Design of Gating System, Metal Flow and Solidification for a Die Casting Component Using Virtual Simulation Technique

Bhushan Shankar Kamble[1], Sandeep Madhukar Kadane[2]

[1, 2] Assistant Professor, Department of Production Engineering, K. I. T's College of Engineering, Maharashtra, India.

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Abstract - *The connecting rod is of the important parts of the engine such as automobile and ship, and it is connected with the piston and the crankshaft, its role is the reciprocation of the piston is converted to rotational movement of the crankshaft, and the force acting on the piston to the crankshaft in order to output power. In modern automotive internal combustion engines, the connecting rods are usually made of steel for production engines, but can be made of aluminum (for lightness and the ability to absorb high impact at the expense of durability). Connecting rods are traditionally produced in ferrous metals by forging or high pressure die casting method of production. There are various reasons for failure of connecting rod as fatigue, gudgeon pin failure, over revving, and hydrolock. Casting defects like micro segregation of gas porosity, air entrapment, metal lap may leads to fatigue crack initiation and crack propagation and sudden catastrophic failure of rod. Here attempt is made to optimize the gating system by selecting the advanced ingate definition in die casting operation to overcome air entrapments, shrinkage porosity and smooth filling of mold cavity. The process parameters like component material, metal fill velocity and filling time are considered for optimizing the process. This could help in finding an optimal production method that could guarantee the required mechanical properties.*

Key Words: Fatigue fracture, Shrinkage porosity, Die casting, Connecting rod

1. INTRODUCTION

The connecting rod is a die casted or forged component which connects the piston to the crankshaft and forms a simple mechanism that converts reciprocating motion of piston into rotary motion of crank shaft in an internal combustion engine. Connecting rods may also convert rotating motion into reciprocating motion. The small end attached to the gudgeon pin or wrist pin, which is press fitted into connecting rod but can swivel in the piston. The big end connects to bearing journal on the crank throw. Generally connecting rods are manufactured by high pressure die casting or drop forging with materials such as steel, aluminium or titanium which are used for making up or producing them for high performance engines or of nodular cast iron(SG Iron) for low cost as compared to steel in category of ferrous alloys.

During the operation of the IC engine, the connecting rod undergoes tensile, compression and buckling loading. In many cases, the major reason causing catastrophic engine failure is the occurrence of the connecting-rod failure and sometimes such a failure can be attributed to the broken connecting rod's shank. Other reasons may be fatigue, gudgeon pin failure, over revving, and hydrolock.

Fig.-1 Various forms of connecting rod failure

During fatigue failure, constant compression during the power stroke and stretching during the exhaust stroke, over thousands of times a minute, eventually wears the metal out and it becomes brittle and finally breaks. In pin failure, pin that connects the connecting rod to the piston (called the piston pin, wrist pin or gudgeon pin) gets a lot of wear and may leads to failure. In new and high performance engines with high acceleration and speed and in low gear the stress is simply too high at extremely high RPMs. In hydrolock type of failure, deformation of the connecting rod is caused when a volume of liquid is greater than the volume of the cylinder at its minimum enters the cylinder. Since liquids are nearly incompressible, the piston cannot complete its travel hence either the engine stops rotating or leads to mechanical failure.

2. GENERAL DEFECTS OCCURED IN DIE CASTED COMPONENTS:

Generally connecting rods are manufactured by high pressure die casting or drop forging. In HPDC, high pressure molten metal (Aluminum/Steel) is injected with a die casting machine under force using considerable pressure into a steel mold or die to form products. Various defects occurs in die casting processes in casted component as gas related defects which are discontinuities formed when hydrogen ,vapor, die-lubricant or air is mixed into molten metal , this latter comes out in form of gas bubbles.

Filling-related defects are caused by anomalous liquid metal flow. During filling of the die cavity, liquid or partially solidified metal veins at different temperatures and sometimes covered by oxide films can incorrectly come into contact (in some cases even with completely solidified metal) causing metallurgical non homogeneities.

In Shrinkage defects, a discontinuity that forms as a result of the volume contraction during solidification in regions where local metal filling is insufficient or even absent. This occurs in regions which are locally the last to solidify (hot spots). Blowhole is relatively large shrinkage cavity, formed at hot spots.

In thermal contraction defects, cracks formed during solidification or cooling to room temperature. When tension stresses arises for the material contraction resulting from solidification or cooling exceeding UTS at the local metal temperature. It may lead to cracks and hot tears. Both cracks and hot tears often occur in regions of stress localization, either due to macroscopic geometrical reasons or to the presence of previously formed microstructural defects like gas porosity.

