DESIGN AND ANALYSIS OF DIE CASTING USING PRO-E SOFTWARE AND TO PRODUCE A PROTOTYPE

Nataraju M¹ and A Naveen kumar²
¹²Mechanical engineering, CIITS College

Abstract—Die casting is the one of the process that produces the precise product in the world. Many of the high precision industrial production used the die casting to produce the product. Thus for this study the main focus is to evaluate the suitable design for the metal casting process weather it can improve the several design in the manufacturing field. As we know, die casting is the one of the important section that produces the entire products that used in the company, home, school etc. So, the design process is important to make sure the product is suitable to be used by the customer. Die casting is a process where liquid metal are injected into steel dies under high pressure and net shape parts are produced after subsequent metal solidification and cooling. This paper is focused to design the selected part and produce the design using the selected machine such as milling, lathe, wire cut and others. To design the selected part, PRO-E software is used. The main objective is to design a complex die to shorter the period of development of the product with high quality in a lower cost. With this design, we can produce the high quality products of the die casting.

Keywords- Die casting, Manufacturing, PRO E software, Design, Complex Die

I. INTRODUCTION

The earliest example of die casting by pressure injection as opposed to casting by gravity pressure-occurred in the mid-1800s. a patent was awarded to sturges in 1849 for the first manually operated machine for casting printing type. The process was limited to printers type for the next 20 years but development of other shapes began to increase toward the end of the century, by 1892, commercial applications included parts for phonographs and cash registers, and mass production of many types of parts began in the early 1900s. The manufacture of die-casting molds or injection molds is a precise yet clean production process. Casting is applied widely in the motor, aeroplane, ship, electronics, and precision machinery industries. The main problems that are want to focus in this project paper is about the die casting design that are including the suitable aspect such as machine, product and the material. This project also was proposed to design the complete system of the die casting. As we know, the entire thing we do should have a planning to make sure our job is smooth. So in the industry, especially in highly risk, to design the die casting it must have the planning and preparation in anything have done to make sure the die design is smooth to produce the product. Sometimes, the die casting failure caused the production will stop automatically because the safety aspect. So, the die casting design must suitable to the product and the casting machine that used in the production. If the design is failed, the product at the final has many defects such as crack, unfilled, weld line and others. The design aspect is important to make sure the die casting system can function quickly and also produces the product in short cycle time.

Objective: a) To make the suitable design based to the product. b) To understand the system that used in the die casting. c) To make the decision of the suitable product, material and machine for the selected product. d) To produce the detailed drawing of the product. e) To produce the prototype based to the selected design.

II. DIE CASTING PROCESS

The Die casting process, developed in early 1900s, is a further similar to permanent mold casting except that the metal is injected into the mold under high pressure of 10-210Mpa (1,450-
Die Casting is the process of forcing molten metal under high pressure into the cavities of steel molds. The molds are called dies. Dies range in complexity to produce any non-ferrous metal parts (that need not be as strong, hard or heat-resistant 8 steel) from sink faucets to engine blocks (including hardware, component parts of machinery, toy cars, etc). In fact, the process lends itself to making any metal part that:

1. Must be precise (dimensions plus or minus as little as .002 inches—over short distances),
2. Must have a very smooth surface that can be bright plated without prior polishing and buffing,
3. Have very thin sections (like sheet metal—as little as .050 inches),
4. Must be produced much more economically than parts primarily machined (multicavity die casting molds operating at high speed are much more productive than machine tools or even stamping presses),
5. Must be very flexible in design; a single die casting may have all the features of a complex assembly.

