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DESIGN AND ANALYSIS OF PLASTIC MOULDING DIE AND RUNNER SHAPE OPTIMISATION USING AHP METHOD

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ABSTRACT

Injection moulding is the most widely used method for the production of intricate shape plastic parts with good dimensional accuracy. The design of a plastic moulding die is of critical importance for product quality and for efficient processing, it is also an integral part of plastic injection moulding as the quality of final plastic part is greatly reliant on injection mould die. The 3D Virtual Model of the moulding die and the core-cavity extraction was performed using the Auto Desk inventor software. The 2D manufacturing drawings were also drafted in Auto Desk Inventor. ANSYS software is used for mould flow analysis and optimum selection of different runner cross section. This work can also be further extended for a detailed stress and fatigue analysis for the core and cavity inserts to obtain better tool life by using ANSYS Workbench. There are various cross sections for the runner of mould design so the best runner cross section is the criteria for the optimization. Here we select the runner cross section by using the analytical hierarchy process.by using this method we arrived at particular solution of the multivariable problem and this method gives the optimum result. The main objective of this of this paper is to develop the relationships among the identified injection moulding parameters using AHP and pair wise comparisons of the element (usually, alternatives and attributes) can be established then can be translated into priority weights (scores).

Keywords: *Injection moulding, AHP method.*

I. INTRODUCTION

Injection Molding is the process of forcing melted plastic in to a mold cavity. Injection molding is used for processing thermoplastics, thermosets, and elastomers. This is a high-rate production process and permits good dimensional control. Injection molding is a versatile process capable of producing complex shapes with good dimensional accuracy and at high production rate.

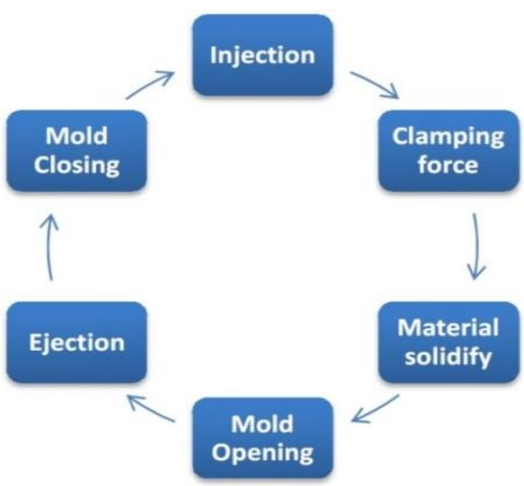

Fig1: Injection moulding cycle

Generally plastic is one of the most versatile materials in the modern age which is widely used in many products in different shapes which are molded through the application of heat and pressure. Injection molding has become the most important process for manufacturing plastic parts due to its ability to produce complex shapes in minimum time of period. There are different injection moulding process cycle which are shown in **fig. 1**

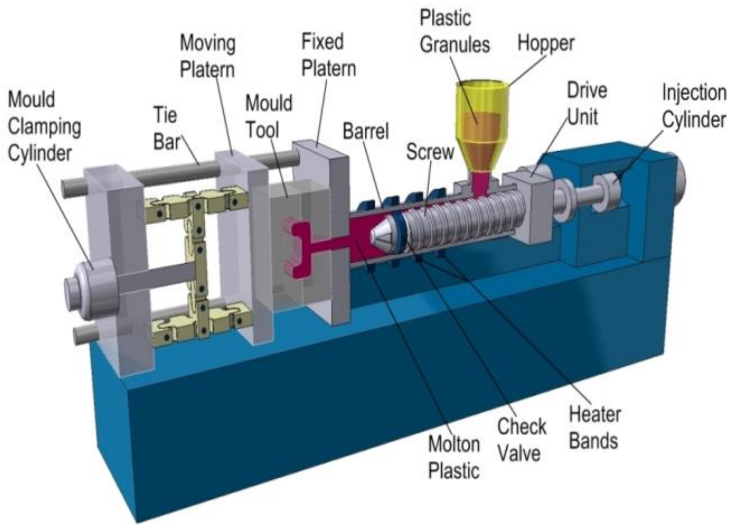

Fig.2: Diagram of injection moulding machine

Injection molding permits mass production net shape manufacturing of high precision, three-dimensional of plastic parts. Traditionally, moulds have been expensive to manufacture. So they were usually only used in mass production where thousands of parts were being produced. There are the different injection moulding process parameters like melt temperature of plastic resin, packing time, cooling time and injection pressure. Injection moulding machine having the different parts like as feed hopper, injection ram, injection screw, barrel, injection cylinder, injection moulding die, injection plates and the clamping units which are shown in fig. 2. The various literature for the mold design for Mold design are listed as follows, (Rahman et al, 2012), (Haddout and Villoutreix, (2012), (Alexander et al, 2012) and (Song et al, 2014). Literature review described the optimization of the process parameters directly related to injection moulding process. They describe the injection pressure, influencing parameters of injection pressure, cooling medium, cooling requirement of mould cavity, sprue position, runner layout, gate location. But there are very few researches that are describing the designing the correct dimension of sprue, runner, gate location and gate size. Researches are not focused on the optimization of runner layout, runner size and mould cavity dimensions that fit for optimum performance of moulding operation to produce the accurate product. It is necessary to find the suitable parameters for optimization of process parameters.

