High Pressure Die Casting Cooling calculation with application of Thermodynamics

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Abstract - *High pressure die casting is type of permanent molding process where in high temperature molten material is injected into die to get desired component with high production rate. In high pressure die casting tool life is main concern because of high temperature of molten metal. This molten metal of temperature 650 degree is injected into die with 1000 bar pressure. Die casting tool faces problems like soldering, Shrink porosity, cracks, erosion, flash. All these problems can be minimized with effective cooling in tool. This cooling channels can be calculated by using thermodynamic principles. These calculations can guide us for cooling channel length as well as its diameter and location from the surface. To achieve better heat transfer H13 material used for tool making.*

Key Words: H13

1. INTRODUCTION

This There are two types of high pressure die casting 1. Hot chamber die casting 2. Cold chamber die casting.

1.Hot chamber die casting- This is type of HPDC where melting furnace includes injection system. No material transfer required. Typically used for low melting temperature metals like zinc. Used for high volume and small parts.

2.Cold Chamber die casting- In this type material is to be transferred from furnace to injection system. Cooling od piston, sleeve and die required. High melting temperature metals can be casted through this process. Used for high volume and all kinds of parts.

This paper is for specifically cold chamber die casting. Below is image for cold chamber die casting fig-1.

Cooling in die casting is very important to decide cycle time for production. Cooling solve many casting defects such as soldering, shrinkage porosity, controls steel thermal expansion and improves die life.

Fig-1. Cold chamber die casting machine

Thermodynamics behind Cooling Calculation:

Heat is form of energy and measured in the unit of Joules. Die casting die works as heat exchanger during production. It absorbs heat from molten aluminum and dissipates heat to cooling channel, spray and environment. Total heat input is heat extracted from molten metal and total heat output is total heat transpired to spray, internal die cooling and to air.

$$Q_{metal} = Q_{spray} + Q_{air} + Q_{cooling}$$

To reach steady state equilibrium condition heat input should be equal to heat output. If more heat added or less heat is extracted, then die attains new higher temperature equilibrium. If less heat is added or more heat is extracted, then die attains new lower temperature equilibrium.

There are three types of heat transfers:

- **Conduction**
- **Convection**
- **Radiation**

1. **Conduction:** Heat is transferred through molecules to molecules without motion. When die absorbs heat from molten metal, it transfers heat to every corner of the tool by conduction through molecules of steel. Fig-2 shows how heat transfers in steel from part.

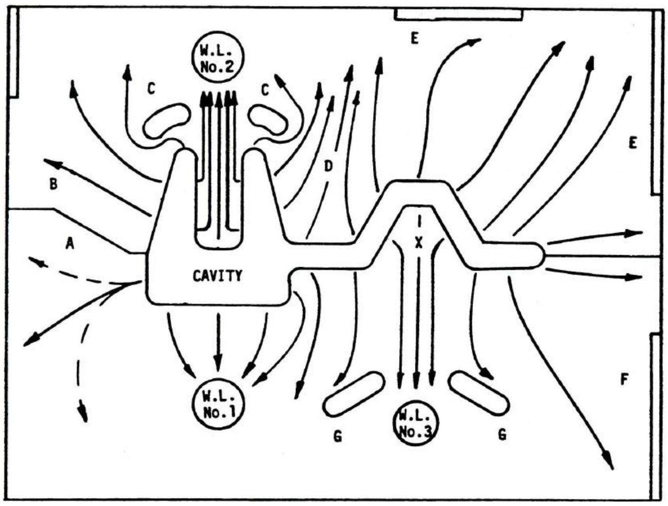
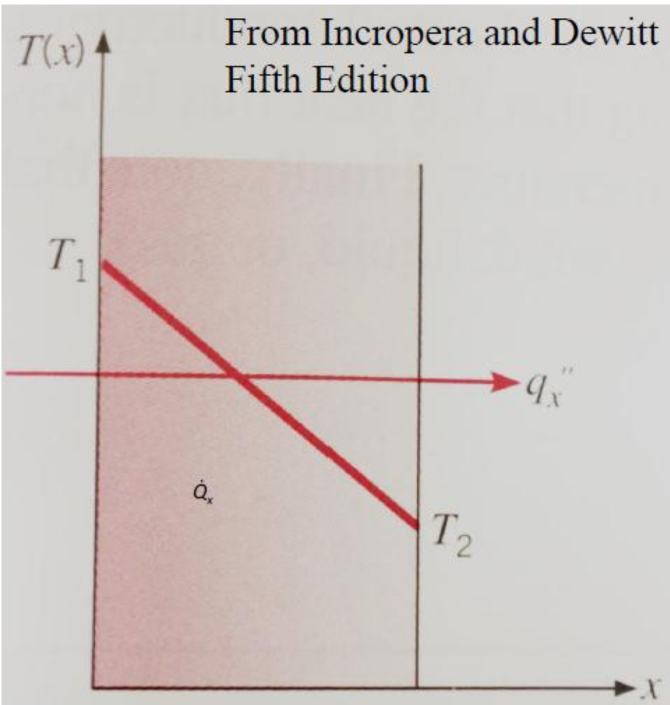