Typical parts made through die casting are motors, business machine, appliance component, hand tools and toys. The weight of most castings ranges from less than 90g (302) to about 25kg (551lb). For many parts, post-machining can be totally eliminated, or very light machining may be required to bring dimensions to size. The Dies are usually made of alloy or tool steel and are quite expensive to make. Some have one or two identical mould cavities for larger parts, and others may have several different cavities. Some dies are more complicated and have sections that move in several directions. Grooves or overflows around the cavity on the parting face permit gases to escape. The overflows of excess metal must be trimmed off by a secondary operation after the casting is removed from the mould. This trimming is done with trimming dies that also removes the sprues and runners. The mould must also have provisions for water cooling so that a constant operating temperature can be maintained. Knock-out pins provides for injection the parts when the die is opened. When cores are used they are made of metal and are usually drawn out before the die is opened. Cores are retracted either in a straight line or in circular motion. Complex components with intricate features are commonly pressure die cast using sophisticated tools. Tool tolerance is critical. Flashing at tool faces can defeat the economics of die casting if it necessitates deburring or secondary finishing. In conventional die-casting tools, molten alloy is forced into the cavity until it flashes out between adjoining surfaces. For zinc-alloy die casting of small components, tools are assembled to tolerances of +/-0.0001 in. -- a tight seal around the cavity which eliminates flash. The quality of die castings is high because of a rapid cooling rated that produces fine grains in the metal. The surfaces tend to be harder than the interior as a result of the chilling actions of the metal die. Porosity is sometimes a problem as a result of entrapped air, but with the proper venting this can be overcome.

Cylindrical cores form holes with a 0.001 in. tolerance, which can be tapped to 60 to 75% h/t thread without drilling. Side cores enable the production of holes and undercut features that are parallel to the major parting line of the tool. A movable core can form a hole or slot of virtually any shape to tolerances of 0.002 in. External, internal face, helical, spur and worm gears are cast to angles of 20’ and can incorporate shafts, ratchets, andcams. Zinc-based alloys are the most commonly used in die casting. Other metals used in die casting are alloys using copper, aluminum, and magnesium. Zinc alloys have the lowest melting point, about 700’~ (3710c), and so have a less destructive effect on dies. Aluminum and Magnesium alloys melt at about 1100’~ (593’~), and copper alloys melt about 1700% (927’~).

Therefore, dies using these alloys have a shorter life because of thermal shock, which causes crazing (micro cracking) on the die surfaces. Cores are used by foundries to cast holes and interior features into castings. These separately made sand forms are then placed into the green sand mould to replicate these special features in the casting.
III. DESIGN ASPECTS OF DIE CASTING

Since the metallic mold of a die casting expands when it is filled with a molten metal and then both the casting and the mold shrinks during cooling the shrinkage allowances taken in the die mold design are smaller than those in the Sand casting. Parts of 0.05 lb (20 g) to 75 lb (34 kg) may be cast. The section thickness of permanent mold casting may vary in the range 0.02” - 0.5” (0.5-12 mm). The dimensional tolerances are 0.01-0.03” (0.25-0.75 mm) depending on the casting section thickness. Allowances of 0.004-0.01” (0.1-0.25 mm) are taken for the dimensions crossing the parting line of the mold. The draft angle is commonly about 1%. Changes of the section thickness should be as gradual as possible. The dies are fabricated from Tool and die steels. The die life is determined the ability of the material to withstand wear caused by the molten alloys and Fatigue caused by multiple heating and expansion. The cores are made of refractory ceramic materials. Sand based cores are not applicable due to their insufficient strength under pressure applied in die casting.

Design Consideration For Die Casting

Designing a die requires a lot of expertise. Many things are to be borne in mind while designing a die for producing successful castings. Some of the important points to be considered while designing are discussed.

Over Flows

Provide area for gases and cold metal to be gathered. Air Vents are provided from overflows. Act as ejector pads. Allow more metal to flow through the system adding heat to the die.

Injection Pressure

| Specific Injection Pressure (kg/cm²) | AI/Mg alloys | Zn alloys | Cu alloys |
|-------------------------------------|--------------|-----------|----------|
| Standard Parts                      | 400          | 100-200   | 300-400  |
| Engineering Parts                   | 400-600      | 200-300   | 400-500  |
| Pressure Parts                      | 800-1000     | 250-400   | 800-1000 |

Factors Affecting Ejection: Surface area of the core, Draft on the core, Strength of alloy at ejection time, Type of ejection, Surface finish of the core, Lubrication on core, Temp of core