II. PLASTIC MOULDING DIE

A mould is simply a machined steel plate with cavities into which plastic resin is injected to form a part. A mould consists of two halves into which the impression of the part product to be moulded is cut. The mating surfaces of the molded halves are accurately machined so that no leakage of plastic can occur at the split line. If leakage occurs it would be expensive to remove. Generally mould is the common terms used to describe the tooling used to produce plastic parts in moulding. It’s usually only used in mass production where thousands of parts were being produced.

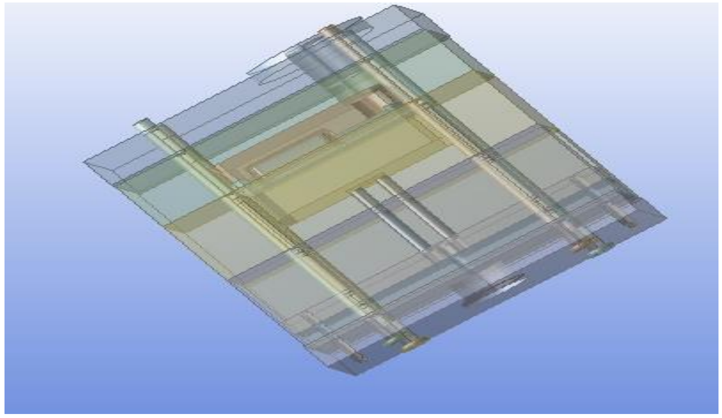

Fig. 3: Injection moulding die

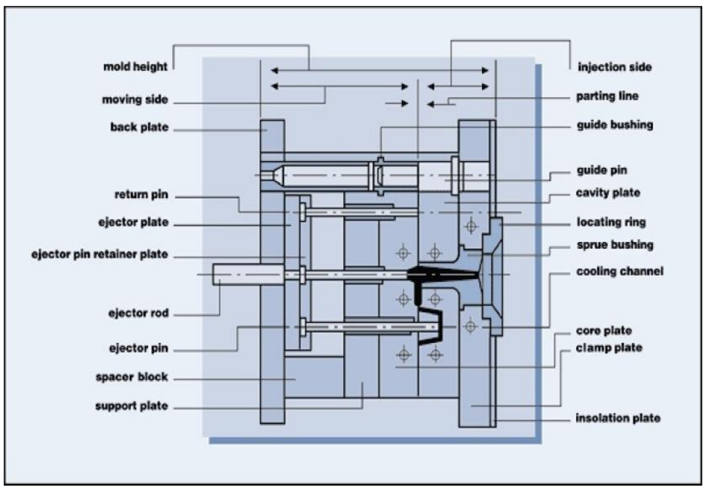

Fig.4: Parts of plastic moulding die

Molds separate into two sides at a parting line, the fixed side, and the movable side, to permit the part to be extracted. Plastic resin enters the mold through a sprue in the fix plate, branches out between the two sides through channels called runners, and enters each part cavity through one or more specialized gates. Inside each cavity, the resin flows around protrusions (called cores) and conforms to the cavity geometry to form the desired part.
The parts of plastic moulding die are described below.

