Review on Die Design for Die Casting

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Abstract—**Pressure Die Casting is one of the significant ways of manufacturing nonferrous metal casting. This is used widely for manufacturing on large scale. In this process a permanent mould or die is used to cast the component. This document givessummary about die designing required for pressure die casting.Brief information related to gating system, die material, maintenance has been described in this paper.**

***Keywords*— Die, Die casting, Design, Maintenance**

I. Introduction

In the die casting process, parts are formed by forcing molten nonferrous metals under pressure into metal moulds called dies. The mould cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mould during theprocess.Mostdie castingsare made from non-ferrous metalsspecifically zinc, copper, aluminium, magnesium, lead, pewter, and tin-based alloys as they possess good mechanical properties and absence of creep is required. Depending on the type of metal being cast, a hot- or cold-chamber machine is used.

Die castings are extensively used for manufacture of intricate engineering components. Typical applications are housings for automotive assemblies and electrical motors/ pumps, and structural parts for electronic equipment. Design of parts for die casting is critical for obtaining good castings. It involves providing proper gating systems and design for uniform metal flow, uniform wall thickness, bosses, avoidance of side cores, provision for inserts, providing generous drafts, and keeping minimum machining allowance.[1]

Die casting is categorized two types namely- Hot Chamber and Cold Chamber as shown in Figure 1&2. Metals like Zinc, tin and lead alloys are casted in hot chamber die casting having melting point below 390^{0}C whereas aluminum alloys are casted in cold chamber die casting machine. Aluminum dissolves ferrous parts in the die chamber and hence preferred to be used in cold chamber die casting. Continuous contact of molten metal is avoided by using a ladle for introducing molten metal directly to the machine.

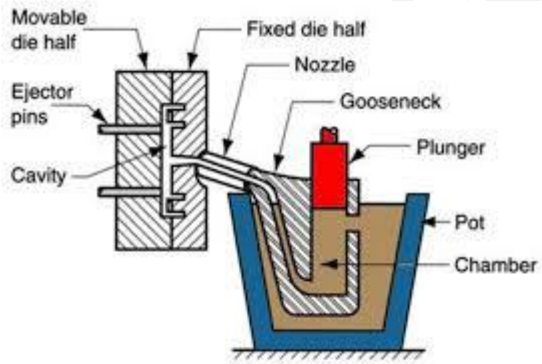

Fig. 1. Hot Chamber Die Casting[2]

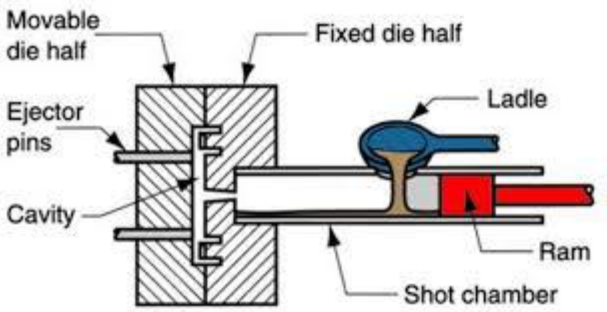

Fig. 2. Cold Chamber Die Casting[2]

II. DIE

In the die casting process, parts are formed by forcing molten nonferrous metals under pressure into metal moulds called dies. The die resembles the common type of permanent mould in that it too has two halves which opens and close along a vertical parting on a die casting machine, the die half called “cover die” is stationary. The other die half which opens and closes is known as the “ejector die”.Die casting die are usually made of alloy steel which should be dimensionally stable with stand heat checking, not get soldered to the cast alloy.Die casting have to be machined with great accuracy.[3]

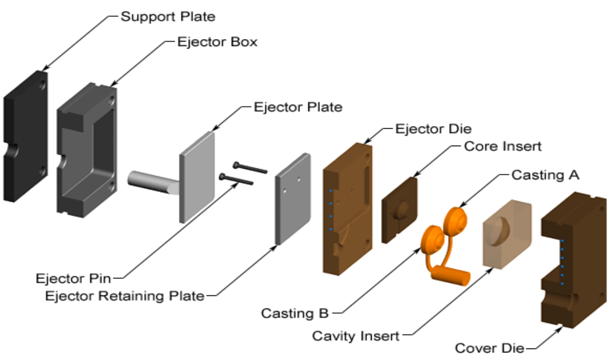

Fig. 3. Exploded View of Die[5]

