Development of Cost Model for Injection Moulds and PDC Dies

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Dissertation Approval Certificate

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Abstract

Introduction of new products having complex features are driving near net shape manufacturing processes like injection moulding and die-casting. This needs cost effective moulds and dies, developed in shorter lead-time. Cost estimation of the dies and moulds plays a significant role in deciding the cost of parts. As there is a scarcity of cost estimation experts, there is a need for developing a systematic and automated cost estimation method.

This project aimed at development of a cost model for injection moulds and pressure die-casting dies which can even be used by less experienced engineers. This is achieved by dividing the total cost into five elements: Mould base, Basic mould (inserts), Mould inserts material & treatment, Standard elements, and Design. Mould base cost is derived from its volume. Decision tables are developed to derive mould base size. The cost of Basic mould, which accounts for over 50% of the total cost, has been estimated by an equation developed after regression analysis of existing cost data of 27 projects. The regression parameters included volume ratio, area ratio, surface area to volume ratio, parting line factor, no. of cavities, and nominal thickness of part. The mould insert sizes derived from decision tables are used to estimate raw material and heat-treatment cost. Cost of standard elements used in mould base is estimated using previous cost data of purchased elements. Design cost is taken as a percentage of sum of all other four elements.

The inputs required for the cost estimation are taken from CAD data of the parts, and mould or die specification, which makes it fast and easy-to-use. The cost model has been validated by comparing the estimated cost with the actual cost of an industrial part.

Key words: Cost estimation, Injection Moulds, Pressure Die-casting Dies.

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Chapter 1

Introduction

Competitive business environment has forced industry to develop new products in shorter lead-time. Near net shape manufacturing processes like injection moulding and die-casting are gaining importance in this, as it involves few steps to obtain the desired shape. On other side product designs are becoming more and more complex. Product designers are taking advantages of improvements in process capabilities and engineering materials by consolidating multiple parts and features in complex parts made by Injection Moulding and Die-casting. This puts pressure on development of moulds and dies in terms of lead-time and cost. As per industrial survey conducted by "Tool and Gauge Manufacturers Association" in India, there are more than 21,500 tool rooms to cater the need of the tooling development having market size of US$ 6 billion. Out of this, market size of plastic moulds and die casting dies is US$ 2.5 billion. This indicates importance of development of injection moulds and pressure die-casting dies.

1.1 Mould Construction

General construction of injection mould and pressure die-casting die is shown in figure 1.1. It is made in two halves namely fixed half and moving half. These two halves are held together in moulding machine under clamping load while material is injected through the fixed half. Material gets solidify by applying forced cooling. Two halves are then opened and article is ejected by ejection mechanism. The main functional elements of injection mould or PDC are core & cavity blocks, feeding system, ejection system, and mould base. Core and cavity blocks are replica of an article to be moulded. These may be in a form of single block or multiple inserts housed together in core or cavity housings. Cooling holes are drilled in these blocks that carry cooling oil during moulding. Feeding system includes sprue bush, runners and gate that create passage for material to flow from machine nozzle to cavity. Ejection system comprises of Ejector pins held in assembly of Ejector plate and Ejector back plate, which is guided in mould base. It is used to eject article after solidification. All these elements are housed in mould base,

which comprises top plate, base plate, supports and guiding elements. Apart form these main elements, based on article requirements side cores, hot nozzle etc. are also added.
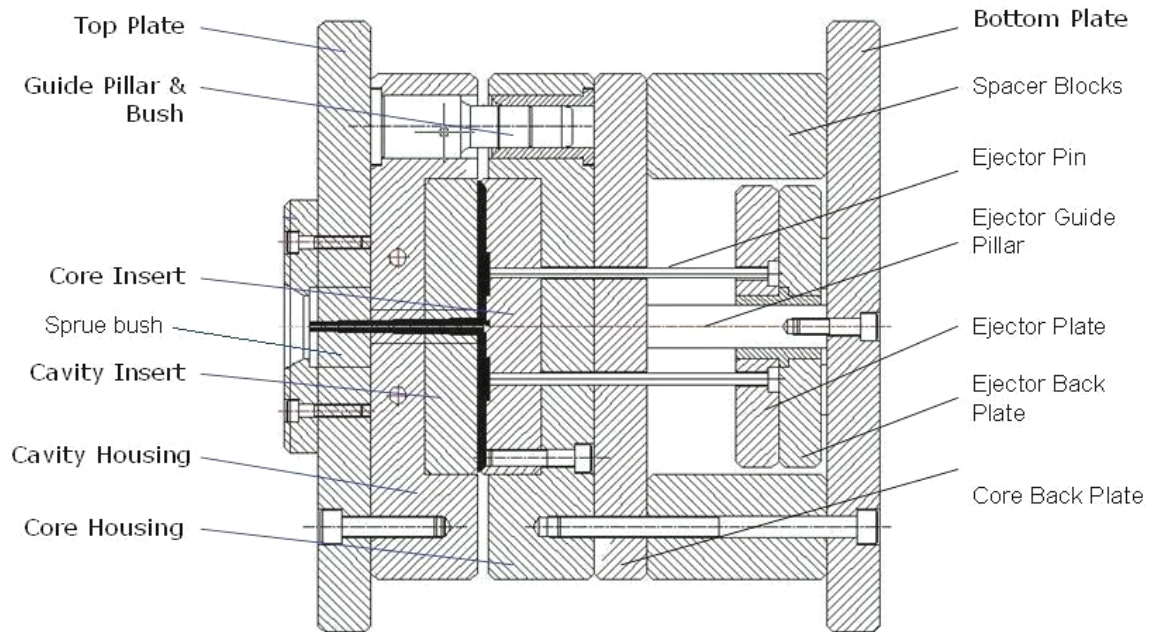
Figure 1.1: General mould construction

1.2 Mould Design and Manufacturing

Manufacturing of injection moulds and PDC represents a significant area of production technology, since it influences the feasibility and economics of producing a very large number of discrete products. Often the intricate geometry with sculptured surfaces and relatively high material hardness make die and moulds development a most demanding and difficult task. Moreover each specific NNS operation imposes its own special requirements on die and mould characteristics. Manufacturing of moulds or die has two major elements: mould base and mould inserts. Mould base manufacturing includes operations like drilling, tapping, jig boring, shaping, milling, and grinding. Manufacturing of mould inserts includes shaping, milling, drilling, tapping, jig boring, NC path generation & CNC milling, heat treatment, EDM- spark erosion & wire erosion, grinding and polishing. In case article has aesthetic requirements like matt finish or

mirror finish then mould insert follows surface treatments like mirror polishing, coating, and texturing.

1.3 Issues in Cost Estimation

The tool room under study for development of cost model develops tools for Electrical & Electronics industries. In Electrical & Electronics industry cost of moulds and dies plays major role in deciding cost of product due to low volumes and shorter product life. The die or mould cost is significant factor for evaluation of design alternatives, negotiation with customers and other decision-making at the product planning stage. Therefore cost estimations of injection mould and pressure die-casting (PDC) dies are getting more importance nowadays.

The cost estimation task for injection moulds and PDC dies is to calculate the cost of making dies and mould. It determines the mould or die making processes based on the mould or die design specification and calculates costs incurred in each die or mould making process along with material costs. In this estimation process one need to consider functional and aesthetic requirements of product, mould or die design, manufacturing process in mould and die making and its economics etc… As the decisions in various aspects are interrelated, changing one aspect may have a negative effect on the other aspect. Therefore this cost estimation process involves a component driven by substantial practical knowledge. Knowledge and expertise of more than one specific area are required. Normally experienced person having high standard knowledge or team of expert's does mould and die cost estimation work. At the same time, very low order to quote ratio doesn't justify time spent by experts in doing this cost estimation. The availability of expertise for cost estimation is serious concern in most of the tool rooms. Even this expertise are available, the time they need to spend on cost estimation can not be justified. Therefore some method needs to be adopted which will give cost estimation quickly without involving expertise. The aim of this project is to develop such system.

1.4 Report Organization

Literature on general cost estimation methods is reviewed in chapter two. It also explains the parameters affecting mould cost. This chapter ends with literature review on cost models for Injection mould and Pressure Die-casting dies.

Chapter three describes the problem including motivation, objectives and scope of this project. The approach adopted in developing new cost model is briefed here.

Chapter four includes mould base cost estimation. This chapter elaborates decision tables developed to find out mould base and mould insert size. It also elaborates regression equation for cost of mould base.

Chapter five explains basic mould cost estimation. Difficulties in estimating basic mould cost and approach adopted is explained here. The regression equation developed using cost data of mould insert manufacturing for estimating mould insert manufacturing cost is briefed here.

Chapter six deals with other cost elements of injection moulds & PDC dies. It includes cost estimation of raw material, treatment of mould inserts, design, standard elements, and overheads.

In chapter seven, structure of developed cost model is explained along with inputs required for the same. It also includes calculations for estimating cost of injection mould which is considered for validation of cost model.

Conclusion is mentioned in chapter eight by summarising work done during this project. Limitations and future scope is also mentioned here.

