Design Modification of High Pressure Casting Die to Improve the Fatigue Life

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Abstract- **The die casting is the process in which molten metal tends to flow in to the mould cavity under high temperature and pressure. During high pressure die casting, molten aluminum at temperatures 600–710°C is injected into the mould at velocities between 30 and 100 m/s. The Injection pressures are between 50 and 80 MPa. The mould cavity/die is created by using hardened tool steel of grade H13. Due to pressure and thermal fluctuating loads during operation and stoppage, possibility of fatigue failure is very high (Crack formation). This leads to reduction in die life. Since the dies are expensive, the numbers of components produced per die needs to be increased to make it economical and more profitable to the companies. Tool changing or down time due to failure of die needs to be avoided. In the current scenario, a die which is under use is having a capacity to produce some number components before it is been replaced. The objective of this project is to improve the life of die to increase the capacity of parts produced (20%) to reduce frequent die changing/repairing cost.**

Key words **– Hyper mesh, Abaqus, cornering fatigue test, axial compression test, cornering fatigue test, fatigue life.**

1.0 INTRODUCTION

Casting is the manufacturing process in which the molten metal poured in to the mould, and allowed to cool until it gets solidified. Then the casted part ejected out from the mould.

The die casting is the process in which molten metal tends to flow in to the mould cavity under some amount of pressure. The mould cavity/die is created by using hardened tool steel. Advantages of die casting process include conformity to the mould and favourable mechanical properties. The process is used in aerospace, automobile, and electrical appliance manufacture.

The die casting method is classified into following types depending on the metal flow in to the cavity and type of mould material.

1.1 Sand casting:

In this procedure Moist holding sand is pressed around a pattern. At that point the pattern is evacuated to make the mold, then molten metal filled depression. To supply fundamental molten material amid solidification Risers are utilized. At last shape is then broken to evacuate the casting part

1.2 Gravity Die Casting:

In this type of Casting the molten metal just poured in to the pre heated die cavity under gravity. The die is then open and casting is removed, this is also known as everlasting mould casting.

1.3 Pressure Die Casting:

In this method the molten metal injected with high pressure (100+bar) and temperature into the mould cavity, This process is used to produce parts from aluminum, magnesium, copper and zinc.

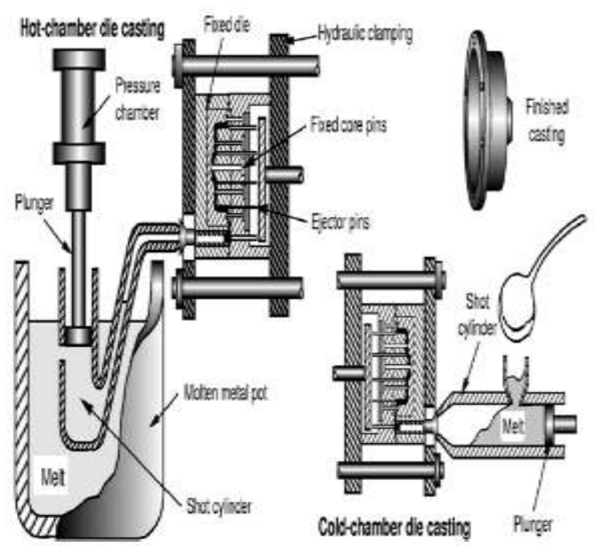

Fig 1.1. Pressure die casting

1.4 High Pressure Die Casting Present requirements and future perspectives:

[2]The transportation industry, and also specifically in the automotive production, is compulsory to pursue light materials in the development of healthy parts. The universal manufacture

of aluminium and magnesium alloys has therefore improved, and the usage of aluminium simultaneously crosses the present production ability of primary metal. It is therefore necessary to adventure, or discovers, economically viable processes that can give light weight products with combined purposes that fulfil the desires for recycling and fuel consumption rules. High pressure die casting (HPDC) is a technique fine suited for those kinds of needs. HPDC is a completely automatic, large volume; great productivity process for the production of complex, thin walled near net shape castings parts, with part weights ranging from a few grams to more than 15kg. It has usually remained used in the production of housings etc., but this has altered. Presently, possible products are automotive front end structures and instrument panels in magnesium alloys and B-pillars in aluminium alloys. However, for HPDC to be competitive for prolonged automotive applications and good-looking for new market sections the crash worthiness and fatigue properties must be improved and a scientific knowledge of the process and metal actions is required.
The main two die casting processes are the

- Hot chamber process and
- Cold chamber process.