A. Material for Die:

Failure consideration while selecting die materials:

1. Thermal fatigue: Severe thermal shocks loadings due to rapid acceleration of high temperature and chill are imposed upon those surfaces of the dies which come in contact with molten metal. Thermal fatigue causes heat checking which results from the difference in heating and cooling rates between the die surface and the steel below the surface. This condition sets up tensile stress and gives rise to minute cracks at the point of stress on the die surface, which in turn are transferred to the casting in the form of hair lines.
2. Mechanical erosion: Dies should be soft enough in order to resist heat checking but at the same time they should not gall, erode or deform rapidly under loads; they should be able to withstand washing, wearing and peening.
3. Chemical attack: A chemically attacked and thus decarburized die loses surface hardness and leads to pitting and washing. Decarburization may occur in heat treatment or during solidification of a cast die.[4]

For dies of pressure die casting carbon steels, low-alloyed steels, high-alloyed steels, chrome steels, tungsten steels and chrome-molybdenum steels are used.

- Carbon steels are used for die parts being not in contact with liquid metal as the clamping die box, the guide and supporting plate of ejectors and the hydraulic drawer of cores.

- Low-alloyed steels are used especially for zinc alloys. They are steels with the content 0.30 up to 0.45 % C alloyed with Cr respectively V and Mo.

- High-alloyed steels contain so many carbide-created elements that by tempering at temperature higher than 400 °C it comes to increase of hardness measured at room temperature marked as the secondary hardness. It is higher at larger number of the carbide- created elements connecting with the origin of complex carbides and shifting into higher temperatures. Therefore, the steels for dies shifted from the chrome and tungsten steels to the combinations W-Cr, W-Cr-Co, Cr-Mo, Cr-Mo-V, Cr-Mo-V-W.

- Chrome steels are martensitic with so large content of chrome that they are anticorrosive and heat-resisting and with so large content of carbon that they are hardenable.

- Tungsten steels are the steels with the content 0,30 up to 0,35 % C, 2 up to 2,5 % Cr and 4,5 up to 11 % W.[6]

EN8 is a very popular grade of unalloyed medium carbon steel, which is readily machinable in any condition. It is a medium strength steel and has good tensile strength. EN8 is suitable for the manufacture of parts such as general-purpose axles and shafts, gears, bolts and studs, stressed pins, keys etc.EN8 Carbon Steel Grade Equivalents. Other steel grades in ASTM, DIN, JIS standards are similar and equivalent to EN8 steel, as follows:

BS 970-1991:080M40

AISI/ASTM A29:1038, 1040, 1045

DIN Werkstoff No.: 1.0511, 1.1186, 1.1189

BS & DIN European: C40, CK40, C45, CK45

JIS G4051: S40C, S45C.[7]

H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs as a result of cyclic heating and cooling cycles in hot work tooling applications.H13 is a chromium, molybdenum, vanadium hot work tool steel which is characterized by high hardenability and excellent toughness. The chromium content assists H13 to resist softening when used at high temperatures. H13 offers an excellent combination of shock and abrasion resistance, and possesses good red hardness.[8]

B. Designing of Die

Following points are kept in mind while designing die-

1. Fixed core can be placed in either the ejector or the cover(fixed) portion of the die. A fixed core must have its axis parallel to direction of motion of the die. Movable cores must have its axis parallel to the direction of motion of the die. Movable cores must be provided with positive means for moving and lever admirably fulfils the purpose. But where a short motion is required, it is simple set a pin at an angle engaging with a hole, such that the piece containing the hole move transversely when the pin is moved longitudinally.
2. A loose core or “Knock-out” is essential for forming a shape having an internal undercut or recess which cannot be produced by core attached permanently to die. In such cases, loose pieces which come out along with the casting when the latter is ejected, are also suitable. They are then knocked out and can be used again.
3. The casting must invariably cling to the ejector portion.Ejector pins should be made to bear at such points on casting where pin marks will not be noticeable or objectionable. As far as possible, the pins should be made to bear on the runners, flash, or other projections which are subsequently cut off. Pins should also be so placed that the casting is not deformed.