3. OBJECTIVE:

To overcome filling related defects a well-designed runner and gating system is very important in producing good quality die castings by providing a uniform and homogenous mould filling [1]. Die casting simulation has become a powerful tool to predict the location of defects and eliminate them by visualizing mould filling, solidification and cooling [2]. A ***Click 2Cast*** die casting simulation software is used in optimizing ingate size and its location which will minimize air entrapment, gas porosity etc. and to predict defect location.

4. METHADOLOGY:

4.1 We had created the 3D model of the part using CATIA V5-R16 version and converted it to .stl file format which is compatible to open in ***Click 2Cast*** simulation software. All engraved fonts from part or geometry are erased for ease in meshing

4.2 Generation of meshing and part material selection:

Fig.-2 Connecting rod advanced meshing with 0.2mm element size made in Click2Cast

Advanced meshing method is adopted. Meshing element size 0.2 mm with 50574 tetrahedral, 20434 triangular, 13625 nodes, volume 58.7176 mm^3 and modulus 0.21327 mm meshing is generated. Alloy steel Die material is selected with mold temperature of 150^{0}c .Basic Process parameters like ingate velocity of 10 m/s and mold filling time of 5 sec is selected.

Table 1: Commonly used Connecting rod materials and their composition are listed below [4]

Al Alloy	6061 Al alloy	7075 Al alloy	2014 Al alloy
Al%	95.8-98.6	87.1-91.4	90.4-95
Cr%	0.04-0.35	0.18-0.28	0.1
Cu%	0.15-0.4	1.2-2.0	3.9-5.0
Fe%	0.7	0.5	0.7
Mg%	0.8-1.2	2.1-2.9	0.2-0.8
Mn%	0.15	0.3	0.4-1.2
Si%	0.4-0.8	0.4	0.5-1.2
Ti%	0.15	0.2	0.15
Zn%	0.25	5.1-6.1	0.25
Melting Point	~580^{0}C	477 - 635°C	507 - 650°C

4.3 Ingate size and location:

The gate is the most restrictive orifice in the total fluid flow concept of the filling operation in the die-casting die. It is the point at which the metal enters into the die cavity. Most of the casting defects such as bad surface, improper filling, flow marks, cold shuts are caused due to improper gating. The location, size, and type of gate are three important factors in gating [1]. In this case Advanced Square shaped ingate with width 5mm and height 5 mm is selected for further simulation.

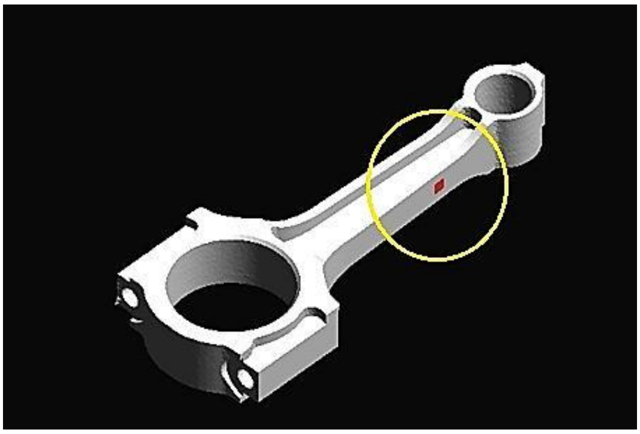


Fig.-3. Ingate location for entering molten metal in die cavity.

4.4 Running the simulation:

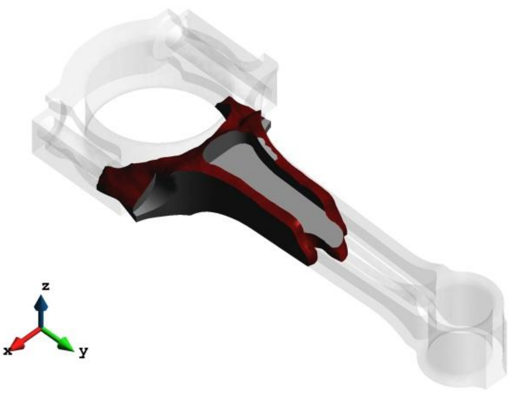
Click2 cast is an innovative die casting process simulation tool that basically simulates mold filling and solidification. This will help you save energy, material and eventually use less of the resources on our planet. Simulations visualize the consequences of a specific design of gating system. Casting defects, such as porosity, cold-shuts, shrinkage cavities can be avoided by optimizing the design of the gating system.