IV. PROCEDURE FOR DIE DESIGN

a) Create 3D model in Pro/E software.
b) Identify and select the parting line.
c) Perform draft check on the model & rectify if necessary.
d) Introduce drafts in the model before giving fillets (Rounds).
e) Add machine allowance in the model, if already added leave it.
f) Make 2D drawing from the model.
g) If any deviation observed, do the required corrections or modifications in the 3D model as per the customer drawing and make the 2D drawing once again from the corrected 3D model.
h) If there is any discrepancy in the model which is not possible mathematically, inform customer and if customer requires the feature leave the model as it is and ask tool maker to make it in the die.
i) Send the 3D model for prototype.
j) Receive the prototype and inspect all the dimensions with respect to the 2D drawing.
k) Send the prototype to the customer if he asks in the contract review, if not send it directly to the vendor to have clarity about the model.
l) After the 3D model and 2D drawing are completed then start your Die Design.
m) Selection of suitable machine, through locking force calculation and by using suitable specific injection pressure based on the pressure tightness of the 3casting.
n) Decide the no. of cavities whether single cavity or multi cavity based on the size, requirement, productivity and machine availability.
o) Design of shot sleeve diameter to achieve a fill ratio of 35~40%.
p) The design calculation includes cooling system amount of heat being injected into the die is calculated and suitable cooling system is provided.
q) A rough layout of tool is drawn to check suitability of machine.
r) Die core and cavity extraction is done using PRO-E.
s) 3-D modeling for full tool is done using PRO-E.
t) Design of runner and gate system through PQ2 analysis(REF to NADCA and Buhler Design)
u) Design the mechanical (finger cam type) or hydraulic cylinder type core movement based on the suitability and core movement.
v) Design the die taking into account the injection position, ejection systems and all other dimensions with respect to SMED standards (Refer SMED Standards available)
w) Detail all the parts as per the Drafting standards.
x) Check the detailed drawings as per the die drawing approval checklist.
y) In case of any deviations, correct the drawing and check again.
z) Release the drawings for die manufacturing. Send the 2-D drawing and 3-D model and (Prototype of the casting if necessary) to the vendor for die manufacturing.

Formulae For The Design Of Die

- Weight of component(gms) = (volume) × (density)
- Density (gms/cc): Based On Alloy
  - Used for casting: Al-2.6 to 2.7
  - Zn-7.8, Cu-9, Mg-1.7
- Volume Of casting cm³ = (Weight of component)/Density
- Short Weight = (Weight of Casting)+(Weight of runner overflow)+(weight of biscuits)
  [Weight of Runner Of =10% of weight of Casting
  Weight of biscuits =20% of weight of casting]
- Gate Velocity (Vg) in m/sec
- Gate thickness Hg(mm),
- Volume Of Metal Through Gate : P(cm³)
  P= (volume of casting)+(volume of overflow)
  (Volume of overflow =10% of volume of casting)
- Cavity fill time (millisecond)
- Fill rate(Q)cm³/sec: Q= (p×1000)/t; t-fill time in milliseconds
- Gate Area(Ag)(cm²):
  Ag= (Q)/ (100×Vg)
Gate Length –Lg(mm)
\[ Lg = \frac{(Ag \times 100)}{Hg} \]
Runner Area-Ar=7.5×Ag×(Number of cavity)
Runner Depth-D(mm),D=\sqrt{Ar/1.6} - \sqrt{Ar/2}
Runner Width(w=2D)(mm)

Selection Of Die Casting Machine Calculations:
- Total Component Projected Area: (cm\(^2\)) = (component projected area) + (component Projected Area)
- Projected Area of Runner ,biscuit and O/F =20% of the total component projected Area
- Total projected Area(cm\(^2\))
- Locking Force = (total projected Area) × (specific injection pressure)
  [Specific injection pressure Range 400-600kg/cm\(^2\)]

Machine Specification
Select Machine based on the Locking Force

Plunger Diameter –D (Cm):
- Maximum plunger stroke-20/30mm
- Total shot weight (gms)
  = (shot weight) \(_1\) + (shot weight) \(_2\)
- \(D2=\sqrt{\frac{(4\times \text{shot weight})}{(\pi \times \text{Effective plunger stroke} \times 0.75 \times 2.5)}}\)