2.0 METHODOLOGY

- Studying the existing design.
- Analysing the existing design using numerical technique.
- To determine the critical regions of the die.
- Adopting the cooling lines to minimize the stresses in the die.
- Analysing the die with cooling lines.
- Comparing the results with existing design
- Estimating the life of the modified designs (Die with cooling).
- Selecting the best design.

➢ Study the existing design.

In this section we are going to study the existing design, material data, physical loading conditions and boundary conditions. Before that we have to study the geometry of the model.

➢ Analyse the existing design using Numerical technique.

Numerical techniques are used to solve the problems using the help of computers. There are several software's are commercially available for the FE analysis (Ex: Ansys, Abaqus, Nastran etc). Here we are analyzing the existing design by the help of ABAQUS tool. Because it is robust in solving of any kind of non-linear problems.

➢ Determine the critical regions of the die.

By analysing the component we are going to understand the critical regions in component, critical regions are more likely stress acting regions.

➢ Adopting the cooling lines to minimize the stresses in the die.

After finding the critical regions next job is to reduce the stresses and deflections in the critical regions where the stress are more likely to present. We can reduce these critical regions by several methods like by introducing the fillets, adopting cooling lines, providing some coatings etc.

In this project we are going to reduce the stresses in the critical regions by adopting the proper and efficient cooling lines near the critical regions.

➢ Analyse the die with cooling lines.

After adopting of the cooling lines the effect of the cooling lines has been verified by numerical analysis of the die with cooling. And the results are noted.

➢ Comparing the results with existing design

The results from the numerical analysis of die with cooling are compared with die without cooling (i.e. existing design) It helps to know effect of the adoption of cooling in critical zones.

➢ Estimating the life of the modified designs (Die with cooling).

Once the comparison of design is done the life estimation of the die has been made for the both cases with the help of the appropriate fatigue formulas.

➢ Selecting the best design.

After the estimating life of the both cases the conclusion has been made as per the obtained result values.

2.1 FE methodology:

2.1.1. CAD Model and material details:

The CAD modeling of die geometry is created and also modified by using software CATIA V5. The material used for the die is TOOL STEEL H13. The die material is the mixture of carbon, silicon, magnesium, chromium molybdenum and vanadium. The composition of these metals helps to improve the following properties in the die the composition helps to improve the following properties in the die.

- High level of toughness and ductility
- Good resistance to abrasion at both low and high temperatures
- Uniform and high level of machinability and perishability
- Good high-temperature strength and resistance to thermal fatigue
- Excellent through-hardening properties
- Very limited distortion during hardening.

Material property	Values
Youngs modulus (Gpa)	215
Possions ratio	0.3
Density kg/m^3	7800
Thermal expansion(/c)	$10.4*10^{-6}$
Thermal conductivity(W/M-K)	28.6
Specific heat (J/g c)	0.460
Melting point (^{o}c)	1427

Table 2.0 : Properties of tool steel

2.1.2. Meshed model details:

Meshing is the operation in which the continuum is discretised in to number of smaller regions called elements which are interconnected by nodes, from which infinite degrees of freedom is converted to finite degrees of freedom. The choosing of element types in the meshing is depends on.

- Type of analysis
- Time allotted for project
- Computer configuration availability.
- Degree of accuracy of result.

In this project the die is meshed with the help of first order TET elements, First order TET elements are chosen because of the reasons

- Easy to mesh for complex geometries.
- First order elements doesn't require much time solving the problem compared to second order.
- Availability of the computer configuration.

2.1.3 Mesh Convergence:

This method used to observe that outcomes acquired from a FE programming are right. In Finite Element Method the outcomes are reliant on element size and number. Increasingly the quantity of elements more will be the precision of results. In any case, if the quantity of elements are expanded the computational time increments and the setup of the framework must be improved which builds the expense of work. The outcomes will likewise relies on upon the element measure so before we can accept on results we should make certain that the outcomes are not any more subject to the element size. This is finished by expanding or diminishing the element size and contrasting the outcomes and the past results. In the event that the got results are having a blunder under 10% then it can be said that work size is right. Here for this situation an element size of 4 and to do the cross section union lattice of model with element size 3 and 5 and found that the outcomes are not depending any more on the element size.