5. FLOW SIMULATION:

Simulation is carried over material which was used for analysis is *Aluminum 2014 Al* alloy. The various process parameters conditions were considered while doing the filling analysis of the component was metal temperature of 650^0C and die temperature of 150^0C with a fill time of 5 seconds and ingate velocity of 10 m/s.

6. SIMULATION RESULTS AND DISCUSSION:

6.1 Front Flow Results:



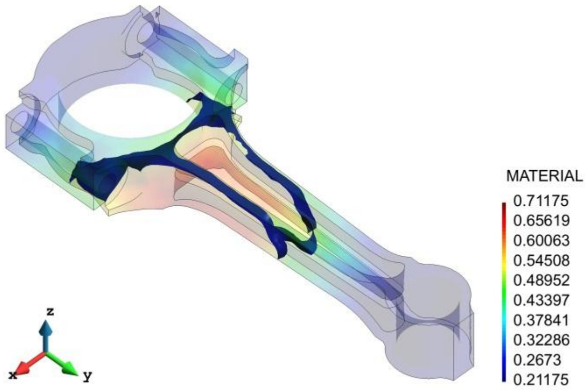


Fig.-4 Front flow die cavity filling in Click2Cast process simulation software

Front flow results show the filling material evolution in die cavity. This virtual visualization gives a preliminary idea of the filling time, and the way the part is filled. It is useful to decide the position of ingate and overflows to avoid air entrapment. Because of improper location of ingate there are chances of turbulent flow in metal which may arises defects like pin holes and lap.

6.2 Temperature Evolution Results:

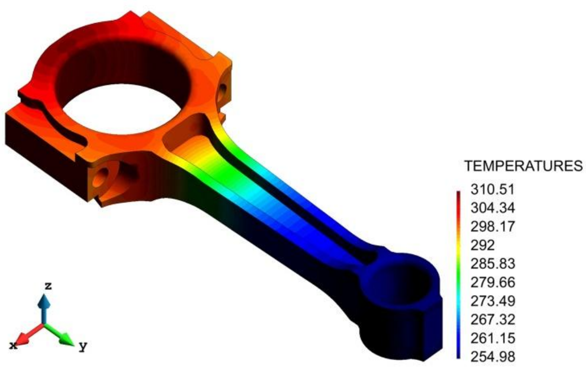


Fig.-5 Temperature evolution results in Click2Cast process simulation software

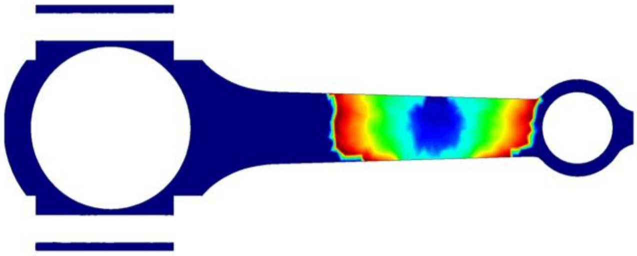


Fig.-6 Cut sectional plane showing Temperature evolution results in Click2Cast process simulation software

The metal which is poured from a ladle into a cold chamber die casting must have high temperatures in order to produce good quality castings. The temperature of the metal should be ideal and not too high as it influences the casting density. Temperature evolution results show the evolution of temperatures during filling. With this animation, it is possible to determine the temperatures at which two advancing fronts of molten material overlaps and possible chances of risk of cold welding at overlapped junction

6.3 Metal Velocity Results:

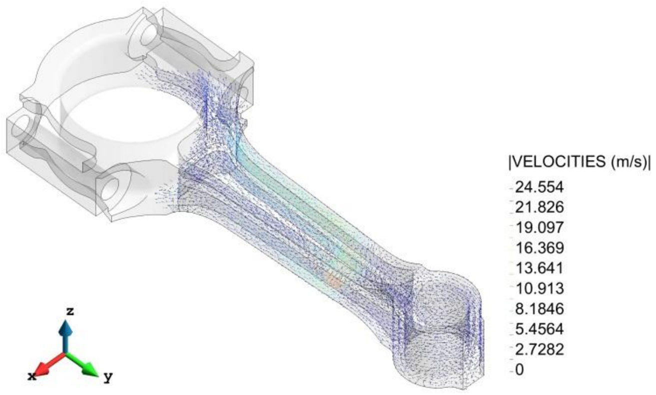


Fig.-7 Metal velocity during filling die cavity in Click2Cast process simulation software

The metal flow inside the casting with very high velocity leads to flash/fin. It is a thin web or fin of metal on a casting which occurs at die partings in the form of projection. The velocity simulation is very much useful in designing the overflows which need to present in component. As the filling velocity increases, the density of the casting increases up to a certain limit and decreases rapidly. High quality castings must have high density and thus higher velocity affects the quality of the castings [1].