For Big Bearing Housing
Model Volume=268143mm\(^3\)
=268.143cm\(^3\)
- Weight of Component(gms)
  = (volume)×(density)
  =268.143×2.7 \[∵\ Density of Al Alloy Lm 24-2.7\]
  =723.98gms
- Volume of casting=(Weight of component)/Density =723.98/2.7
  =268.14cm\(^3\)
- Shot weight= (Weight of Casting)+(Weight of runner overflow)+(weight of biscuits)
  [Weight of Runner O/F =10% of weight of Casting
  Weight of biscuits =20% of weight of casting]
  =723.98+72.398+144.79
  =941.16gms
- Gate velocity(V\(_g\))in (m/sec): (Refer Table )=30m/sec
- Gate Thickness=Hg=1.5mm (Refer Table )
- Volume Of Metal Through Gate : p(cm\(^3\))
  \[ p = (\text{volume of casting})+(\text{volume of overflow})=268.14+26.814=294.95\text{cm}^3\]
- Cavity Fill time 450 milliseconds \[∵\max thickness=27mm\]
- Fill rate(Q)cm\(^3\)/sec:
  \[ Q = \frac{(P \times 1000)}{t} = \frac{(294.95 \times 1000)}{450} = 655.4\text{cm}^3/\text{sec}; \ t-\text{fill time in milliseconds}\]
- Gate Area(Ag)(cm\(^2\))Ag =\frac{Q \times (100 \times V_g)}{655.4/(30 \times 100)}=21\text{mm}^2
- Gate Length –Lg(mm):
  \[ Lg = \frac{(Ag \times 100)}{Hg} = \frac{(0.21 \times 100)}{1.5} = 14.53\text{mm}\]
- Runner Area-Ar=7.5×Ag×(Number of cavity)=7.5×21.0×1=157.5mm\(^2\)
Runner Depth $D = \sqrt{\frac{A_r}{2}} = \sqrt{157.5/2} = 8.8 \text{mm}$

Runner Width $(W=2D) = 2 \times 8.8 = 17.6 \text{mm}$

**Small Bearing Housing**

Model Volume $= 215455 \text{mm}^3 = 215.45 \text{cm}^3$

- Weight of component (gms) = (volume) $\times$ (density) = $215.45 \times 2.7 = 581.71 \text{gms}$
- Volume of Casting (cm$^3$) = (Weight of component)/Density = $581.71/2.7 = 215.45 \text{cm}^3$
- Short weight (gms) = (Weight of Casting) + (weight of runner overflow) + (weight of biscuits)
  
  Weight of Runner O/F = 10% of weight of Casting
  Weight of biscuits = 20% of weight of casting
  
  = $581.17 + 58.17 + 116.34 = 756.22 \text{gms}$

- Gate Velocity $(V_g)$ in m/sec = 30 m/sec (Refer Table)
- Gate thickness $H_g$ in mm = 1.5 mm (Refer Table)
- Volume of metal through gate $p$ (cm$^3$)
- $P$ = (volume of casting) + (volume of overflow)
  
  (Volume of overflow = 10% of volume of casting)
  
  = $215.45 + 21.54$
  
  = 236.995 \text{cm}^3$

- Cavity fill time 450 mill second  

- Fill rate $(Q)$ cm$^3$/sec:
  
  $Q = \frac{(p \times 1000)}{t}$
  
  = $(236.99 \times 1000)/450$
  
  = 526.64 cm$^3$/sec

- Gate Area $(A_g)$ (cm$^2$):
  
  $A_g = \frac{Q}{(100 \times V_g)}$
  
  = $526.64/(30 \times 100)$
  
  = 0.1755 cm$^2$
  
  = 17.55 mm$^2$

- Gate Length $- L_g$ (mm):
  
  $L_g = \frac{(A_g \times 100)}{H_g}$
  
  = $(17.55 \times 100)/1.5$
  
  = 11.7 mm

- Runner Area- $A_r$
  
  $A_r = 7.5 \times A_g \times$ (number of cavity)
  
  = $7.5 \times 17.55 \times 1$
  
  = 131.6 mm$^2$

- Runner Depth- $D$(mm):
  