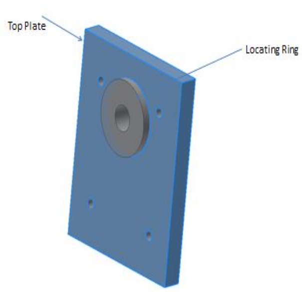

Fig.5: Top plate

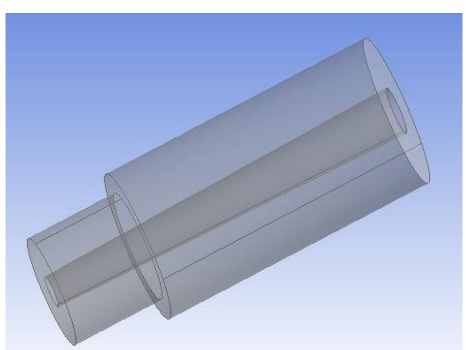

Fig 6: Sprue bush

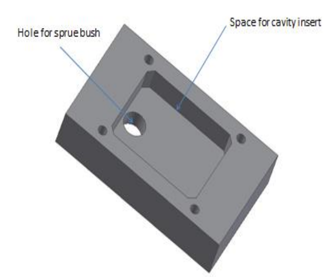

Fig.7: Cavity Plate

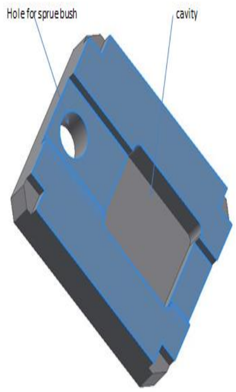

Fig.8: Cavity inserts

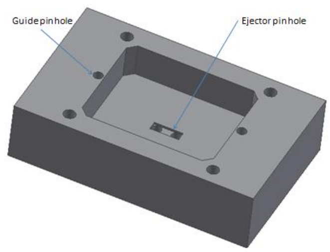

Fig.9: Core plate

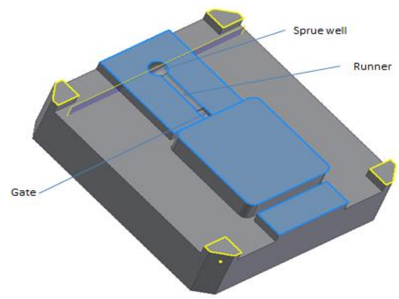

Fig.10 Core inserts

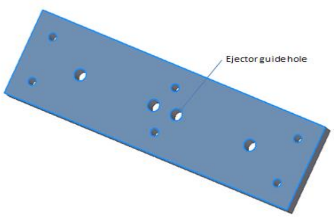

Fig.11 Ejector plate

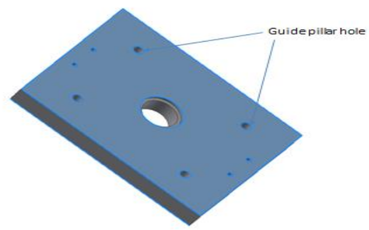

Fig.12 Bottom plate

III. MOLD DESIGN

Mold design is a process of Designing of mold dimensions and selects the data from the standard design data book. The runner is as specific which follows the Path for the material to flow. The section of the runner is the variable, as we change the different cross section. The Flow Diagram Shows the process of mold Design. Flow Diagram Shows Main Objective Function is Stress Reduction and Secondary is improving Quality. The Design variables for mold are Different Shapes of Runner and location of runner. After design of mold by using the analysis of design we get resultant effects like principal stress, maximum deformation, and equivalent stress on mold. **The fig. 21** shows the flow diagram for the design of the mold runner for the multivariable problem, we select the number of variable for the different cross section of the runner and if the stress would not minimize then we redesign the mold runner cross section and if stresses will Reduces then design will perfect for the Manufacturing. In designing of moulding die first step is to design the product and calculate the all dimension of the product. In product design mass of material used in product moulding is calculated by considering the density of that plastic material. In next step we should decide the number of cavity according to need production rate and shot capacity. plate mould for easy design and removal after moulding. In next step we select type of runner cross-section for optimum performance.

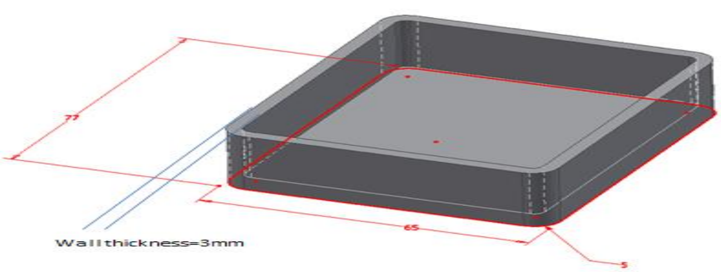

Fig13: Product Design

We have chosen PVC as material for product and product is rectangular tray. Dimension of the product is given below

External length (L) =77mm
External width (B) =65mm
External height (H) =22mm

Wall thickness (t) =3mm
Corner radius (r) =5mm
So Total External Volume of Product (V) =L*B*H-(25-3.141/16*25*22
=77*65*22- (118.03) mm^3
=109991.97mm^3
Total internal Volume of Tray=71*59*19-(25-3.141/16*25*19) mm^3
=79489.16mm^3
So Volume of plastic material required for product=109991.97-79489.16mm^3
=30502.9mm^3
=30.502cm^3
Density of PVC = 1.48gm/cm^3
So weight of product=density of polymer*volume of material
=1.48*30.502gm
=45.16gm

The injection machine shot capacity is also a factor in determining the number of cavities. Taking 80 percent of the machine capacity as the shot weight (S) and divide by the part weight (W) to get the number of cavities.
Number of cavities = S / W
We have selected the injection machine capacity=75gm
So shot capacity (S) =80% of 75gm
S=60gm
Number of cavity=60/45.16
=1.33
=**1 (Cavity)**