6.4 The Pressure Distribution Results:

The objective of performing a pressure simulation on the component is that the component should have uniform pressure distribution when the metal is fully filled inside the cavity. This is also used to detect the possibilities of formation of turbulent flow that might occur during the flow of the metal inside the cavity.

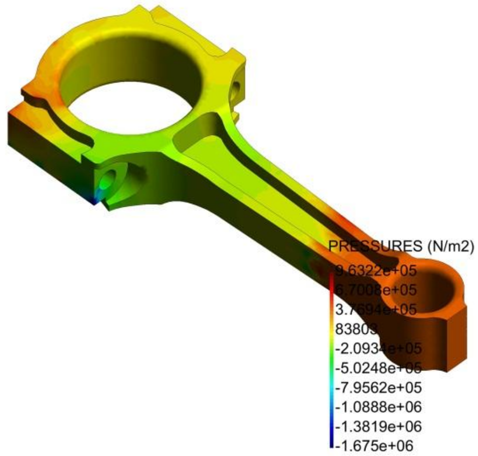


Fig.-8 Pressure distribution during filling die cavity in Click2Cast process simulation software

A negative pressure during the flow may indicate possibilities of turbulent flow. Metal turbulence may leads to defects in the component like gas porosities, shrinkage porosity etc. [1].The simulation shows uniform metal entry at every corner of die cavity. This in turn will produce better quality castings.

6.5 Cold Shut Results:

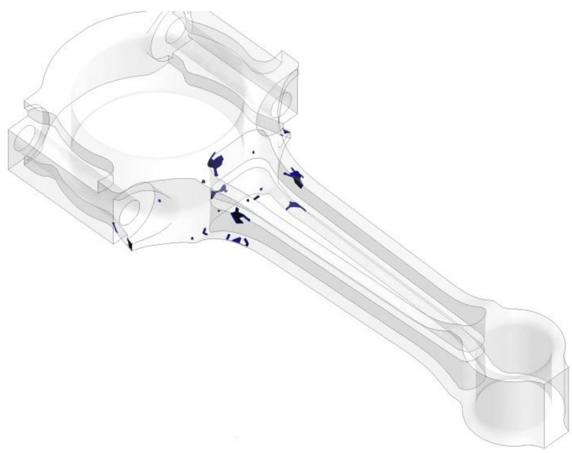


Fig.-9 Blue colored cold shut location during solidification of casting in Click2Cast process simulation software

These are formed when a small portion of molten metal comes into contact to the die and rapidly cools. Its rapid solidification causes a finer microstructure with respect to that of the surrounding region, from which it could also be separated by a thin oxide layer. In any case the presence of a cold shot means the existence of an at least partial microstructural discontinuity with respect to other regions of the cast. In some cases the metal flowing into the die can cause detachment of some of these rapidly solidified regions and can drive them inside the cavity, without completing their melting. Thus, cold shots can also be internal defects. Cold shuts option shows the front encounter of material during the evolution of the filling. The blue areas are where fronts encounter material in cast component. This option is useful in prediction of the cold unions.