  $D = \sqrt{\frac{A_r}{2}} = \sqrt{131.6/2} = 8.1 \text{mm}$

- Runner Width : $(W=2D) = 2 \times 8.1$
  
  = 16.2 mm

**Figure 1:** Return pin  
**Figure 2:** Ejector Die Block
VI. THERMAL ANALYSIS OF DIE CASTING ASSEMBLY

Introduction:
ANSYS is a sophisticated and comprehensive finite element program that has capabilities in many different physics fields such as static structural, nonlinear, thermal, implicit and explicit dynamics, fluid flow, electromagnetic, and electric field analysis. It can also perform coupled field
analysis combining one or more of these different physics. Obviously because ANSYS is huge program with so many capabilities (even within one of these physics fields) it is impossible to cover everything in this short guide. This document will give an introduction as to how the ANSYS program works and how these basic skills will be applicable to any type of analysis within ANSYS. The most important concepts in using ANSYS will be addressed here in a compressed format. The key to becoming productive in any computer aided engineering program is to start to think like the program thinks, to get the big picture of how it works in general. That is the primary goal of this guideline.

**Couple Of Preliminaries:**

ANSYS is an integrated program with all operations performed under one GUI. Creating the model, running it, and post processing the results are all done without leaving the ANSYS environment. There are several different ways of working within ANSYS. This stems from the fact that like every program, ANSYS is driven by commands. The difference between ANSYS and say, Microsoft Word, is that when you click on an icon in Word, you have no idea what command was executed behind the scenes to make the program do what you asked. ANSYS gives you easy access to these commands if you want to use them. These commands are simple to use; just a keyword followed by several arguments. By stacking these commands together in a text file the power to automate and script.

ANSYS is one key reason why I think it is superior to other FEA codes on the market. New ANSYS users generally don’t care much about scripting to start with and just want to figure out how to do what they want within the GUI environment, and that’s where we will start as well. Each key concept will be explained as succinctly as possible, then at the end we will do a simple problem using several different approaches to put it all together.

**VII. CONCLUSION**

- For the given thermal loading and boundary conditions, displacement and stresses developed in die are well below acceptance range for respective materials.
- From the above results one can conclude that Die design and used material are safe and suitable for the respective casting process.
- From theoretical survey where there is more temperature gradient we can except more stresses at that region, the same thing is proved by static analysis in this project report.

**VIII. FUTURE SCOPE**

- As this is steady state thermal analysis, only static thermal load and static conditions are consider for process simulation.
- If anybody wants to simulate molten flow and wants to know stresses and displacements, one has to perform transient thermal analysis supported by computational fluid dynamic(CFD) analysis.

**REFERENCES**

[1] ASM Handbook Volume 15, Casting (2008 Edition).
[2] Blum W. Y.J.Li, Zeng X.H., Vongrobman B., and Haberling C.,(2005), “Creep deformation mechanism in High-pressure aluminum base alloys”, Metallurgical and material transactions A, vol.36A,pp.1724.
[3] Wei Ying-hui, Hou Li Feng, Yang Li-jing Xu Bing-she Kozuka Munehiro and Ichinose Hideki.(2009) “Microstructure and properties of die casting components with various thickness made of AZ91D alloy” Journal of materials processing technology 209.pp.3278-3284.
[4] Matthew S, Dargusch a, Dourb G, Schauer c, Dinnis C.M. and Savaged G (2006), “The influence of pressure during solidification of high pressure die cast aluminium telecommunication components” Journal of materials processing technology 180. Pp.37- 43.
[5] Zhi-Peng a Guo, Shou-Mei a Xiong, Bai-cheng a Liu, Bai-cheng a Liu, Li b Mei, Allison b Jhon. (2008), “Effect of process parameter, casting thickness and alloys on the interfacial heat transfer coefficient in the high pressure die casting process” Metallurgical and material transactions A, The minerals, metals and materials society and ASM international 2008. Vol.39A.pp. 2896.

[6] Zhu J.D., Cockcroft S.L., and Maijer D.M.(2006)“Modelling of micro porosity formation in A 356 Aluminium Alloy Casting” Metallurgical and materials transactions A. Vol. 37A.pp.1075.