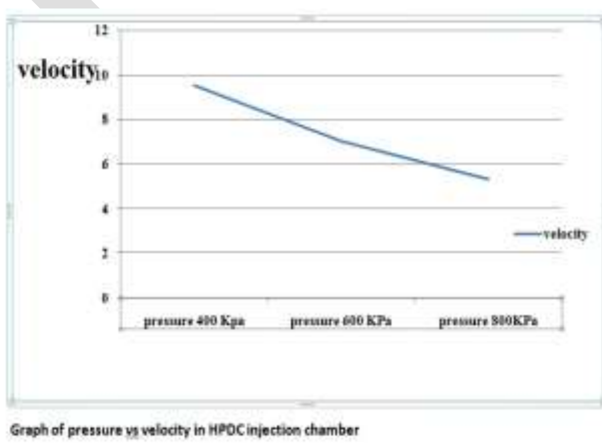

Fig 33. Plot between pressure and velocity

- Analysis from experiment and software as the pressure increases ,the velocity decrease
- For every change in pressure there is change in flow behaviour of liquid aluminium.
- This lead to the conclusion that for a specific size of injection chamber there is a fixed range of pressure.

- The smaller the branch angle, the less the applied pressure at the plunger is needed. This is because smaller branch angle offers less resistance to the metal flow which is also a reason for the back flow of molten metal in injection chamber.

When a pressure of 40000 kPa is applied by a plunger of 40 cm diameter to a specific area of cavity, the velocity of the liquid aluminium inside the injection chamber increases. As the pressure is further increased to 60000 kPa the velocity of the molten metal inside the injection chamber gradually decreases. The actual pressure at which the casting process takes place i.e 80000 kPa the velocity decreases, which also satisfy the Bernoulli's principle.
From the graph above it has been observed that, when the pressure 40000 kPa is applied, there is frequent change in the pressure inside the injection chamber which can be seen from the change of colour in the pressure graph, but when the actual pressure of 80000 kPa is applied ,which is suitable for model prepared (engine cover), the large variation of pressure inside the injection chamber decreases. Thus for the specific area of casting there must be a fixed range of pressure.

CONCLUSION

An attempt has been made to analysis the flow behaviour of metal (Aluminium) in HPDC injection chamber. The future work involves the experiment on the basic of which the final parameter for minimizing the defect will be decided. Analysis of the flow behaviour is observed on the basis of graph plotted with the help of GAMBIT which is a application that is distributed along with FLUENT. FLUENT is able to read geometries generated in GAMBIT and model fluid flow within. The formation of vortex has been seen in the graph due to the pressure variation.

Several simulations were carried out using different combinations of plunger speed and movement to demonstrate importance of right plunger movement profiles. For every change in pressure there is change in flow behaviour of liquid aluminium. This lead to the conclusion that for a specific size of injection chamber there is a optimum value of pressure.

Future Scope

- Improvement of the casting quality by minimising the entrapped air during the shot sleeve process.
- Optimisation of the whole casting process by controlling filling with optimal plunger movement.

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