Chapter 2

Literature Survey

2.1 General Cost Estimation Methods

Cost estimating is the estimation of the cost likely to be occurred in producing a product before the actual production is started. It differs from cost accounting from the point of occurrence of the activity. Cost accounting occurs after the product has been made while cost estimation is a prediction of cost of product before it is made.

Cost estimation is a complex process and requires understanding of product design, materials, manufacturing processes, inspection methods, quality control, repair and servicing, product safety and environmental safety along with knowledge of costing.

It has got importance in industry due to following reasons (Creese et al., 1992). : -

1. Used to consider economical viability by manufacturer.
2. Enables to choose most economical alternative of production.
3. Enables to fix a selling price in advance of actual production.
4. Enables manufacturer to take make or buy decisions.
5. Enables to plan tools and raw material procurement.
6. Enables to set standards for production to be achieved in actual practice.
7. Helps to plan equipments, labour and capital requirements.

It is clear form above-mentioned reasons that cost estimation at the design stage is essential to evaluate various design and manufacturing alternatives. Recent trend of research indicates following five cost estimation approaches (Duverlie, et. al., 1999 and Nagahanumaiah, et. al., 2005):

1. Intuitive
2. Analogical
3. Analytical
4. Geometric feature based
5. Parametric

2.1.1 Intuitive method

Intuitive method is based on the experience of the estimator. The estimator acquires the wisdom and intuition concerning cost through long association with the industry producing similar product. Usually estimations are done along with product designers. The results always depend on estimator's experience and his interpretation. The advantage of this approach is that, even exceptional circumstances can be taken into consideration. The disadvantage is that it depends on the competence of the individuals and requires considerable previous experience in cost estimation. It is likely that estimator may not be in position to identify all the risk factors and to quantify many of them which leads to wrong estimation. In spite of these disadvantages this method is widely used in small workshops.

2.1.2 Analogical method

Analogical method is based on basic thinking that similar problems have similar solutions and reuse of these solutions is more practical than solving problem from scratch. In this method estimator compares new product with similar existing product manufactured by the firm to estimate cost. Principles of group technology consisting classifications and coding of the parts are used to generate data of the existing product. Whenever new product cost is to be estimated, similar existing case close to new product is retrieved and it is compared with new product in terms of physical features and functions. As this method is depending on previous data of the products, it needs proper data management and retrieval system.
 This method is mainly used for technologically similar products. The analogical method presents advantages such as low effort and ability to produce rapid solutions.

2.1.3 Analytical method

Analytical method involves decomposition of work into elementary tasks. Entire manufacturing activity is decomposed into elementary tasks and each task is associated

with an empirical equation to calculate the manufacturing cost. This method gives an accurate estimate. But as this method needs lot of efforts and time to make details of product and production methods, is not used very frequently.

2.1.4 Geometric feature based method

In geometric feature based method geometric features such as cylinder, slot, hole and rib of the product are used for estimating cost of the product. The relationship between geometric features of the product and manufacturing process is established to calculate cost. There are limitations of this method when free form feature are under consideration. Feature recognition and classification becomes difficult in case of free form features. These design features are then used as the basis for cost estimation. This method has been used mainly for machining cost estimation.

2.1.5 Parametric method

Parametric method uses technical, physical or functional parameters as basis for cost estimation. The parametric model is a set of cost estimation relationships, rules, assumptions, variables and constants that define a specific situation. There are three types of parametric method identified (Duverlie et al., 1999) such as a) Method of scales – It identifies most significant technical parameter of the product, which is used to define ratio to quantify. It is used for simple products of variable size, b) Statistical model - It is constructed by using set of statistical relationship of the activities done to make the product, and c) Cost Estimation Formula - a mathematical relationship is built between technical parameter of the product and cost. As parametric method allows estimator to proceed from technical values characterizing the product to economic value it is very useful in estimating cost at early design stage. But this method functions like black box as it doesn't take into account details of the product and hence cannot justify results.

As most of the costs are built in product design stage cost estimation at product design stage has got lot of importance. Many researchers have put their efforts in developing

system to estimate cost at product design stage. Weustink et al. (2000) described generic framework for cost estimation based on information management system related to order information, product information and resource information. The cost estimation methods are broadly classified as variant based and generative cost estimating.

In Variant based cost estimating, the cost record of the previously manufactured products are used as a template in the cost estimation process of the new products. This method is useful in small and medium batch manufacturing of relatively standard products.

In Generative cost estimating, required production operations are determined to estimate the production costs. This method is closely related to process planning and will usually be applied for new product elements for which no variants exist.

As any product consists of relatively standard elements, which are already manufactured, and product elements that are completely new, cost estimation is done by using both the above-mentioned methods.

In construction field three methods are found having wide applications (Gwang et al., 2004). Cost estimation based on multiple regression analysis, use of Neural Network and Case-based reasoning method. Multiple regression analysis is based on mathematical formula and fitting data to suit regression curve. Neural network is computer system that simulates the learning process of the human brain. Case based reasoning is analogical method where new problem is solved by adopting solutions of similar old problem in past. A detailed comparison between these three methods is studied by Gwang et al. (2004).

2.1.6 Design to Cost

Global trend of cost competitiveness forces many companies to produce low-cost and high quality products. As 70% of the production costs are built in design, it is important to control cost at design stage itself. This calls for cost estimation at early design stage so

that designer can design product to meet target cost while achieving functional requirements of the product. Basically this cost estimation at early stage of design enables product designer to asses various design alternatives to arrive at the most economical one. The cost estimation method at early stage of design involves use of product features to determine the process plan, selection of machining processes, their sequence and machining parameter.

A system developed by Shehab et al., (2001) for such cost estimation is composed of a solid modelling system, graphical user interface, various knowledge bases, process optimization, databases, and cost estimation module. The system is integrated with CAD system and material selection software to facilitate the product representation and the material selection process.

For estimating cost of casting at the early stage of design, Chougule et al., (2006) have developed a hybrid model by combining analytical and parametric approaches in integrated product- process design environment. Part solid model is used for automatic computation of geometric attributes. A part model along with inputs regarding casting material, quality attributes and production requirements drives process design. The output of process design program along with geometric, material quality and production attributes of the part are used for casting cost estimation.

2.2 Parameters Influencing Cost

Injection moulding and pressure die-casting are methods of near net shape manufacturing process used to reduce lead-time of product manufacturing. Though it involves fewer steps to obtain a desired shape, developing these dies is not easy task. Availability of Injection moulds and Pressure die-casting die is always on a critical path of any product manufacturing and availability to market.

As development of injection mould and PDC die is always critical in terms of cost and lead-time of product, estimation of cost becomes an important activity. Basically cost of injection mould and PDC die is directly related to the article produced.

Following parameters influence the cost of injection moulds and PDC dies.

1) Core and Cavity features
2) Parting line
3) Undercuts and Side cores
4) Surface finish and tolerances
5) Die material
6) Special accessories

2.2.1 Core and cavity features

Core & cavity features are replica of an article. It involves machining of feature like slots, protrusion related to article, holes with tight tolerances and pockets for insert fitments. Machining of these core and cavity involves drilling, tapping, Jig boring, reaming, CNC milling, EDM etc. In case of hardened block heat-treatment is also needs to be considered.

The manufacturing cost of core & cavity is determined by manufacturing process needed and its duration. Both are influenced by the shape complexities of the mould cavity features (Chen et al., 1999) derived from article features. In case of deep cavities which do not have access for CNC milling, EDM operation is done which increase lead time and cost. Size of core & cavity also influences lead time and cost. Basically amount of material to be removed from steel block and respective machining process to be adopted for the same, decides cost and lead-time for core and cavity machining.

2.2.2 Parting line

Parting line selection is important activities in die and mold design. Selection of parting line is basically guided by the ejection of part from die cavity, ease of manufacturability

and aesthetic issues. A complex parting significantly increases the manufacturing cost due to increase in machining complexity and die assembly time (Nagahanumaiah et al., 2005 and Chin et al., 1996). A non-planar parting surface makes it difficult to match the two halves. Parting surface complexity is divided into three levels: straight, stepped and freeform parting surfaces. Straight parting surface will not impose any additional cost. However, stepped and freeform parting surfaces increase the mold cost by 10-20%, and 20-40% respectively (Nagahanumaiah et al., 2005).

2.2.3 Undercuts and sidecores

Undercuts are product geometry preventing the simple removal of the moulded part from the mould. As compared with an in-line-of-draw part, an undercut part demands more complicated mould construction such as sidecore, angular ejection, sprung core etc. This results in high mould cost of making inserts and mould assembly. Sidecores need secondary elements like guide ways, cams and hydraulic/pneumatic actuators, which impose an additional cost. If product geometry necessitates a number of sidecores that are actuated in different directions, then die size and cost increase significantly. This is further aggravated by additional die cooling arrangements, increased mold assembly time and finish machining during assembly.

2.2.4 Surface finish and tolerances

As importance of aesthetics is increasing in product designs, most of the plastic articles call for textured surfaces. This requirement has to meet by providing surface texture on mould inserts. This calls for specialized processes like EDM texturing, chemical etching etc. For articles used for optical applications, die insert surface needs to be highly polished. This needs additional operations and efforts from toolmakers resulting into increase in mould cost. Tight tolerances on article dimensions call for precision machining using appropriate machines, processes and processing parameters and tools. All these affect machining time and cost.