6.6 Air Entrapment and Shrinkage Porosity Results:

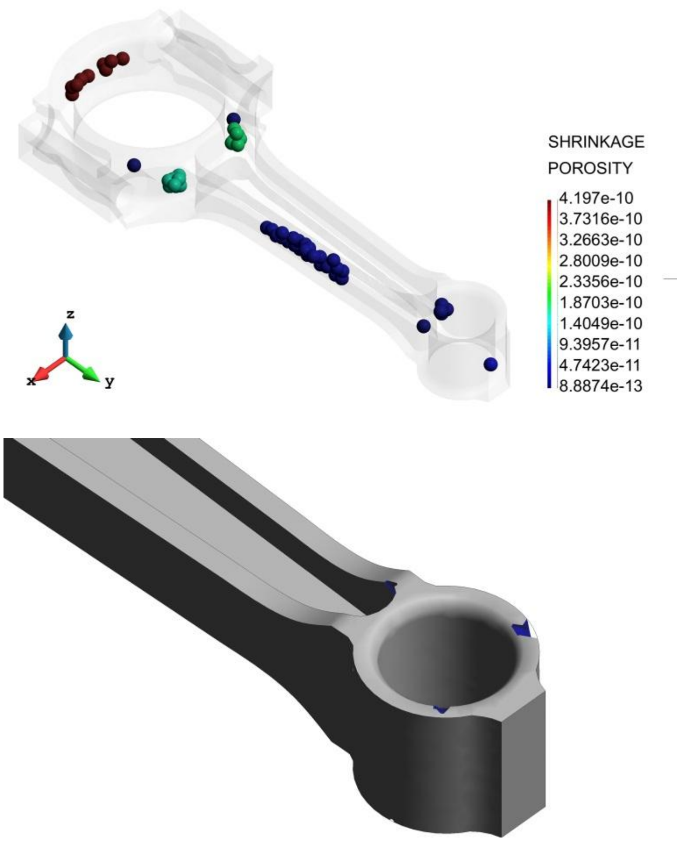


Fig.-10 Air entrapment and Shrinkage porosity location during solidification of casting in Click2Cast process simulation software

These discontinuities are formed when gas is in solution into molten metal or when, for different reasons, this latter contains gas bubbles. Internal gas-related defects are spherical or round-shaped cavities (often known as porosity for their small size) characterized by their smooth surface. These gases may arises from abrupt reduction of hydrogen solubility in the solid phase Aluminum, when air bubbles remain trapped in the liquid metal, Residual humidity on the die surface becomes vapor when it comes into contact to molten metal and then becomes trapped into it or by Die lubricant entrapment. It may also arise due to improper location of ingate and turbulent flow in die cavity.

The air entrapment option shows the last areas to fill the part and the air entrapment during the evolution of filling. The blue areas are where there is air entrapment. This option is useful in order to avoid porosity or change the overflows position. The fig shows an instant picture of the shrinkage porosity percentage in volume over the total volume of the part.

7. Temperature evolution graph:

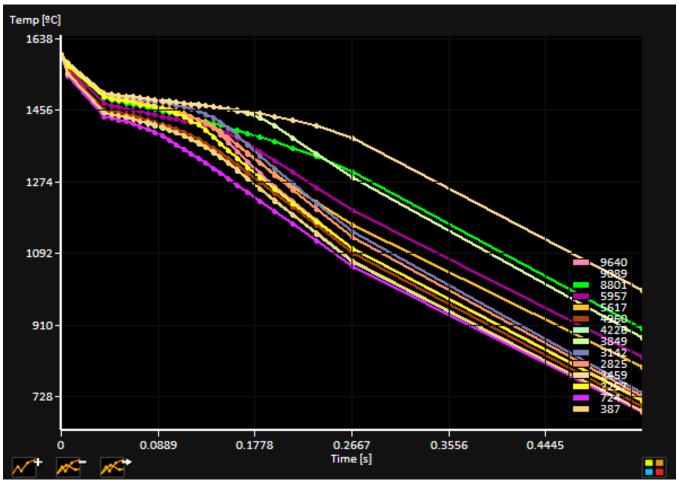


Fig.-11 Graphical representation of temperature evolution with respect to time during solidification

This option generates graphs. By Clicking on different points of the geometry nodes a graphical representation will be generated automatically to visualize evolution of temperature of these points in relation to time. There are two results available for graphic option: temperature and velocity evolution during filling and temperature evolution during solidification. By Clicking on the lines of the graphic will show the points selected over the geometry. Flexible option is provided to Add and remove points.

8. CONCLUSIONS :

The case study deals with optimization of gating system of a die casting due to which various casting defects and the manufacturing lead time were significantly reduced. The die casted components are more prone to fail under fatigue loading which may arise due to entrapment of gas and micro porosity in component. The virtual simulation helps in optimizing a casting design by detecting the part features with potential flow and solidification problems, evaluating gate system and overflow design alternatives.

The simulation done over Click 2cast provides real results virtually. While it is of great use for foundries in better and faster decision-making with greater benefits achieved by analyzing cast products at the design stage itself and preventing potential problems through suitable changes to part features and gating system. Casting simulation can minimize the wastage of resources required for trial production. In addition, the optimization of quality and increased yield implies higher value-addition and lower production cost and improving the profit.

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BIOGRAPHIES:

Bhushan Shankar Kamble
Assistant Professor,
M.E. (Mechanical Production Engg.),
Department of Production Engineering,
KIT's College of Engineering,
Kolhapur.

Sandeep Madhukar Kadane
Assistant Professor,
M.E. (Mechanical Production Engg.)
Department of Production Engineering,
KIT's College of Engineering,
Kolhapur.