Fig-2-Conduction Heat Transfer

From Fouriers Law Heat transfer rate in conduction can be calculated as below:



$$Q_x = \frac{KA\,(T_1\text{-}T_2)}{D}$$

Q_x= Heat transfer rate in (Joules/sec)

K= Thermal conductivity of the material

A=Area of the surface

D= Distance from the surface

T_1= Temperature at surface

T_2= Temperature at L

2. **Convection**: Heat transferred due to mass motion of the fluid.Heat transferred by convection from die steel to cooling channels.This is the most effective heat transfer mode. Heat loss during cavity filling is by convection. Heat transfer by cooling channel is shown by fig-3.

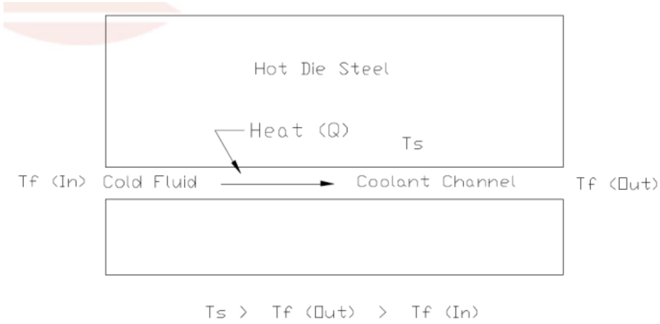
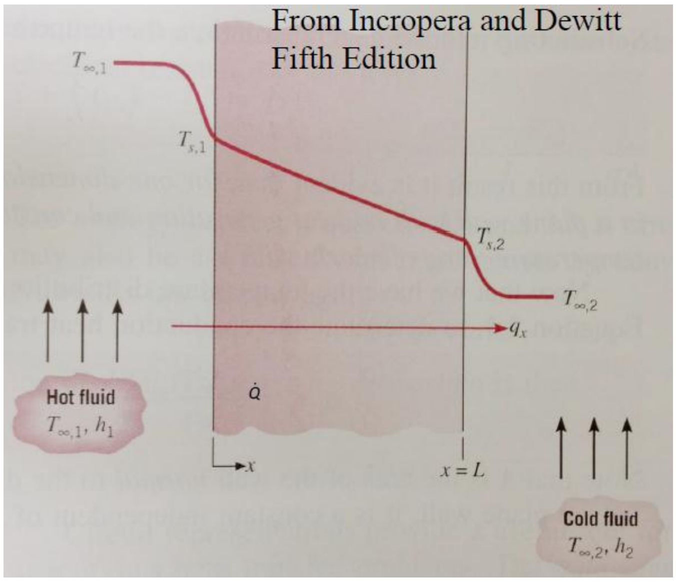


Fig-3 Convection Heat Transfer

Heat transfer rate through convection can be calculated by below formula:



$Q = hA(T_s - T_f)$

Q= Heat transfer rate in (Joules/sec)

h= Heat transfer coefficient

A= Area of surface

T_s= Surface temperature

T_f= Fluid temperature

To calculate Heat transfer coefficient, we should know Reynold Number and Prandtl Number for specific cooling channel.