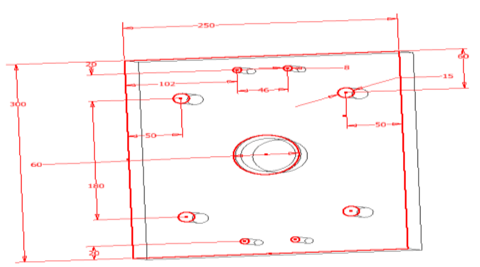

Fig14: Bottom plate design

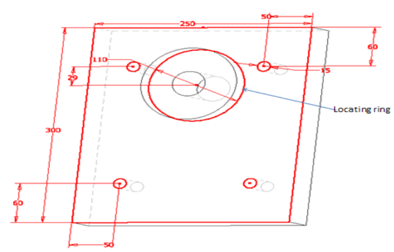

Fig15: Top plate design

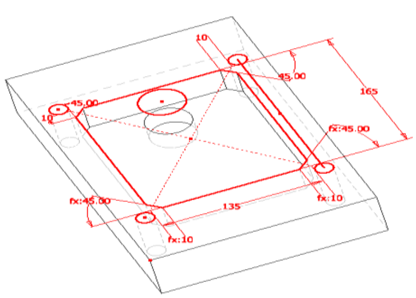

Fig16: Cavity plate design

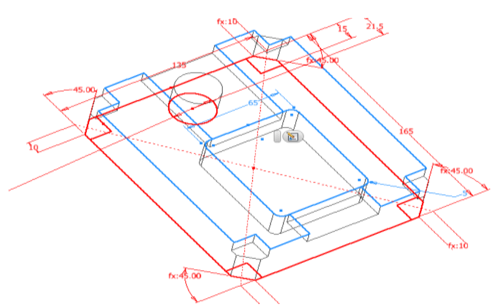

Fig17: Cavity insert design

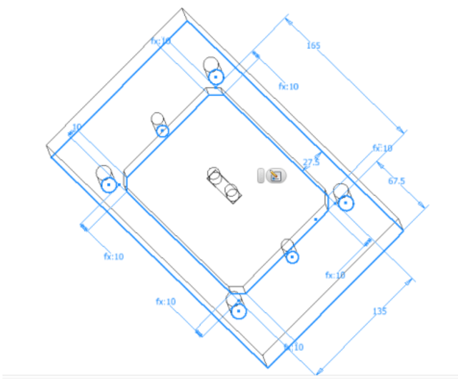

Fig18: Core plate design

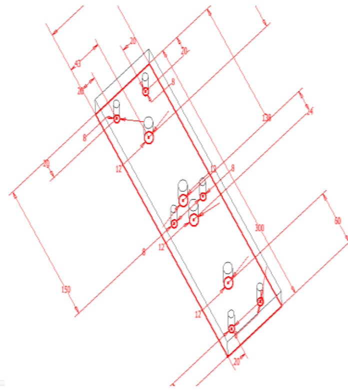

Fig19: Ejector and ejector back plate design

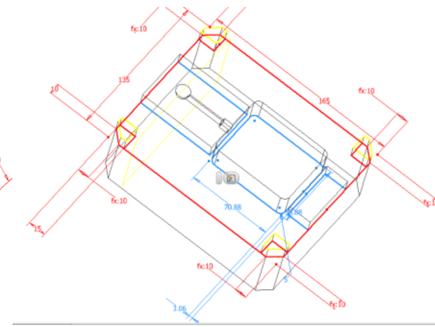

Fig20: Core inserts design

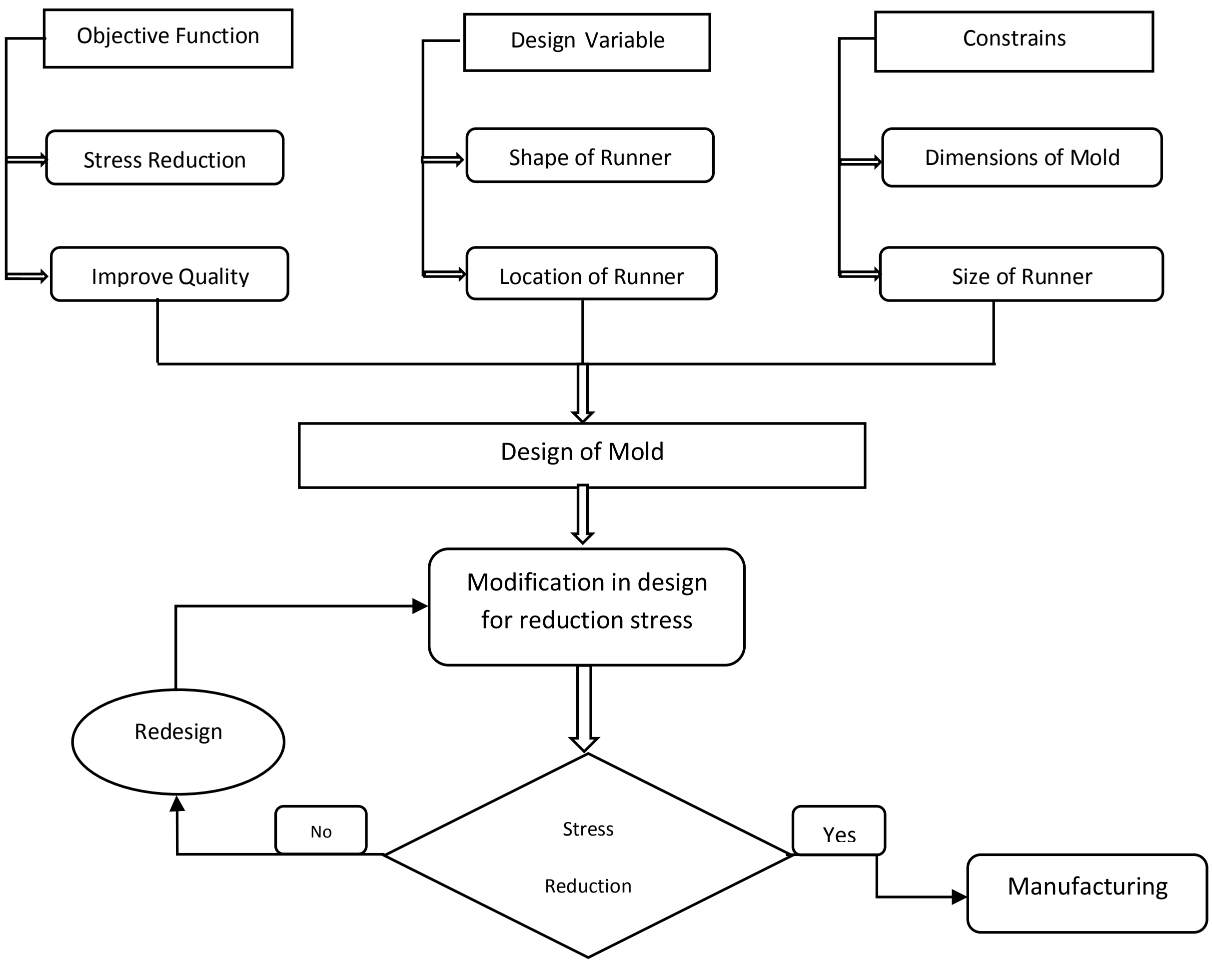

Fig. 21 Flow diagram of Mold design Process

(A) DESIGN OF RUNNER:

A runner system directs the melt flow from the sprue to the mold cavities. Additional pressure is required to push the melt through the runner system. Shear (frictional) heat generated within the melt while the material is flowing through the runner raises the melt temperature, also facilitating the flow. There are several common runner cross-sectional designs.

i) Full-round runner ii) Trapezoidal runner iii) Half-round runner iv) Rectangular runner

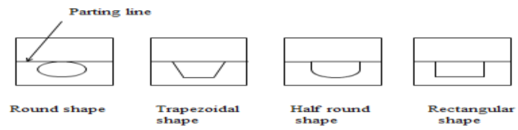

Fig22: Runner cross-sections