2.2.5 Die material

Most of the injection moulds and PDC dies are made up of hardened tool steels. In few cases where production quantities are low and material doesn't contains any abrasive additives pre-hardened steel is used. Manufacturing process and parameters are directly dependent on material manufacturability. In case of hardened steel heat-treatment operation is essential. Hence die material influence mould machining lead time and cost.

2.2.6 Special accessories

To meet special requirements of articles, special accessories are required to be incorporated in mould. To minimize material wastage in feeding system Hot runners systems are widely used. For some articles the ejector mechanism needs to be pneumatically actuated or on injection side. All these needs additional element of work in moulds and PDC dies which affects the cost.

2.3 Cost Models for Injection Moulds and PDC Dies

Literature available on cost estimation for injection moulds and PDC dies broadly classifies two basic approaches: Cost similarity and Cost functions. In cost similarity approach cost of new mould is determined by comparing cost similar existing mould already manufactured. This calls for proper storage and retrieval system of past data. This approach is good for the tool room's handling similar type of moulds. But generally this is not the case in tooling industry. In Cost function approach dependency between the cost of mould and its characteristics is expressed in mathematical function. The characteristics are the independent variables or affecting quantities, which determine the cost.

Combination of these two approaches is used by Menges et al. (1993) for estimating cost of injection mould. Cost function approach is used for calculating core & cavity cost while cost similarity approach is used for mould base and other std. elements cost. The

mould cost is divided into four groups namely, i) Cavity ii) Mould Base iii) Basic functional components, and iv) Special functions.

i. *Cavity*: Core and cavity cost estimation is done by multiplying estimated machining time by machine and labour hour rate.

$$C_c = (t_c + t_E) \cdot C_{MW} + C_M$$

where,

C_c = Cost for cavity

t_c = Time spent on cavity machining

t_E = Time spent on EDM

C_{MW} = Average machine and labour cost

C_M = Additional material cost (inserts, electrodes etc.)

The time t_c is calculated by using parameter as follows

$$t_c = \{ C_M \cdot (C_D + C_A) \, C_P \cdot C_S + C_C \} \cdot C_T \cdot C_{DD} \cdot C_N$$

where,

C_M = Machining procedure

C_D = Cavity depth

C_A = Surface area of cavity

C_P = Shape of parting line

C_S = Surface quality

C_C = Number of cores

C_T = Tolerance

C_{DD} = Degree of difficulty

C_N = Number of cavities

The above-mentioned parameters and factors needs to established and calculated further with respect to injection mould under estimation.

ii. *Mould base:* Cost of mould base is considered with grades pertaining to production requirements. As it is available as a standard set in market cost of the mould base is taken from supplier's catalogue.

iii. *Basic functional components:* Basically injection mould consists of three functional systems such as injection, cooling and ejection. Various costs associated with the components of these functional systems are calculated separately. For injection system cost of machining sprue, runners and gate is calculated. Cost of cooling system depends on no. of holes to be drilled in plate. Cost of Ejection system is derived from Ejector pin purchase cost and machining in Ejector and ejector back plate.

iv. *Special Functions:* It includes costs of some special requirements like unscrewing mechanism, three-plate mould accessories, slides etc.

Estimated cost of the above-mentioned cost groups are added to get estimated cost of the injection mould.

Chin et al. (1996) developed an estimation approach, which uses knowledge based decision tables, to estimate the cost of injection moulds. Typically decision tables provide a means to handle "If-Then" situations to link the numerous decision factors in decision-making process. A decision table based system (DTMOLD-1) was developed to customise the mould cost estimation procedures and processes at the early product design stage. The decision tables are built by using technical data, knowledge and mould making rules in die making industry. For each decision table, the rules for the evaluation of a specific target are included in the same decision table. The injection mould cost is broken down into several categories according to the basic functional components of an injection mould, namely, mould base material cost, mould insert material cost, cost of accessories and processing cost. The first three cost elements are material costs while the processing cost is basically the labour cost and process overheads. The processing cost is further

divided into: i) mould base, ii) mould insert and assembly, and iii) surface finish, and polishing.

i)   The mould base processing cost mainly includes the machining of the mould, such as slot or pocket openings, ejecting system making, gate and runner making, etc.

ii)   The mould insert making and assembly cost are the costs incurred to make the cavities and cores which usually require milling, EDM and heat-treatment processes as well as the mould assembly.

iii) The costs of surface finish and polishing include the electro-plating of nickel, chromium, etc., texture etching, and polishing processes.

Software called DTMOLD-1 is used to estimate mould cost, which is based on the knowledge based decision tables. Figure 2.1 shows the flow diagram of the system (DTMOLD-1) developed by Chin et al. (1996).
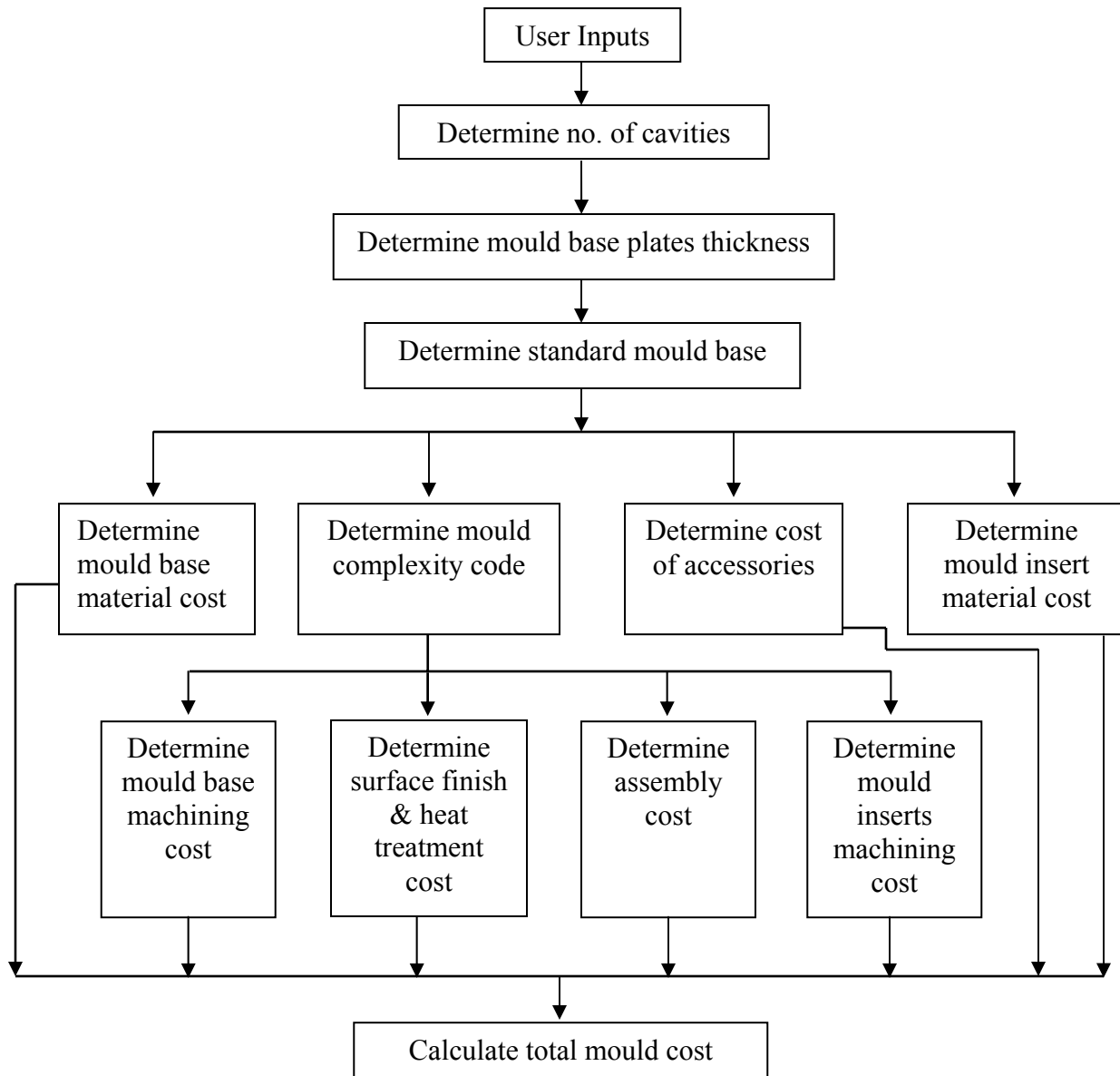
Figure 2.1: Flow chart (Chin et al., 1996)

Each cost element is estimated by using decision tables. Decision table for no. of cavities is based on part size, presence of thread, number of undercuts, part tolerance requirements and complexity of contour shape. Decision table for cost of mould base includes factors like unscrewing moulds, slide-core moulds, split moulds and moulds without undercut. Thickness of mould base is determined by depth of article from parting line. For calculating processing cost of mould base, decision table based on injection system, cooling system and ejector system is used.