1. Reynolds Number:

   $R_e = \frac{v^* D^* \rho}{\mu}$

2. Prandtl Number:

   $P_r = \frac{Cp^* \mu}{k}$

Where

V= Velocity of fluid

D= diameter of cooling channel

ρ= Density of fluid

μ= Dynamic Viscosity of fluid in Kg/sm

C_p= Specific heat of fluid

K= Thermal conductivity of fluid

By using above to Number, we can calculate heat transfer coefficient by using Dittus-Boelter relationship as follows

Considering Reynolds Number more than 2300, we have following equation:

$$N_u = 0.023^* R_e^{0.8} {}^* P_r^{0.3}$$

and Heat transfer coefficient as

$$h = \frac{Nu^*K}{D}$$

So $$h = \frac{0.023^* R_e^{0.8} {}^* P_r^{0.3*}K}{D}$$

3. **Radiation**: Heat transferred by radiation from source to atmosphere. In die casting heat transferred through radiation is very less maximum 2%.

Heat Load To DCD:

Total heat load to die casting die is the summation of latent heat and sensible heat.

$$Q_{tot} = Q_L + Q_S$$

Q_S **Sensible Heat:**

This is the heat required to raise the temperature of substance.

OR heat released during lowering the temperature.

This can be calculated by following formula:

$$Q_s = m^*C_p^*(T_i - T_e)$$

Where,

Q_s= Sensible heat energy (Joules)

m= mass of material (Kg)

C_p= material specific heat

T_i= Injection Temperature

T_e= Ejection temperaure

Q_L **Latent Heat:**

This is the heat required to change the state of the substance(solid to liquid). OR heat released during change of state of the substance(liquid to solid).

This can be claculated as follows:

$$Q_L = m^*L_f$$

Where,

Q_L= Latent heat (Joules)

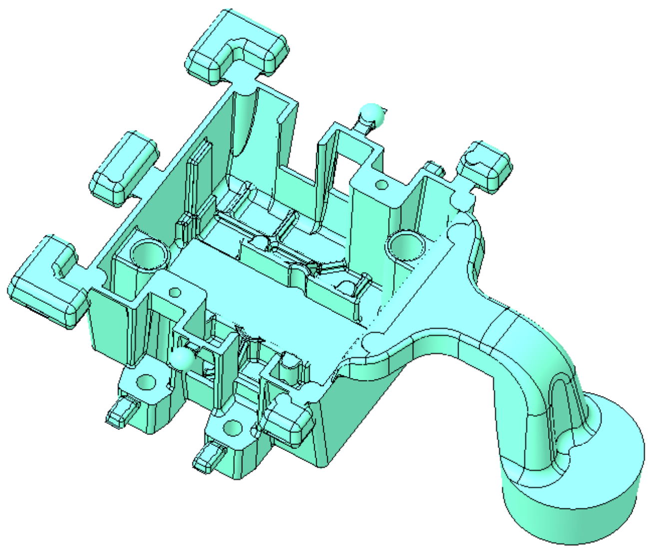
m= mass of material (Kg)

L_f= material latent heat of fusion

Cooling Calculation:

Considering one die casting tool example, we will calculate cooling channel length and its position in the die.

Casting- Contactor Housing



Weight of the Casting-400gm

Molding material- Aluminum

Die material – H-13

Machine Tonnage-250Ton

Below data captured from 3D software Creo.