Runner diameter can be calculated by the formula:

$$D=\left(\sqrt{W}\right) \times \left(\sqrt[4]{L}\right)/3.7$$

D= runner diameter (mm)
W= part weight (gm.)
L= runner length (mm)

Round shape runner	Diameter=4.7 mm,
Half round shape	Diameter=4.7 mm,
Trapezoidal shape runner	Height =4.7 mm
Rectangular cross-section runner	Width=4.7 mm height will be 80 % of Width then=3,76 mm

Table 1 different cross sections of runner

(B) ANALYSIS OF MOLD: We make the design of Mold for above Four Cross Section of Runners. After Mold Design, We check its feasibility by Using Simulation Software. For that we use ansys Software for Analysis of mold. The analysis are Shown in Below Figures.

1. Analysis for circular cross-section: In all analysis injection pressure is kept same also in mould cavity and runnerr system.

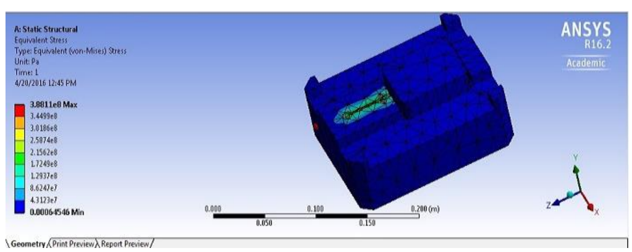

Fig23: Equivalent stress (Circular)

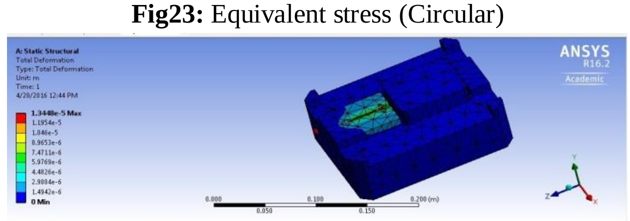

Fig24: Total deformation (Circular)

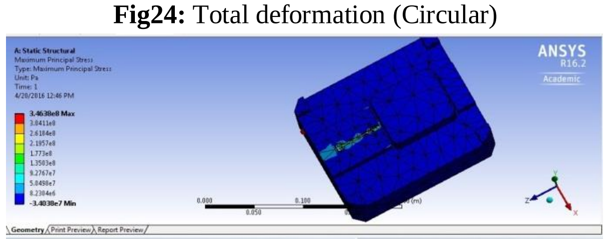

Fig25: Max principal stress (Circular)

2. Analysis for half circular cross-section:

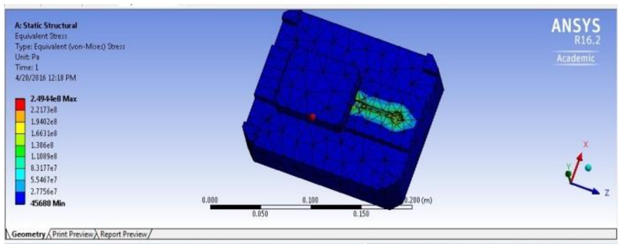

Fig26: Equivalent stress (Half circular)