4. Vents are fitted on the die parting to allow the air to escape when the molten metal is injected. Vents are normally formed by machining grooves about 0.2mm deep.
5. Sprue,runners and gates should be provided that they facilitate the removal of the casting. Sprue holes are always tapered. A sprue pin is usually fixed at the inner end of the sprue to deflect metal into runner. Runner is cut at die parting. Gates join the runner with die cavity. The dimensions of gating system affect the soundness and surface finish on the casting;these should therefore be decided with due care.
6. Overflow wells are sometimes included. They collect the extra metal and facilitate escape of air, thus contributing to the soundness and uniformity of mechanical properties in casting.
7. Large dies required for mass production are usually water-cooled. Holes are drilled through the dies for the circulation of water. Large core may also need water cooling.
8. The provision of several die cavities in the same die increases productivity. Where the shape and size permit such as arrangement, it is worthy of attention.

Design:

1. *OverflowDesign:* Overflow is needed in most aluminum die-casting applications to reduce non-metallic inclusions and air entrapment and help balance the thermal effect during the die filling. In practice, if the 3D model of die-casting is divided into several segments according to the flow paths, the overflow of each segment will be sized in proportion to the volume of the segment. The flow distance of molten metal also affects the volume of overflow due to the heat loss. The overflow should be enlarged accordingly when the flow distance increases. Generally, the overflow is located at the point the flow reaches last or the point where two flows meet.
   Overflow Area = 0.5×Gate area
2. *Gate design*: Gate design involves both the gate (or ingate) and the gate runner. The gate is a narrow opening into the cavity from the gate runner. Its cross-sectional area is determined in accordance with die-casting thickness, cavity and overflow volume, gate velocity, die and metal temperature, etc. It can be accurately estimated by using the P-Q2 technique. Usually, the tangential gate is employed where the segment of a die-casting is shaped like a parallelogram and fan gate is adopted if the segment approximates the shape of a trapezoid. In fact, they are often used together if the die-casting part is complex in shape.
   1. Gate thickness (tg) = 0.8×min wall thickness of casting
   2. Fill rate= (volume of cavity & overflow)/fill time(from standards) mm^3/s
   3. Gate area (Ag) = Fill rate /gate velocity mm^2
   4. Gate length (Lg)=Total area of the gate (Ag)/ gate thickness (tg)
3. *Runner design*: Runner is to distribute metal from the sprue or shot sleeve to the gates. The cross-sectional area of runner must be larger than that of gate so as to produce an increase of flow velocity along the flow path. If a cavity has two or more gates, branch-runners are used to connect the gates with the main runner. The area of the main runner should be larger than the sum of the area of all the branch-runners. The runner normally has a consistent cross-sectional area, whose cross-sectional profile may be a circle, half circle or trapezoidal. By sweeping a 2D profile along the guide curve of certain flow paths, the parametric models of runners could be formed. The geometry of the runner can be modified by the means of changing the guide curves and the dimensions of the sectional profile.

   1. Runner area (Ar) =2.1×Gate area × number of cavities mm^2
   2. Width of runner (W) = (Area of runner)1/2 (mm)
   3. Depth of runner = W/1.8 (mm)

4. *Shot sleeve and sprue design*: A shot sleeve is used to deliver the molten metal into the die in the cold chamber machine and a biscuit is formed at the end of the shot sleeve after the molten metal solidifies. Usually, the biscuit is a tapered cylinder with a diameter equal to the plunger and its geometry could be created by simply extruding a circle with a taper angle. A sprue is used in the hot chamber machine instead and standard sprue parts are available commercially. When designing the shot sleeve or the sprue, it must be assured that the cross-sectional area of the shot sleeve or sprue must be greater than the total cross-sectional area of the runners.
   1. Weight of the component
   2. Over flows and Runners weight = (40% of component weight)
   3. Total Weight (m) = Wt. of Component + overflows & runner weight gm
   4. Density of the metal ADC12 (d1)= gm/cm3
   5. Total volume of the component (Vt) = m/d1
   6. Actual shot volume = Vt + biscuit volume= Vt + (π /4)d22h Where h = biscuit thickness, d2= diameter of plunger
5. *Redesign of gating systems*: The modification or redesign of the gating system is carried out in accordance with the feedback of production or the analysis result if a CAE package is used. Tools are provided for modifying the previous design, with which the designer can add, delete, resize, reposition and rotate the gating element easily. If there is any change made, the system will evaluate the validity of whole gating system, and then guidance will be given for further modification. The system allows the designer to keep the previous design of gating system in the library for future reuse. If

two die-casting parts have an analogous geometry with each other, a similar design of gating system can be applied to them.[4]

C. Manufacturing of Die

There are various ways for die manufacturing. Wire cut EDM is most widely used method for manufacturing die. Wire electrical discharge machining is a high-precision method for cutting nearly any electrically conductive material. A thin, electrically-charged EDM wire held between upper and lower mechanical guides forms one electrode, while the material being cut forms the second electrode. Electrical discharge between the wire and the workpiece creates sparks that rapidly cut away material. Submerging the workpiece and wire in deionized water, allows cutting debris to be flushed away.