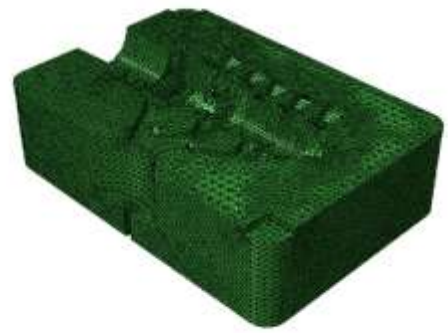

Fig2.1: Meshed models.

Element type: C3D4T continuum 3 dimensional four nodded temperature. i.e. first order TET element.

Loading and boundary condition details:

The failure of die is mainly caused by two types of loads variation temperature and fluid pressure, both loads are caused by the flow molten metal in high temp and pressure respectively. Loading and boundary conditions are applied as per the physical conditions.

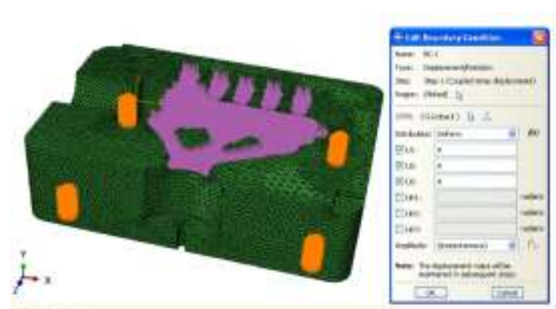

Fig2.2: Boundary conditions and loading contour.

2.1.4. Analysis type:Fully coupled thermal-stress analysis.

[13]A coupled temperature-displacement technique is utilized to understand at the same time for the stress/displacement and the temperature fields. A coupled analysis is utilized when the thermal and mechanical arrangements influence each other emphatically. For instance, in fast metalworking issues the inelastic twisting of the material causes warming, and in contact issues the warmth led crosswise over crevices may depend firmly on the hole freedom or pressure. Both Abaqus/Standard and Abaqus/Explicit give coupled temperature-displacement analysis systems, however the calculations utilized by every project vary significantly.

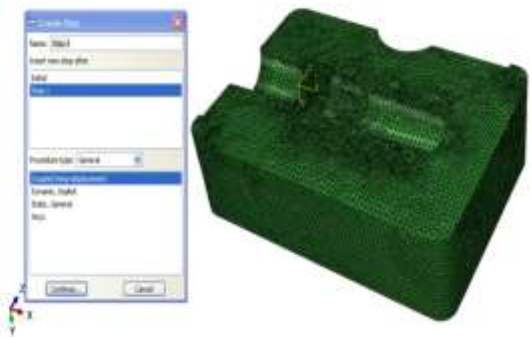

Fig2.3: Analysis type step choosing.

In Abaqus/Standard the warmth exchange conditions are coordinated utilizing a retrogressive contrast plan, and the coupled framework is unravelled utilizing Newton's method. These issues can be transient or unfaltering state and linear or nonlinear. In Abaqus/Explicit the warmth exchange conditions are incorporated utilizing an explicit forward-distinction time mix standard, and the mechanical arrangement reaction is acquired utilizing an explicit focal contrast coordination principle. Completely coupled thermal-stress analysis in Abaqus/Explicit is constantly transient. Depression radiation impacts can't be incorporated into a completely coupled thermal-stress analysis.

2.1.5. Solver details:

1. Ad-Stefan

Casting Simulation System, ADSTEFAN visualize physical phenomena that occur in a mold when molten metal is filling or Solidifying. We can predict what types of phenomenon or defects occur inside of the Mold without trial casting.

ADSTEFAN helps in reduce trial casting, designing time and cost, and also to improve quality of a product. Adstefan is used in this project for

	Stage name	**Time**
One compete cycle	Fluid flow	6
	solidification	8
	Die open	5
	Spray	4
	Air blow	4
	Die close	5
	Total cycle time	32

Table2.2: Stages of one complete cycle

- Die temperature analysis and cycle study
- Fluid flow analysis.
- Solidification analysis.
- Temperature mapping to FEA software's.