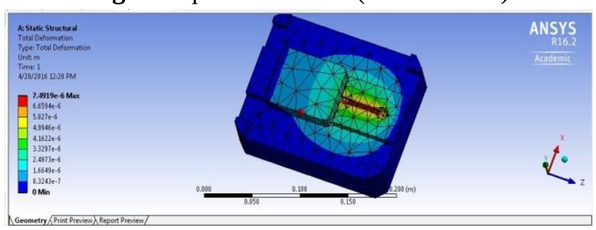

Fig27: Total deformation (Half circular)

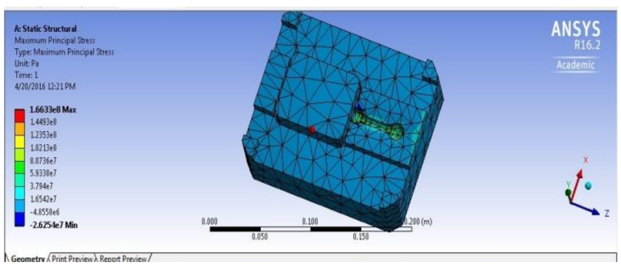

Fig28: Max principal stress (Half circular)

3. Analysis for trapezoidal cross-section:

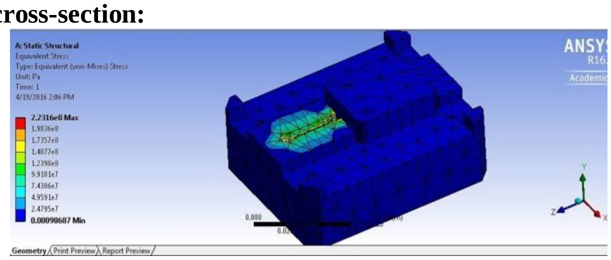

Fig29: Equivalent stress **(Trapezoidal)**

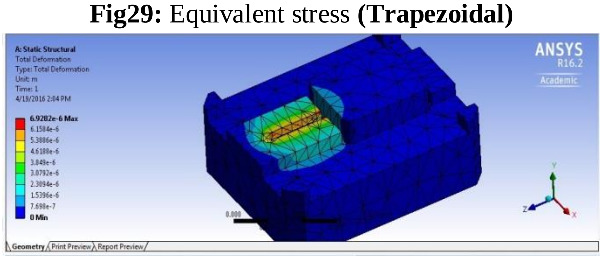

Fig30: Total deformation **(Trapezoidal)**

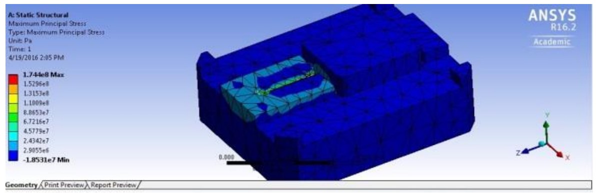

Fig31: Max principal stress **(Trapezoidal)**

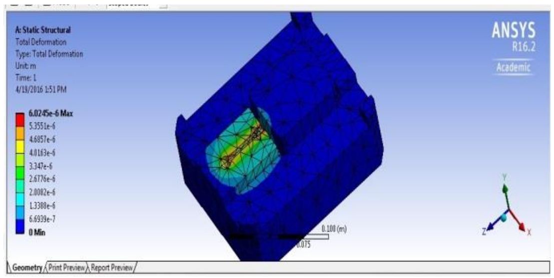

Fig32: Total deformation (**Rectangular)**

4. Analysis for rectangular cross-section:

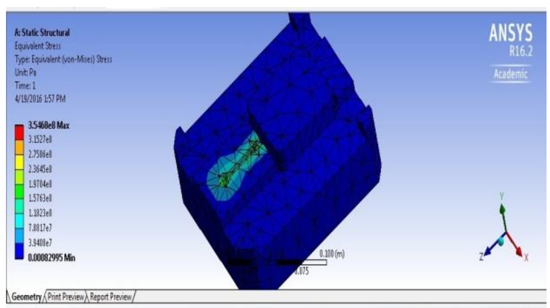

Fig33: Equivalent stress (**Rectangular)**

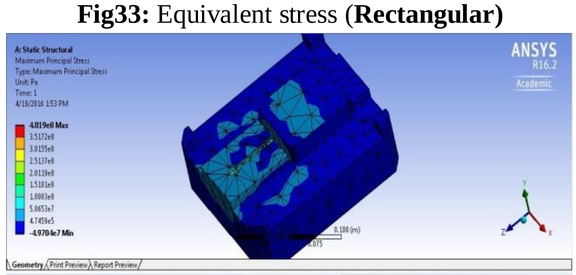

Fig34: Max principal stress (**Rectangular)**

IV. OPTIMUM SELECTION OF RUNNER CROSS SELECTION USING AHP METHOD:

We have various cross sections for the design of the mold as discuss earlier, the problem arises for the optimum selection of these runner cross section. This is the case of multi variable modeling problem. For that purpose here we use Analytical Hierarchy Process as Multiple Criteria Decision Making Method. AHP is a well-established decision making process Therefore, AHP can help in the decision making process for the identification of the injection moulding parameters. The AHP method has the ability to structure complex, multi-person, multi-attribute, and multi-period problem hierarchically. Pair wise comparisons of the element (usually, alternatives and attributes) can be established using a scale indicating the strength with which one element dominates another with respect to a higher-level element. This scaling process can then be translated into priority weights. Analytic Hierarchy Process (AHP) Method is one of Multi Criteria decision making method, which was originally developed by Prof. Thomas L. Saaty. It is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc. and, from subjective opinion such as satisfaction feelings and preference.

AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.
Analytical Hierarchy Process having two stages:
1. Determination of Relative Weightage
2. Determination of Relative Ranking
Scope of AHP can be defined as below:

1. Objective (Goal):
i) Selection of Design of Runner Cross Section.

2. Criteria (Problem Factors):
i) Maximum equivalent Stress ii) Maximum deformation iii) Volume of Runner Section iv) Maximum Principle Stress

3. Alternatives (Runner shape):