As the charged wire never makes physical contact with the workpiece in EDM machining, there are no cutting forces involved, making it possible to manufacture extremely small and delicate parts. Parts that require levels of accuracy and intricacy that traditional machining cannot achieve can easily be produced via wire EDM.[9]

Why Choose Wire-cut EDM Over Die-sink EDM or Water-jet cutting?

Concerns about residual stress are often the primary reason why manufacturers choose Wire-Cut EDM over other methods. Residual stress can contribute to premature failure of a part, so to avoid creating residual stresses during the manufacturing process is to extend the life of the part. Wire EDM creates minimal residual stress. Moreover, preventing residual stress eliminates the need to relieve those stresses – this is just another example of how Wire EDM makes the manufacturing process efficient.[9]

D. *Testing of Die:*

In the experimental part of our work the failures on the working surface of the fixed half of the testing die for die-casting of aluminium alloys were observed with the use of non-destructive testing methods: such as thermographic analysis, penetrants, and metallographic examination of polymeric replicas.For economical production of aluminium and aluminium alloys die castings it is important that the dies have a long working life. The replacement of a die is expensive in both: money and production time.Besides, the die design, the material selection and the process thermal stress fatigue course, which is the consequence of the working conditions, the inhomogeneous and to low initial temperature of the die, contribute to the crack formation.It is clearly seen from the presented thermographs, that the required temperatures and homogeneity of the temperature field of the discussed case are not possible to reach without the changing both: the heating method and the die design. Therefore, in the first stage a solution of the problem should be in changing of the position of heating and/or cooling channels, i.e. their closer shifting to the working surface of the die.[3]

E. *Defects in Die's*

Aluminium die-casting dies fail because of a number of different and simultaneously operating stresses. The stresses are of two basic kinds the first which are created during the manufacturing of the die, and the second which are produced during exploitation process. For economical production of aluminium alloys die-castings it is important that the dies have a long working life. The replacement of a die is expensive in both: money and production time. The most frequent failures of aluminium alloys die-casting dies can generally be divided into four basic groups:

1. Heat checking
2. Big cracks
3. Cracking in corners, sharp radii, or sharp edges
4. Cracking due to wear or erosion.

It is generally agreed that one of the principal causes of termination of die life is heat checking, which occurs through a process of crack initiation and propagation from the thermal stress fatigue induced on a die surface. Some of the factors that affect die failures may be controlled to some extent by the die-casting experts (designers, manufacturers and operators). These factors include:

1. Design
2. Materials selection
3. Heat treatment
4. Finishing operations
5. Handling and use.[3]

F. *Maintenance*

Inspection

After the shakeout of the casting it is inspected for defects. The most common defects are misruns and cold shuts. These defects can be caused by cold dies, low metal temperature, dirty metal, lack of venting, or too much lubricant. Other possible defects are gas porosity, shrinkage porosity, hot tears, and flow marks. Flow marks are marks left on the surface of the casting due to poor gating, sharp corners, or excessive lubricant.

Evaluating the Condition of Worn Out Dies

Dies do wear out! Even with the best of care, a die cast die does not lastforever. It will be less difficult to convince our customer that it's time to replace acavity or a complete die if we maintain good records of monthly shot countsand tool condition. How do we know when a die is worn out?Sometimes there is no question regarding the ability of a die to make anothercasting. A catastrophic failure could occur when a large chunk of cavity steelbreaks out of a die, or a cavity breaks into several pieces due to gross cracking.At these times when it becomes necessary to repair or replace a tool the die caster needs to answer the question Are you satisfied with the number of shotsthat was obtained from the tool? Was this condition expected or unexpected?It is far better to vigilantly monitor the condition of each tool during its life andnot be taken by surprise when a major failure occurs.The following guidelines can be used for measuring the gradual deterioration ofa die. These will allow you to monitor and document the die's conditionthroughout its life and to predict when major repair orreplacement will benecessary.[10]

Points to keep in mind while inspection: -

1.Before mould maintenance, you must keep the final die casting products.