Volume of shot -287.85 cm^3

Total surface area of shot-1153.31cm^2

Volume of casting with overflow-176.87cm^3

Surface area of casting with overflow-957.84cm^2

Surface area for moving side=446.9 cm^2

Surface area of fix side=386.04cm^2

Projected area on moving side=14163.9mm^2

Projected area on fix side=18128.9mm^2

Inputs from machine:

Cycle time=25 sec

Injection temperature Ti=660°C

Ejection temperature Te=425°C

Cavity surface temperature =220°C

Water temperature inlet for core & cavity=25°C

Calculate heat transfer coefficient for specified cooling channel considering machine water flow rate of 3lpm.

Cooling medium= water

Diameter of cooling channel D=10mm=0.01m

Velocity of fluid V= 0.64 m/sec.

Thermal conductivity of fluid K=0.58 (w/mk)

Density of fluid ρ = 996.3 (kg/m3)

Dynamic viscosity of fluid μ= 0.0008684(Ns/m2)

Specific heat of fluid =Cp= 4072.7 (J/Kg/K)

Calculate Reynold Number:

Re = VD ρ /μ

= 0.64*0.01*996.3/0.0008684

=7342.6

Calculate Prandtl Number:

Pr= Cp* μ /k

= 4072.7*0.0008684/0.58

=6.097

Calculate Heat transfer Coefficient h:

$h=0.023* R_e^{0.8}*P_r^{0.3}*k/D$

$= 0.023*(7342.6)^{0.8}*(6.097)^{0.3}*0.58/0.01$

=2840.45 W/m^{2}K

Calculate Total heat input to the die steel:

Consider material data:

Liquidus temperature of material: 580°C

Solidus temperature of material: 507°C

Die temperature around water line: 120°C

Calculate weight of molten aluminum on core side & cavity side:

Weight on mov side m_m = Volume * Density

=446.90*0.1847*0.00125

=0.1031 Kg.

Weight on fix side m_f= Volume * Density

=386.04 *0.1847*0.00125

=0.089 Kg.

Calculate Total Heat Input:

Consider heat input for each cycle so= n=1/25=0.04

Total Heat Input= Latent Heat + Sensible Heat.

Latent Heat for Aluminum= 389000 J/Kg

Following data for aluminum:

Specific heat for aluminum: 963 J/Kg/C

Sensible heat per second =n* m*Cp*(Ti-Te)

Total Heat on mov side :

$Q_{mov}= Q_l +Q_s = n*m_m*L_f + n*m_m*C_p*(Ti-Te)$

= (0.04*0.1031*389000)+ (0.04*0.1031*963*(660-425))

=2538.78 Watt

Total Heat on fix side:

$Q_{fix}= Q_l +Q_s= n*m_f*L_f + n*m_f*C_p*(Ti-Te)$

= (0.04*0.1031*389000) + (0.04*0.089*963*(660-425))

=2193.06 Watt

Calculate Length & Position of water line:

1. **Length of water Line required for mov side:**

   Consider below heat transfer through convection equation:

$Q= hA(T_s- T_f)$

Where A=πDL

D = cooling channel diameter

L = Length of channel required to maintain cavity surface temperature

$L= Q/ (h\pi D(T_s- T_f))$

L= 2538.78/{2840.45*π*0.01(120-25)}

L=299.53mm

2. **Depth of cooling line from surface for mov side:**

Consider below heat transfer through conduction equation:

$Q_x = \underline{KA\ (T_1\text{-}T_2)}$

D

$$\text{Depth } D = \frac{KA\,(T_1 - T_2)}{Q}$$

K= Thermal conductivity of H13 material =0.0273 w/mm°C

D = 0.0273*14163.9*(220-120)/2538.78

Depth from surface= 15.23mm

Fix side:

Calculate in same manner for fix side

1. Length of cooling channel for fix side: 258.74mm
2. Depth of cooling hole from cavity surface: 22.56mm

3. CONCLUSIONS

After cooling calculation, we found required cooling length and its location from depth to achieve required cycle time for best production. In older tool design cooling channel found as 250mm for mov side and 200 for fix side. Now this channel modified to achieve 300 for mov side and 260 for fix side. It solved soldering problem in the casting. Refer below Fig-4 image for better understandings of the result.

Fig-4- Trial Sample Casting Image

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