i) Circular Cross Section ii) Half circular Cross Section iii) Trapezoidal Cross Section iv) Rectangular Cross Section

Problem formulation steps for AHP method:
Step 1: Structure a hierarchy. Define the problem, determine the criteria and identify the alternatives.
Step 2: Make pairwise comparisons. Rate the relative importance between each pair of decision alternatives and criteria.
Step 3: Synthesize the results to determine the best alternative. Obtain the final results. The output of AHP is the set of priorities of the alternatives.

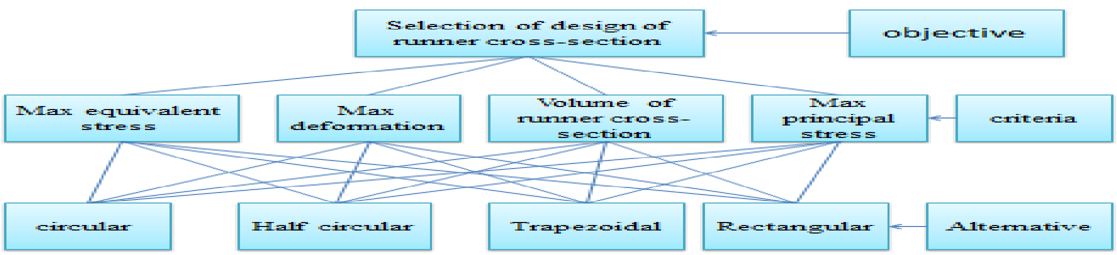

Fig35: Hierarchy tree diagram

(A) RANKING OF CRITERIA AND ALTERNATIVES:
Pairwise Comparison Made With Grades 1-9. It Contributes A is absolutely more important that Contribute B and is rated at 9 than B is must be absolutely less Important that A and is Graded as 1/9. Pairwise comparisons are carried out for all factors to be considered usually, not more than 7.

Numerical Ratings	Judgments
1	Equally important (preferred)
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2, 4, 6 & 8	Intermediate

Table 2 Ranking scale

n	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.32	1.41	1.45	1.49	1.51

Table3: Value of RI

(B) PAIRWISE COMPARISONS FOR SELECTION OF RUNNER CROSS SECTION:

For the comparisons of runner cross-section first we decide the comparison matrix

	MAX EQ.. STRESS	MAX. DEFORMATION	VOLUME OF RUNNER	MAX PRINCIPAL STRESS
MAX. EQ. STRESS	1	3	2	3
MAX. DEFORMATION	1/3	1	1/3	1/3
VOLUME	½	3	1	1/2
MAX PRINCIPAL STRESS	1/3	3	2	1

Table 4: Comparison matrix

After writing the comparison matrix its Eigen value is determined using online solving method (bluebit.com).on solving the matrix for Eigen value maximum Eigen value is known i.e**.** **λ max.=4.206**

Now we will calculate the value of CI by using the formula:

Consistency Index CI= (λ max-n)/n-1

CI= (4.206-4)/4-1

CI=0.0686

So value of Consistency ratio **(CR) = CI/RI**

CR=0.0686/0.9

CR=0.076

Now we can see that CR<0.1 so the value of comparison is in acceptable limit.

Normalized matrix:

Table 5: Matrix after summing column element

	MAX.EQ. STRESS	MAX. DEFORMATION	VOLUME OF RUNNER	MAX PRINCIPAL STRESS
MAX.EQ. STRESS	1	3	2	3
MAX. DEFORMATION	1/3	1	1/3	1/3
VOLUME OF RUNNER	½	3	1	½
MAX PRINCIPAL STRESS	1/3	3	2	1
Sum of column	2.16	10	5.33	4.83

This Comparison matrix is after dividing each element by their respective column sum and then sum of all respective row elements is calculated.