Mould inserts processing and mould assembly cost is calculated by using decision table to determine two-digit code for degree of complexity. First digit of this code is based on decision tables, which considers attributes like complexity of the parting line (straight, stepped or curved), the disposition of the cavity shape between mould halves and the presence of undercut and types of undercut. The second digit takes into account mould complexity due to the part size, the number of undercuts and the number of surface with holes. The costs of accessories are estimated by using decision table, which includes part size numbers and individual cost of these accessories.

Thus mould cost is estimated by software built on these decision tables. With limited inputs from user related to article specification, the software calculates estimated cost of injection mould.

While developing system for cost-effective design for injection moulded articles Chen and Liu proposed feature-based cost estimation method for injection moulds (Chen et al., 1999). The system is based on features of an article. The mould cost is linked with the features of the article they are forming. An article size and shape complexity is considered as main factors influencing cost of an injection mould. Shape complexity of an article is determined by its feature structure and their interactions. Feature mapping is done along with parting line, which determines the impact of feature shape and interactions on mould insert cost. The surface finish requirement and tolerances on features are also considered for estimating mould cost. Rather than exact calculation, this approach is used for comparison and decision making at the design stage of an article.

An integrated framework for die and mould cost estimation is proposed by Nagahanumaiah et al. (2005). This methodology is based on concept of cost drivers and cost modifiers. Cost drivers depend on geometry and machining time. Cost modifiers depend on complexity of the mould. In this approach all geometric features are mapped to machining features, which are used as cost drivers and their cost is obtained by

analytical costing method. Other factors affecting the complexity of the mould are considered as cost modifiers.

Total mould cost is calculated using following equation:

Total mold cost =   *(basic mold cost x cost modifiers x number of cavities)*
                        + (Standard mold base cost x assembly factor) + die material cost
                        + secondary element cost + tool design and tryout charges.

Basic mould cost is calculated by using core & cavity features as cost drivers. For each feature machining time is calculated using cutting length and feed. The multiplication of machining time and machine hour rate give cost which is further multiplied by machining complexity factor. Summation of all machining cost of features gives the basic mould cost.

$$\text{Basic mold cost} = C_f = \sum_{f=1}^{n} I_f \left(\frac{L_f}{S} \right) (M_f)$$

where,

L_f = Total cutting length of feature (f=1 to n)

S = Corresponding feed (mm/min)

M_f = Corresponding machine minute rate (hr rate/60)

I_f = Machining complexity factor I

n = number of features

The machining complexity factor of a feature is given by

$$I_f = K \log_2 \left(\frac{d_i}{t_i} \right)$$

where,

K = Machining complexity factor

d_i = Feature dimension

t_i = Tolerance on feature dimension.

The cost modifiers are,

    i)   *Die complexity factor:* It includes parting surface complexity, presence of side cores, surface finish/texture, ejector mechanism and die material.

    ii)   *Parting surface complexity:* Parting surface complexity is divided into three categories namely straight, stepped and freeform.

    iii)   *Core complexity:* Presence of side cores and operating mechanisms

    iv)   *Surface finish / texture:* Polished or textured

    v)   *Ejection mechanism:* Ejector pins, cam operated or hydraulic-pneumatic actuator.

    vi)   *Die/ mould material:* Hardened or pre-hardened.

Values of these cost modifiers are decided based on past experience. For individual tool rooms these values can be established by using Quality Function Deployment (QFD) approach.

2.4 Summary of Literature Survey

Cost estimation approaches available in literatures are useful in tool rooms involved in developments of similar types of moulds having family of similar shapes.

- The method based on use of knowledge-based decision tables (Chin et al., 1996) need software to make use of these decision tables. This is difficult for small and medium scale tool rooms. Also for tool rooms handling different types of tools this approach will not give satisfactory results.
- The feature based approach (Chen et al., 1999) use product CAD model for calculating cost of core and cavity. The other elements of the mould cost are not considered here in details. Moreover this approach is used to compare estimated cost and to get cost-effective solution rather than exact estimation of cost of the mould.

- The cost estimation method proposed by Menges et al. (1993) is suitable for all varieties of job but fail to address finer points of machining core & cavities. Machining time estimation based on mean depth may mislead. The effect of machining type (rough or finish), mould base machining, assembly time etc. are not considered here. Being analytical in nature it involves calculations of many parameters and hence doesn't give quick estimation.

- The integrated framework proposed by Nagahanumaiah et al. (2005) also addresses variety of tools handled by tool rooms. The cost modifier values need to be developed by using QFD technique. This approach needs very systematic calculation of cost drivers and cost modifiers, which is difficult in small tool rooms.

Chapter 3

Problem Definition

3.1 Motivation

Cost estimation of injection moulds and pressure die-casting dies is important for product costing and decision making. Higher estimates may lead in loosing orders while lower estimation will affect profitability. Hence accurate cost estimation needs to be done. At present it is time consuming and needs expertise in mould making. Availability of such expertise in tool rooms is becoming difficult. Hence need is felt to develop a method which can give quick estimation and can be used by less experienced engineer having basic knowledge of injection moulds and PDC design.

3.2 Objectives and Scope

The aim of this project is to develop cost model for injection mould and pressure die-casting die which will fulfil following requirements:-

- Cost model should give estimated cost within 90% accuracy.
- Cost estimation should not be time consuming activity.
- Cost estimation can be done by less experienced engineer having basic knowledge of injection mould and pressure die-casting die design.
- Cost estimation should be done by using common software like Microsoft Excel or Access. It should not call for new software development.

The cost model will give cost estimation of design and manufacturing of injection moulds and PDC. It doesn't include costs incurred due to increase in set up time or WIP carrying charges and overheads. The project aims at estimating cost of two-plate and three-plate mould or die construction. It doesn't include some special mould designs i.e. micro-moulding or stack-moulding etc.

3.3 Approach

The cost estimation of injection moulds and pressure die-casting dies is done by dividing the total cost into three major cost heads:

1) Basic mould cost

2) Mould base cost

3) Standard elements and accessories cost

1) *Basic mould cost:* It is the cost of manufacturing and assembly of mould inserts i.e. core and cavity for injection mould or PDC. This cost is estimated by using regression analysis for component geometric data and mould construction details. The CAD model of an article along with mould or PDC design specification sheet is used by estimator to derive the basic mould cost.

2) *Mould base cost:* Mould base cost is derived from mould base size. Mould base size is decided by using knowledge-based decision tables. These decision tables are developed to determine mould base and mould insert size.

3) *Standard elements and accessories cost:* Database is generated for costs of Std. elements and accessories like hot nozzles, latches etc. The information from accessories manufacturers catalogues is consolidated in common database.

Other cost elements like design cost and overheads are normally considered as percentage of total mould cost, which is addition of above three major cost heads. Apart from this mould insert raw material and Heat-treatment costs are derived from mould insert weight calculated using decision tables.

Chapter 4

Mould Base Cost Estimation

Mould base consists of top plate, supports, guiding elements, punch holder, die holder and ejector plates. Mould inserts forming an article are housed in punch and die holders. These punch and die holders are located by using guide pillar and bush to maintain correct location of punch insert and die insert during moulding. The size of the mould base depends on size of article to be moulded, no. of cavities and presence of sidecore, hot manifold if any.

Mostly these mould bases are available as standard sets from mould base manufacturers like DME, HASCO, etc. The tool room under study for this cost model does not use these standard mould bases. Mould bases are designed along with mould to suit article requirements. However these mould bases are not manufactured in-house but are purchased from vendors. These vendors manufacture the mould base as per design supplied to them.

Therefore to estimate cost of mould base, it is essential to know the size of mould base. To get this size of mould base decision tables are developed which use component details for calculating size of mould base.

4.1 Decision Tables

Knowledge-based systems are used in many fields for making decisions or in the support of decision-making. Basically it has got knowledge about that field of expertise i.e. procedures, strategies, rules of thumb for problem solving etc. This knowledge is derived from human experts in the field and then encoded by some tools. A decision table is one of such tool used to gather such knowledge for making decisions or to support decision-making (Chin et al., 1996).

A decision table is a symbolic way of representing the logical interdependence between events. It provides a means to handle "If-Then" situations to link the numerous decision factors in the decision making process. As decision tables present decision alternatives in a simple tabular form, they are clearly displayed and readily understood by the reader even for complex decision-making situations. Basically these decision tables have condition stub and action stub. Condition stub contains all the conditions that must be considered before selecting a course of action. Action stub contains the entire set of individual actions governed by the decision table.

The objective of this project is to develop cost model for injection mould and pressure die-casting dies which gives cost estimation quickly by less experience engineer having basic knowledge of mould and die designing. Typically experience person having knowledge of design and manufacturing aspects of mould and die making does the cost estimation. From component geometry, that person is in position to understand concept of mould design and difficulties in manufacturing these moulds. It will be difficult to anticipate these things for person having less experience. Hence there is need to develop some mechanism which will support less experience person to decide mould design aspects. The decision tables are considered here as a mechanism to fulfil this need.

4.2 Development of Decision Tables

The decision tables developed here are used to derive size of mould insert and mould base. Once these sizes are derived, cost of mould insert material and cost of mould base can be estimated. The rule of thumbs and practices followed in designing mould inserts and mould base are considered here while formulating these decision tables. The mould insert sizes are then verified to satisfy maximum bearing stress criterion.