2.Full cleaning the metal filling and scales of the mould.

3.Check the final die-casting products:look for any abrasion,mould sticking,pressure tread and size, hole changes.

4.Comprehensive inspection of moulds:Whether the small core is bent or broken,Whether the active core insert positioning are not allowed,Whether the ejector rod and the length changes, with or without insert positioning are not allowed, whether the fastening bolts loose. According to the damage, determine the repair or replacement.

5.On the casting caused a mild abrasion of cavity sinkcrackblock and so on,need local welding repair,welding should be in strict accordance with the rules of operation.

6.Sliding parts such as pulling bodies,guides etc.Should make a thorough cleaning with carefully check the maintenance.Re-lubricate with high-temperature grease after assembly.

7.If there is a hydraulic core-pulling,hydraulic parts and mould maintenance at the same time.The maintenance of hydraulic parts need pay special attention to cleaning,otherwise the whole die casting machine hydraulic system will be pollution.

8.When the mould failure or damage in the process of production, should be in accordance with the specific circumstances to determine the repair scheme.

9.For the already complete maintenance mould,the complete set of mould such as moulding surface,parting line,mounting face need to be rust-proof treatment.

10.The mould should be annealing treatment after production a certain numbers parts,then heat treatment and surface treatment.[11]

Visual Inspection:

1. Last Shot - check amount of heat check, drags, cracks, parting line flash,slide flash, bent/broken cores, ejector pin condition, fusion, ejector pinflash, broken out pieces, etc.
2. Cavity and Cores - check for heat check, cracks, fusion, broken out pieces,damaged cores, caved in parting line.
3. Core Pins, should have a date etched on core heads for life expectancyreference.
4. Holder Block - condition of parting line, flatness, dents, craters, excessiveflash, metal fused to parting line, condition of vents.
5. Slides - check for fit, metal build-up, fit of locks (when hot), condition of anglepin holes, excessive wear.
6. Gibs, Angle Pins, Leader Pins - check for excessive wear.
7. Plates, Rails - check for flatness, bends, warps.[10]

G. Die casting

Applications of Die Casting Processes

Die casting is a process that has far-reaching applications. Die casting process is preferred for nonferrous metal parts of intricate shapes. Any part production process that creates high-volume metal components will likely benefit from die casting. A variety of manufacturing industries currently rely on one or many types of die casting processes, including the auto, aerospace and power tools industries. Aluminium alloys die-castings are made for final installation, and need very little machining. They are used in automotive industry, automobiles appliances, hand tools, computer peripherals, toys, optical, photographic equipment, household appliances, electrical industry and installations, fittings, etc. Other applications include carburettor bodies, hydraulic brake cylinders, refrigeration castings, washing machine gears and gear covers, oil pump bodies, typewriter segments, aircraft and missile castings.[14]

Advantages of die casting

1. Excellent dimensional accuracy (dependent on casting material, but typically 0.1 mm for the first 2.5 cm (0.004 inch for the first inch) and 0.02 mm for each additional centimetre (0.002 inch for each additional inch).
2. Closer dimensional tolerances can be achieved. High production rate.
3. Smooth cast surfaces (Ra 1–2.5 micrometres) and better appearances.
4. Chilling effect of the metal mould helps producing a fine-grained metal surface.
5. Ability to make many intricate parts such as hole opening slot trademark number etc.
6. Thinner walls can be cast as compared to sand and permanent mould casting (approximately 0.75 mm or 0.030 in).
7. Metal cores employed in permanent moulds can produce holes of much smaller diameter than sand casting.
8. Inserts can be cast-in (such as threaded inserts, heating elements, and high strength bearing surfaces).
9. Reduces or eliminates secondary machining operations.
10. Casting tensile strength as high as 415 megapascals (60 ksi).
11. Casting of low fluidity metals.[12] [13]

Disadvantages of the die casting process

1. Microporosity in the die casting products is a common problem because of faster solidification, trapped air and vaporized die lubricants.Undercuts cannot be found in simple two-piece dies.
2. Hollow shapes are not readily casted because of the high metal pressure.
3. Limited sizes of the products can be produced based on the availability of the equipment
4. High melting temperature alloys are practically not die casted.
5. Flash is present except for very small zinc die casting.
6. Large scale production is economical.Initial investment is high.
7. The process is limited to high-fluidity metals, and casting weights must be between 30 grams and 10 kg.[12] [13]

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