	MAX. STRESS	MAX. DEFORMATION	VOLUME OF RUNNER	MAX PRINCIPAL STRESS	SUM OF ROW
MAX. STRESS	0.462	0.3	0.375	0.621	1.758
MAX. DEFORMATION	0.154	0.1	0.062	0.069	0.385
VOLUME OF RUNNER	0.231	0.3	0.187	0.103	0.821
MAX PRINCIPAL STRESS	0.154	0.3	0.375	0.207	1.036

Table 6: Sum of all respective row elements

Now we are taking Arithmetic mean of sum of row by dividing them by order of comparison matrix to find the weightage of criteria.

1.758/4	**0.43950**
0.385/4	0.09625
0.821/4	0.20525
1.036/4	0.25900

Table 7: Weightage of criteria

Total sum of the All Weightage are=**0.4395+0.09625+0.20525+0.259= 1**

That shows sum of all Criteria Weightage Are **100%**

Percentage Weightage of those Criteria as:

Maximum Stress	**43.95%**
Maximum Displacement	**9.625%**
Volume of runner section	**20.525%**
Max principal stress	**25.9%**

Table 8: Percentage weightage of criteria

(C) CALCULATION OF AHP FOR MOULD:

We have selected four parameters for each cross-section of runner i.e.

i) Maximum Equivalent stress.

ii) Maximum deformation.

iii) Volume of runner for that cross-section

iv) Maximum principal stress.

Figure given below shows the analysis result of maximum equivalent stress, maximum deformation, volume for runner cross-sections, and maximum principal stress for different cross-section of runner shape.

Cross section of Runner	Maximum Eq. Stress(KPa)	Maximum Deformation(mm)	Volume(mm3)	Maximum Principle Stress(KPa)
Circular section	3.88*10^5	0.0134	737.35	3.46*10^5
Half circular section	2.49*10^5	0.00749	368.67	1.66*10^5
Trapezoidal section	2.23*10^5	0.00692	1214.28	3.74*10^5
Rectangular section	3.50*10^5	0.00602	771.03	4.01*10^5

Table 9: Value of parameters

By using The Value and Weightage:

A1 = (3.88*10^5*0.4395) + (.0134*0.09625) + (737.35*0.20325) + (3.46*10^5*0.259)

A2 = (2.49*10^5*0.4395) + (.00749*0.09625) + (368.67*0.20325) + (1.66*10^5*0.259)

A3 = (2.23*10^5*0.4395) + (.00692*0.09625) + (1214.28*0.20325) + (3.74*10^5*0.259)

A4 = (3.50*10^5*0.4395) + (.00602*0.09625) + (771.03*0.20325) + (4.01*10^5*0.259)

Result of AHP method:

A1 (circular)	= 2.60***10**^5
A2 (half circular)	= 1.53***10**^5
A3 (trapezoidal)	= 1.95***10**^5
A4 (rectangular)	= 2.58***10^5**

Table 10: Value of weightage

V. RESULT AND DISCUSSION OF AHP

The results of AHP Method are shows in the Table 10. From AHP method calculation for different four cross-sections of runner, the half Circular section has minimum value. So for Manufacture of mould, half Circular Section runner gives optimum Result. By using AHP method for multiple Criteria Decision making we get the value AHP Solutions for Four Different Sections as Shown in the Table10. Final selection of mould Runner section is based on the values of the AHP solution. For problem of maximization we select the maximum Value and for Minimization problem we select minimum value of the AHP solution. For different cross-section of runner for mould the maximum principal Stress in rectangular Cross section Runner has maximum and for half Circular section the value is minimum. The optimized design concepts are discussed and selected for the final design and the same was developed**.** The mould design process involved in the design of various injection moulding elements such as cavity and core insert, housing plates, side core actuation, ejector plates, top and bottom plates, etc. After designing the above elements, the various type of analysis was carried out on the moulding die. A proper runner and gating system is very important to secure good quality die castings through providing a homogenous mould filling pattern. By various calculation of runner shape for round shape, half circular, trapezoidal and rectangular using design methodology we have determined the optimum runner diameter=4.7mm. Runner length for all shapes of cross-section is kept 42.6 mm so that pressure drop in the runner along its length is minimum. For half circular shape the weightage value of criteria is minimum. We have designed the other part of plastic moulding die according to design methodology and analysis.

VI. CONCLUSION

For moulding with single cavities, adjusting injection parameters of cavity to the same level is particularly difficult. The resultant rate of failed product is untenable. The aim is to gain high levels of productivity and to reach a level of accuracy that meets the required conditions. To achieve a good gating system design, the following aspect should be taken into consideration:

1. Total volume of the cavity, to be injected. In regular practice, a single cavity is chosen frequently. But by using a multi-cavity die will save labor cost and improve the production efficiency. The designer should consider the economic and technical issues in order to select an acceptable cavity number that meets the overall requirements.
2. In runner shape optimization our aim is to minimization of all the Parameters we are select as minimum Value of the AHP solution. So we select the half circular section, because for the half circular section AHP method we get best result.
3. Here we used AHP technique which enables to decision making by use of Ranking, Pairwise Comparison and Synthesis. By use of that select optimal solution of problem.

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