The estimator will have component drawing or model for which an injection mould or pressure die-casting die is to be made. Using basic knowledge of die designing estimator will be in position to decide parting line for component. Length, width, depth in punch side and depth in core side will be derived from this. If the component has undercuts in

parting directions then sidecores are required. Number of side cores and respective travel can be determined from component drawing or model. The gating position will be decided considering functional and aesthetic requirement of component. Product designer will validate this position. The filling pattern will be judged and taken into account for gate position. Gating position can be at centre of the component or on side face. Number of cavities is decided by customer taking into account annual requirement of the component. Majority of cases it is singe cavity or two cavities. All these will be input to the cost estimator to use decision table to decide mould insert size and mould base size.

The inputs mentioned above are used in condition stub in decision tables. From length, width and thickness in punch and die, the mould insert sizes will be derived. The mould insert thickness is derived from depth of component in punch side and die side. Mould insert sizes are then used to determined mould base length and width. The punch holder and die holder thickness are derived from respective mould insert thickness. Ejection stroke is derived from component thickness in punch side. This will be used to decide spacer thickness on moving side. Using all this thickness details the mould base height or shut height is derived.

4.3 Decision Tables for Mould Layout

The figure mentioned below gives details of nomenclature used as inputs available to cost estimator for using decision tables.
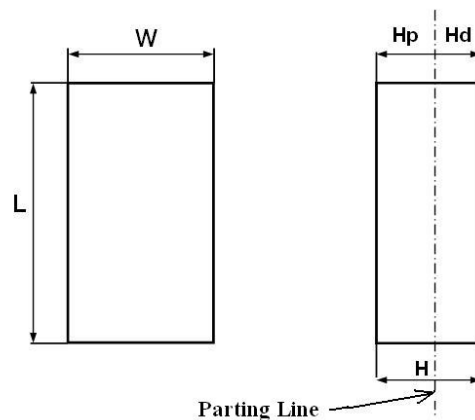
Figure 4.1: Component nomenclature

Where,

L= Component length

W= Component width

H= Component thickness

Hp= Component thickness on punch side

Hd= Component thickness on die side

Figure mentioned below indicates typical layout of an injection mould and nomenclature of the mould base sizes used in decision tables.
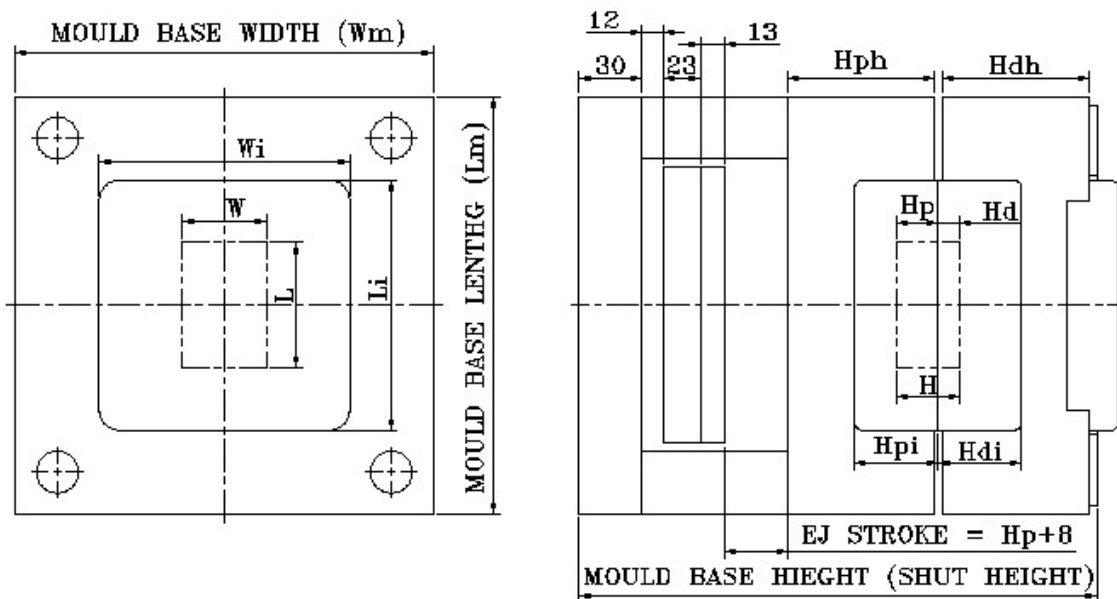
Figure 4.2: Injection mould layout

Where,

Li= Length of mould insert

Wi= Width of mould insert

Hpi= Thickness of Punch insert

Hdi= Thickness of Die insert

Hph= Thickness of Punch holder

Hdh= Thickness of Die holder

Lm= Mould base length

Wm= Mould base width

S.H.= Mould base height or Shut height

Table 4.1: Decision table for single cavity mould having gate at centre

Component Length (L)	Component Width (W)	Insert Length (Li)	Insert Width (Wi)	Punch Insert Thickness (Hpi)	Die Insert Thickness (Hdi)	Mould base Length (Lm)	Mould base Width (Wm)	Suitable machine
< 90 If (L x W) < 4500	< 50	L + 2 { Max (25 or 0.6Hp or 0.6Hd)}	W + 2 { Max (25 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (50 or Hpi or Hdi)}	Wi + 2 { Max (50 or Hpi or Hdi)}	30 T
< 120 If (L x W) < 12000	< 100	L + 2 { Max (30 or 0.6Hp or 0.6Hd)}	W + 2 { Max (30 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (50 or Hpi or Hdi)}	Wi + 2 { Max (50 or Hpi or Hdi)}	80 T
< 180 If (L x W) < 22500	< 120	L + 2 { Max (35 or 0.6Hp or 0.6Hd)}	W + 2 { Max (35 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (60 or Hpi or Hdi)}	Wi + 2 { Max (60 or Hpi or Hdi)}	150 T
< 250 If (L x W) < 45000	< 180	L + 2 { Max (40 or 0.6Hp or 0.6Hd)}	W + 2 { Max (40 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (60 or Hpi or Hdi)}	Wi + 2 { Max (60 or Hpi or Hdi)}	300 T

Table 4.2: Decision table for single or two-cavity mould having gate on side face

Component Length (L)	Component Width (W)	Insert Length (Li)	Insert Width (Wi)	Punch Insert Thickness (Hpi)	Die Insert Thickness (Hdi)	Mould base Length (Lm)	Mould base Width (Wm)	Suitable machine
< 90	< 50	L + 2 { Max (25 or 0.6Hp or 0.6Hd)}	2 {W+30+ Max (25 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (50 or Hpi or Hdi)}	Wi + 2 { Max (50 or Hpi or Hdi)}	30 T if LxW=4500 for Sigle Cavity
								30 T if LxW=2250 for Two Cavity
< 120	< 100	L + 2 { Max (30 or 0.6Hp or 0.6Hd)}	2 {W+30+ Max (30 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (50 or Hpi or Hdi)}	Wi + 2 { Max (50 or Hpi or Hdi)}	80 T if LxW=12000 for Sigle Cavity
								80 T if LxW=6000 for Two Cavity
< 180	< 120	L + 2 { Max (35 or 0.6Hp or 0.6Hd)}	2 {W+30+ Max (35 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (60 or Hpi or Hdi)}	Wi + 2 { Max (60 or Hpi or Hdi)}	150 T if LxW=22500 for Sigle Cavity
								150 T if LxW=11250 for Two Cavity
< 250	< 180	L + 2 { Max (40 or 0.6Hp or 0.6Hd)}	2 {W+30+ Max (40 or 0.6Hp or 0.6Hd)}	Hp+30	Hd+25	Li + 2 { Max (60 or Hpi or Hdi)}	Wi + 2 { Max (60 or Hpi or Hdi)}	300 T if LxW=45000 for Sigle Cavity
								300 T if LxW=22500 for Two Cavity

Table 4.3: Decision table to derive mould base thickness

Component Length (L)	Component Width (W)	Die Holder Thickness (Hdh)	Punch Holder Thickness (Hph)	Parallel Thickness (Hs)	Base Plate Thickness (Hb)	Mould Base Hieght / Shut Height
< 90	< 50	Hdi+25	Hpi + 40	Hp + 56	30	Hdh + Hph + Hs + 35
< 120	< 100	Hdi+25	Hpi + 40	Hp + 56	30	Hdh + Hph + Hs + 35
< 180	< 120	Hdi+30	Hpi + 50	Hp + 56	30	Hdh + Hph + Hs + 35
< 250	< 180	Hdi+30	Hpi + 50	Hp + 56	30	Hdh + Hph + Hs + 35