The below table shows the stages in production of one component. I.e. one complete cycle of the operation.

2. Abaqus

Abaqus FEA (formerly ABAQUS) is a softwarecollection for FEA and also computer aidedengineering, released in 1978. The Abaqus product collection consistsof five essential software products.

3.0 RESULTS AND CALCULATIONS

3.1 Fatigue Life Estimations:

Fatigue is the damage criteria caused by the repetitive loading to a component. In this project die is subjected to the thermo fatigue loading condition. That means the fatigue caused by the thermal loading conditions, even though the die is subjected to the pressure loading it doesn't causes much effects on the die life. Thermal loadings are caused by the changes in the temperature of the die with respect to stages. The temperature of the die is very high at the stage1 and it suddenly drops in the stage 6. The variation in temperature at each stages creates the one fatigue loading cycle on the component

Range of stress, $\sigma_r = \sigma_{max} - \sigma_{min}$

Alternating /variable stress,

$\sigma_a = \frac{\sigma_r}{2} = (\sigma_{max} - \sigma_{min})/2$

Mean /steady stress,

$\sigma_m = (\sigma_{max} - \sigma_{min})/2$

Stress ratio,

R= σ_{min} / σ_{max} $R = \sigma_{min}/\sigma_{max}$

Amplitude ratio

, $A = \frac{\sigma_a}{\sigma_m} = (1-R)/(1+R)$

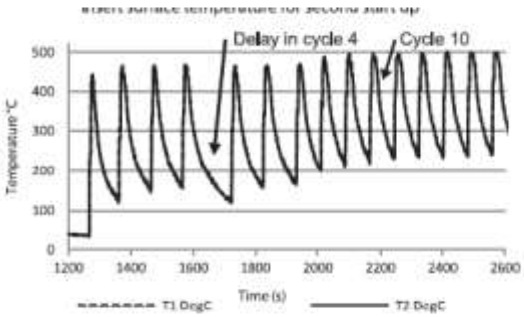

Fig 3.1 cyclic variation of in the die

For the calculation of the fatigue life we found out the critical areas in the die , in the cavity even though the die stress are showing the mises stress values in the above figure we took the directional stresses for the calculation of the fatigue life estimation, because the vonmises stresses are doesn't having the directions so it's very hard to consider the vonmises stresses, hence after the observing the directional stresses we found that stresses are maximum in the minimum principle stress direction hence I took the minimum principle stresses for the fatigue life estimation. We found the critical element in the die cavity we found the life estimation for the same.

4.0 Conclusion: Every component has produced should having its own life span, in engineering every component is manufactured with the expectation of some life span, that means the component shouldn't be failed within that life period, the improvement of the component is beneficial, hence the after the manufacturing of every engineering component the fatigue life span has been estimated. The life estimation can done using the several methods, in this project we are using the S-N diagram for the estimation of the die. S-n diagram of the die material i.e. tool steel has shown below for (400 ^{o}C).

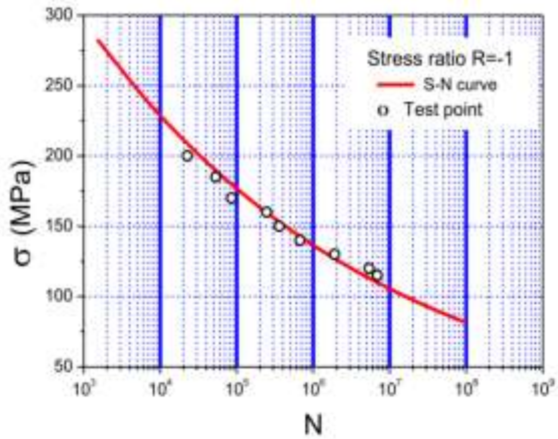

Fig4.1: s-n diagram of tool steel at 500^{o} c

From the observation of the above S-N diagram of tool steel they obtained stress values are co related and life can estimated.

Life estimation	With cooling	Without cooling	% improve in life
Fixed die	1,30,000	95,000	26.9%
Moving die	1,20,000	85,0000	29.1%

From the above observation of the tabulated values it is concluded that providing the cooling lines to the dies will improves the die life effectively. The die life is improved by 26%. And hence it is suggested that the using of cooling lines in the HPDC dies will improve the die life and also it will be more beneficial to the companies.

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