4.4 Moulds with Sidecore and Hot manifold

When an article has undercut which needs sidecore mechanism to form the same, the length and width of mould base increases. This is due to space required to accommodate slide, angle pin or dogleg cam, and wedge for locking during moudling. Following figure indicates nomenclature of component needing sidecore mechanism.
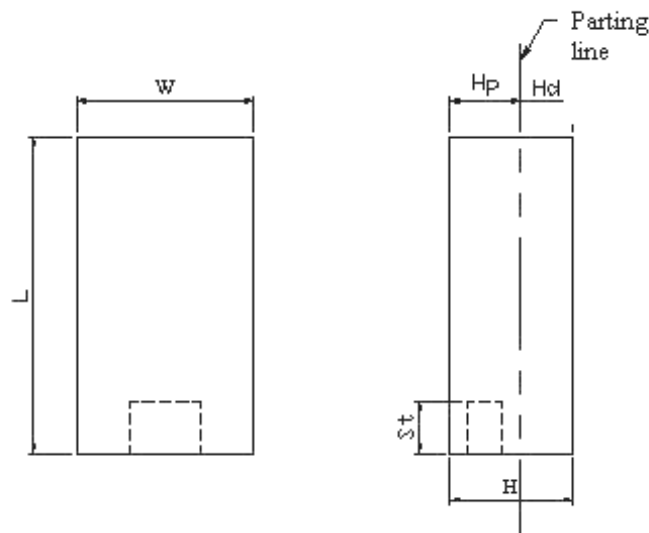
Figure 4.3: Component with undercut

Where,

St = Undercut length

For the component having undercut on surface along with width W, the mould base length will be

Lm = Li + 2 (St + 90)

While for component having undercut on surface along with length L, the mould base width will be

Wm = Wi + 2 (St + 90)

The other values of mould base sizes will be as per decision tables (Table 4.1, 4.2, and 4.3).

When quantity of component produced is higher, the wastage of plastic raw material in runner and gating systems is substantial. Hence mould is designed to avoid this wastage by using Hot manifolds in case of multi-cavity mould and Hot Nozzle system for single cavity mould. To accommodate this Hot manifold plates are added in mould base between Die holder and Fixed platen of the machine. The typical thicknesses of these plates are 90mm and 38 mm for Manifold plate and Top plate simultaneously. Hence when mould is designed for Hot manifolds Mould base height size will increase by 128 mm and when only nozzle is used mould base height will increase by 38 mm. Estimator need to take into account this while considering mould base size.

4.5 Cost of Mould Base

Cost of mould base is sum of cost of raw material and machining of its elements. The raw material for plates is C45 steel whereas guiding elements are of High Carbon High Chromium (HcHcr) steel with hardness up to 58-60 HRC. The machining operation for these plates includes drilling, boring, milling and grinding. These plates are then assembled together using guiding elements and screws. As all mould bases have similarity in construction, manufacturing of these mould bases follows similar machining operations. The factor, which matters to the change in cost, is size of mould base. Therefore analysis is done to find correlation between mould base size and its cost. Past data is collected for purchase of the mould bases of different sizes. Table 4.4 shows data collected for analysis.

Table 4.4: Mould base sizes and costs

SR. NO.	TOOL NO.	PR VALUE (in Rs.)	PR DATE	NO. OF MONTHS W.R.T. ANALYSIS DATE	CORRECTED PR VALUE (in Rs.)	LENGTH (in mm)	WIDTH (in mm)	SHUT HEIGHT (in mm)	MOULD BASE VOLUME (in cc)
1	DCS53107/1P2	327000	07-Feb-05	23.0	399518	446	446	459	91302.44
2	DCM57853/1P1	64000	12-May-04	32.1	84583	220	280	252	15523.2
3	DCM57854/1P1	61000	29-Apr-04	32.5	80923	296	296	281	24620.09
4	DSS53067/1P2	230000	28-Dec-04	24.4	284366	327	450	510	75046.5
5	DSS53000/1A6	82000	14-Sep-06	3.6	84583	430	300	312	40248
6	DSS50005/1A2	273000	29-Dec-04	24.4	337433	340	500	308	52360
7	DCS53678/1P1	100000	15-Jun-05	18.8	117727	260	365	281	26666.9
8	DCS53676/1P1	109000	15-Jun-06	6.6	115439	300	350	320	33600
9	DSS50006/1A3	249000	14-Mar-05	21.9	301150	325	450	520	76050
10	DCM57856/1P1	109000	17-Oct-05	14.6	123792	280	350	370	36260
11	DCS53697/1P1	370000	17-Oct-05	14.6	420210	450	520	520	121680
12	DCS53719/1P1	436000	11-Dec-05	12.8	487335	455	455	525	108688.13
13	DCS53933/1P1	96000	20-Oct-05	14.5	108933	300	315	390	36855
14	DCS53932/1P1	95000	20-Jun-05	18.6	111678	300	300	275	24750
15	DCM57894/1P1	56000	11-Dec-05	12.8	62594	260	296	215	16546.4
16	DCS53927/1P1	110000	20-Oct-05	14.5	124819	300	420	371	46746
17	DSS53010/1A2	164000	09-Jan-06	11.8	181775	400	500	363	72600
18	DSS53027/1P3	104000	02-Aug-06	5.0	108622	380	300	319	36366
19	DCS53069/1P1	132000	11-Dec-06	0.6	132729	380	300	305	34770
20	DCM56028/1P1	160000	20-Dec-06	0.3	160464	330	270	267	23789.7
21	DSS50285/1A1	170000	09-Oct-05	14.9	193518	270	296	293	23416.56
22	DSS50284/1A1	175000	09-Oct-05	14.9	199210	270	296	293	23416.56
23	DCL50914/1P2	270000	09-Dec-06	0.7	271649	450	500	484	108900

4.6 Regression Analysis

Data regarding mould base sizes and its purchase cost is collected. As these purchases are done from last three years, for analysis purpose the purchase cost is converted to current purchase value considering 11% inflation rate per annum. From mould base size mould base volume is calculated. Regression analysis is done to find correlation between modified purchase cost and volume of mould base.

Regression Plot

Corrected PR = 34186.8 + 3.22270 MOULD BASE V

S = 65167.2   R-Sq = 72.8 %   R-Sq(adj) = 71.5 %
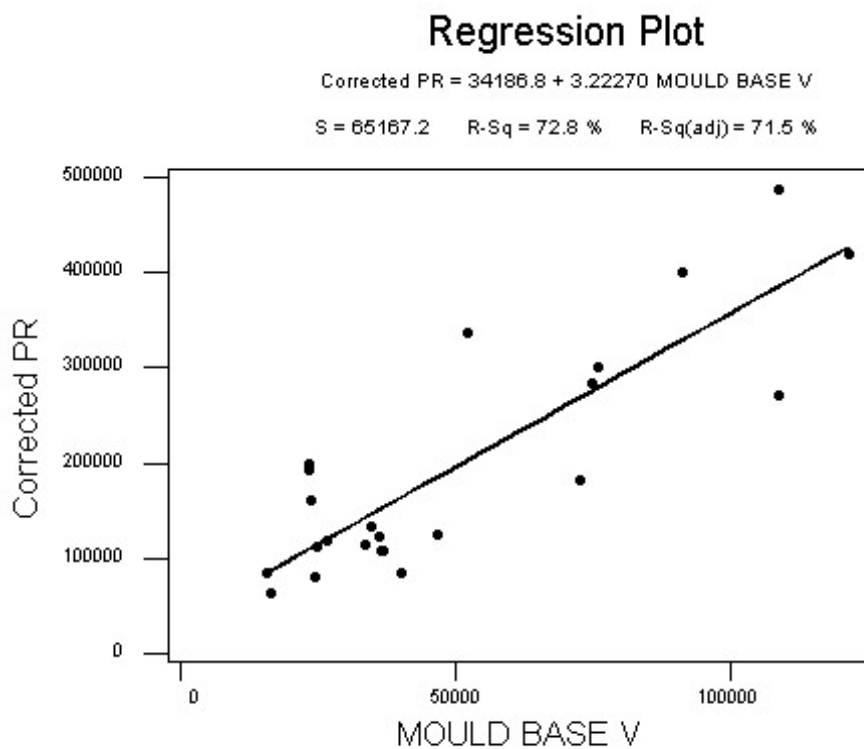
Figure 4.4: Regression plot for Corrected PR value and Mould Base volume
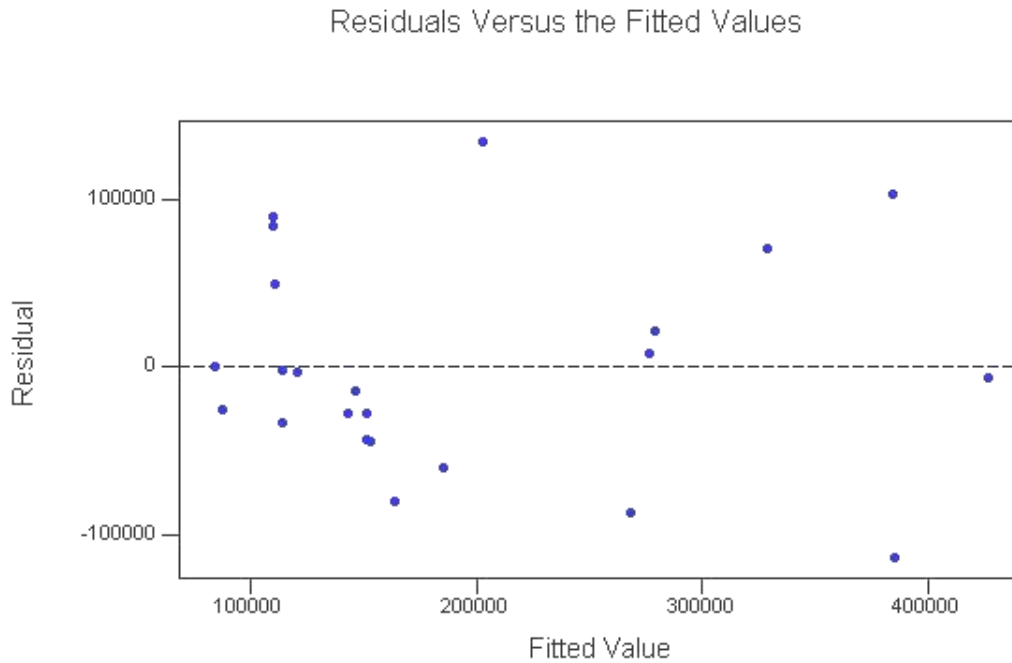
Figure 4.5: Residual plot

From regression analysis, linear relationship is found between mould base volume and its cost. To check this linear model, the residual plot is drawn. From residual plot it is observed that the residuals are spread above and below of the fitted line and hence linear model for this regression analysis holds good (Chatterjee et al., 1991)

4.7 Result

From regression analysis following equation is derived for cost of mould base: -

Estimated cost of mould base (in Rs.) = 34187 + (3.22 X Mould base volume in cc)

..... (4.1)

Chapter 5

Basic Mould Cost Estimation

5.1 Basic Mould Cost

Basic mould cost is cost of core and cavity inserts. Core and cavity inserts are replica of an article. These may be single block or multiple inserts housed together in core or cavity housings, which are part of mould base. In general 50-60% of mould cost is cost of this core and cavity inserts. This cost comprises of material cost and manufacturing cost. Manufacturing cost consists of machining cost and fitting or assembly cost.

Material cost of core and cavity insert can be estimated by using decision tables mentioned in chapter four. From the article data the mould insert length, width and thickness can be derived. From this volume and weight of mould inserts can be calculated. As cost estimator knows rate of mould insert material; raw material cost of mould inserts can be estimated.

The manufacturing cost of mould inserts depends on size and complexity of these inserts. Manufacturing of mould inserts includes following operations in general depending on mould insert profile (Menges, *et al.*, 1993): -

- Shaping and milling
- Drilling and tapping
- Jig boring
- NC path generation and CNC milling
- Heat treatment
- EDM- Spark erosion
- EDM- Wire erosion
- Grinding
- Polishing
- Surface treatments like coating or texturing.

5.2 Difficulties in Basic Mould Cost Estimation

At the time of mould cost estimation, detail mould design is not made and hence the exact size and shape of mould insert is not known. The time available for cost estimation and the low order to estimate ratio doesn't allow detailed mould insert design for estimating cost. In absence of design of mould inserts, the cost estimation becomes challenging task.

The manufacturing processes for mould inserts are dependent on profile of mould insert, which is replica of an article. As tool rooms are involved in handling variety of jobs, where there is very less similarity between two jobs; the previous cost data also doesn't help much in estimating manufacturing cost. Along with this, facility available in tool room also plays important role in deciding the process sequence or manufacturing strategy for mould inserts. As tool room has to handle variety of jobs there is difficulty in standardizing this sequence. All these factors create difficulties in estimating cost of mould insets.

5.3 Cost Estimation Approach

The mould inserts is replica of an article for which mould is designed. Though there is less similarity between mould inserts and there is variation in sequence of machining operations, the amount of material to be removed from mould insert is equal to volume of article. Therefore there should be some correlation between manufacturing cost and volume of an article. Along with this the surface area of an article is same as surface area of mould inserts excluding cut bearing faces where there is metal-to-metal contact of mould inserts in two halves. Therefore it is decided to check the correlation between mould insert machining cost and article volume, surface area.

It is also observed that for the same volume or same surface area manufacturing cost is related with complexity of an article. For same volume of material removal, mould inserts having simple geometries can be manufactured by only milling operation but for complex profile machining, along with milling operation spark erosion has to be performed on mould inserts. This changes manufacturing cost of mould insert to great

extend due to low material removal rate of EDM operations. Hence there is need to check correlation between complexity of article and mould inserts manufacturing cost.

The mould insert are to be fitted into fixed half and moving half of mould base and has to insure perfect contact with each other along parting line to ensure flash-free article during moulding. The matching of these inserts depends on parting line profile. The time and accuracy of machining required is high for complex parting line than straight parting line. Along with this if article has an undercut that needs sidecore, extra elements for sidecore mechanism has to be provided in mould, which increase cost of mould insert manufacturing and time taken to assemble these sidecores. In case of multi-cavity mould there is advantage of repeating same manufacturing process for all cavity inserts. Though machining operation time remains same, the CNC programming time and setting time reduces drastically. Therefore cost of mould inserts for multi-cavity mould is definitely lesser than single cavity mould insert of same component. Therefore effect of parting line, sidecore and multi-cavity mould construction are to be taken into account while estimating mould insert cost.

5.4 Regression analysis

Regression analysis is carried out to find correlation between basic mould cost i.e. cost of manufacturing of mould insert and different parameters like volume, surface area, complexity factor, parting line type, no. of sidecores, no. of cavities etc. as discussed in previous section. For this cost data of the injection moulds and pressure die-casting dies manufactured in recent past is collected. Required geometric data of an article; which is formed by these moulds is gathered. Mould construction is checked to find out parting line type, no. of cavities. Table 5.1 on next page gives data collected regarding details of component data and mould data. This data collected includes small component of size 36.5 x 10 x 2.5 mm having volume 314 mm^3 to a large component of size 554 x 554 x 59 mm having volume 910614 mm^3. Being confidential, this table indicates data for only three moulds. Refer Appendix for details of all the elements. This also indicates 3D view of these components along with overall sizes, volume, Surface area, and Nominal thickness.

Table 5.1: Component details and mould details

Sr. No.	Tool No.	Length (mm)	Width (mm)	Height (mm)	Component Volume (mm3)	Component Surface Area (mm2)	Nominal Thickness (mm)	No. of Cavities	No. of Side cores	Parting Line type
1	DCS53933/1P1	36.5	10	2.5	314	542	2	6	0	Straight
2	DCM57853/1P1	36.5	34.8	20	2928	3359	1.7	1	1	Stepped
3	DSS50284/1A1	53.5	53.5	4.3	4275	7246	1.25	2	0	Straight
4	—	—	—	—	—	—	—	—	—	—
5	—	—	—	—	—	—	—	—	—	—
6	—	—	—	—	—	—	—	—	—	—
7	—	—	—	—	—	—	—	—	—	—
8	—	—	—	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—

For the injection moulds and PDC mentioned in Table 5.1 cost data is collected. This cost data was available with respect to operations performed on mould insert. The cost data is then divided into following cost heads: -

1) Design cost
2) Pre-machining cost
3) CNC milling cost
4) Heat-treatment cost
5) EDM cost
6) Grinding cost
7) Fitting and Assembly cost
8) Vendor out machining cost
9) Mould base and Std. Element purchase cost
10) Overheads

The manufacturing cost of mould insert is calculated by following equation: -

Mould insert mfg. Cost = Pre-machining cost + CNC milling cost + EDM cost + Grinding cost + Vendor out machining cost + Fitting and Assembly cost

.... (5.1)

The cost incurred for Heat-treatment of mould insert is excluded from this as it can be calculated by using size of mould insert derived form decision tables and per kg rate of Heat-treatment operation. Due to in-house capacity limitations, small mould insert are machined at vendors. This cost incurred is included in Vendor out machining cost.

As we are interested in analyzing manufacturing cost of mould insert with respect to component volume, surface area etc. the mould insert manufacturing cost per cavity is derived using no. of cavities in the mould. The injection moulds and PDC dies used here for analysis are manufactured in last two years and hence mould insert cost per cavity is corrected to current mould insert manufacturing cost considering 11 % inflation rate per annum. Table 5.2 gives all these cost elements discussed above for the moulds & dies mentioned in Table 5.1 in same sequence. The details of only three moulds are mentioned in this table. Refer Appendix for cost details of all moulds. All cost mentioned in this table are in Rs.

Table 5.2: Mould insert manufacturing cost data.(in Rs.)

Sr. no.	Pre-machining cost	CNC milling cost	EDM cost	Grinding cost	Vendor out machining cost	Fitting & Assembly cost	Total Mould Insert mfg. cost	No. of Cavities	Mould Insert mfg. Cost per cavity	Date of mfg.	Corrected M.I.mfg. cost per cavity
1	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—	—	—
4	34157	144071	57383	41726	10260	54501	342098	1	342098	31-Dec-05	391461
5	90129	163229	174977	90732	16019	201347	736433	6	122739	30-Jun-06	133271
6	23075	0	14000	16680	61535	35045	150335	2	75168	28-Feb-06	84555
7	—	—	—	—	—	—	—	—	—	—	—
8	—	—	—	—	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—	—

From Table 5.2 we get cost of mould insert manufacturing for respective component. The component volume is also mentioned in Table 5.1. Therefore we can find out cost of mould insert manufacturing per volume for each component. This cost of mould insert manufacturing per volume is used to perform regression analysis. The cost per volume will change as part become more and more complex. Following factors are considered as characteristics of component and mould, which will affect cost of mould insert manufacturing per volume: -

1) Volume Ratio = $\dfrac{\text{Volume of Bounding Box}}{\text{Volume of component}}$

2) Area Ratio = $\dfrac{\text{Surface area of component}}{\text{Surface area of cube having equivalent component volume}}$

3) $(S.A.)^{1/2} / (Vol.)^{1/3} = \dfrac{(\text{Surface area of component})^{1/2}}{(\text{Volume of component})^{1/3}}$

4) No. of additional cavities = Total no. of cavities in mould - 1

5) Parting line factor: From literature on mould cost, it is found that straight parting surface will not impose any additional cost. However, stepped and freeform parting surfaces increase the mould cost by 10-20%, and 20-40% respectively (Nagahanumaiah et al., 2005). In statistical tools to indicate relationship between two parameters factors 1, 3 & 9 are used to indicate low, medium, and strong relationship respectively. Similarly factors 1, 3 & 9 are used here for straight, stepped and complex parting line.

6) Nominal thickness of component

Table 5.3 shows the data of all the above-mentioned factors used for regression analysis. This table indicates values for three moulds. Refer Appendix for details of all the elements.

Table 5.3: Data for regression analysis

Sr. no.	Tool no.	No. of additional cavities	Parting line factor	Nominal Thickness	(Volume Ratio)$^{1/3}$	(Area Ratio)^2	(S.A.)$^{1/2}$ / (Volume)$^{1/3}$	Corrected M.I. Mfg. cost per cavity (Rs.)	Cost per Volume (Rs/mm3)
1	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—
5	—	—	—	—	—	—	—	—	—
6	—	—	—	—	—	—	—	—	—
7	DCS53914/1P1	1	3	2.0	1.8036	14.3684	4.7690	298000	43.5800
8	DCS53677/1P1	1	9	1.5	2.0550	23.7785	5.4091	296042	42.1472
9	DSS53027/1P3	3	3	1.5	2.2949	14.0991	4.7465	349904	46.1859
10	—	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—	—
23	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—
27	—	—	—	—	—	—	—	—	—

5.5 Equation for Basic Mould Cost Estimation

Regression analysis is performed on the cost data mentioned in Table 5.3. It is observed that correlation coefficient, R-sq is 73.9% which is ok, but observation no. 20 has large residual. Hence it has been removed form data set and regression anlysis is performed again. From this analysis we get following equation for cost of mould insert manufacturing per volume.

Cost per Volume (Rs/mm3) = $C_0 + C_1$ (Volume Ratio)$^{1/3}$ + C_2 (Area Ratio)^2

$\qquad$ - C_3 { (S.A.)$^{1/2}$ / (Volume)$^{1/3}$ } + C_4 Parting line factor

$\qquad$ - C_5 No. of additional cavities – C_6 Nominal Thickness.

$$\dots (5.2)$$

Being confidential, the values of factors C_0 to C_6 are mentioned in Appendix. The correlation coefficient, R-sq value for above equation is 82.1%, which indicates validity of above equation. Along with this, the graph plotted for residual versus order of data also indicates that observations doesn't show any specific trend and residuals are randomly distributed about origin.
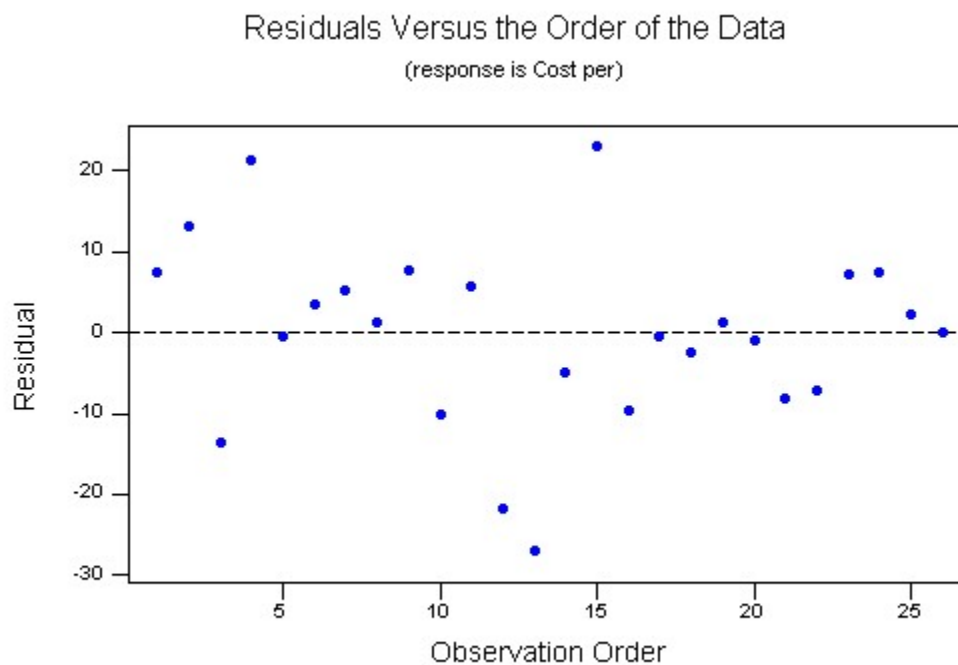

Figure 5.1: Residual plot versus order of data

From the above-mentioned equation it is observed that cost of mould insert manufacturing increases as component becomes more and more complex. As complexity increases, volume ratio and area ratio increases and hence cost per volume will increase. The effect of surface area to volume ratio of component has to be considered with area ratio and volume ratio. As parting line becomes more and more complex the cost of mould insert manufacturing will increase. The effect of side core needs to be considered while deciding parting line factor. Increase in no. of additional cavity will reduce cost of manufacturing of mould insert as it gets advantage of repeating same operations. In case of multi-cavity mould, the efforts on CNC programming, set up etc. gets divided over number of cavities. Regression equation shown here clearly indicates this fact. It can be also observed that there is reduction in cost per volume as nominal thickness of component increases. This is because as nominal thickness increases, the insert splitting and machining becomes simpler.

5.6 Result

The basic mould cost or cost of mould insert manufacturing is calculated by using cost per volume as follows:

Basic mould cost (Rs.) = Cost per Volume (Rs./ mm^3) x Volume of component

x No. of cavities   ….(5.3)

   Where cost per volume is calculated by using equation (5.2).

Chapter 6

Other Cost Elements

Mould base cost and cost of mould inserts are major elements in cost of injection mould and pressure die-casting dies. Apart from these two elements mould cost includes its design cost, heat-treatment cost, surface treatment cost, raw material cost of mould inserts, standard elements purchase cost and overheads. This chapter elaborates cost estimation of these cost elements.

6.1 Mould Insert Material and Treatment Cost

Mould inserts are normally of HCHCR steel having hardness up to 52-54 HRC. From decision tables mentioned in Chapter Four the size of mould insert can be derived. This will give volume of mould inserts and hence weight. By knowing per Kg rate of raw material the mould insert material cost can be estimated. Similarly by knowing per kg rate of Heat-treatment operation estimator can find out cost of Heat-treatment. The following equation will give cost of raw material and Heat-treatment.

Mould insert material and Heat-treatment cost = (per kg rate of material + per kg rate of Heat-treatment operation) X

$$\left\{ \left[(Li \times Wi)(Hpi + Hdi) \right] \times 7.85 \times 10^{-6} \right\}$$

…. (6.1)

Where,

Li= Length of mould insert in mm.
Wi= Width of mould insert in mm.
Hpi= Thickness of Punch insert in mm.
Hdi= Thickness of Die insert in mm.

As mentioned above the values of Li, Wi, Hpi and Hdi will be derived from component size and mould construction using decision table. Cost estimator need to have an update on cost of raw material for mould inserts and heat-treatment cost.

Most of the time plastic components have aesthetic requirements like matt finish or mirror finish on external face of component. This call for surface treatment of mould inserts forming these external surfaces of component. Cost of these surface treatment is considered in this regards is basically cost of providing matt finish by EDM or chemical etching, polishing, coating etc. This cost can be estimated by knowing cost of surface treatment and surface area of component needing this treatment. Following equation gives this estimated cost:

Surface treatment cost = Surface area of component having aesthetic requirement

x Rate of corresponding surface treatment.

…. (6.2)

6.2 Design Cost Estimation

Design cost of injection mould and PDC is proportional to total cost of the same. Typically it is estimated as certain percentage of total mould cost depending on design deliverables. Though this percentages changes with respect to no. of cavities, no. of sidecores, complexity etc., same will change total cost of mould. For tool room under study for development of cost model, it is observed form past data of moulds and PDC that design cost is 20% of total mould cost excluding overheads. Therefore in the cost model developed design cost is calculated by using following equation:

Design cost = 0.2 x (Mould Base cost + Mould insert raw material & treatment cost +

cost of standard elements + Basic mould cost)

…. (6.3)

6.3 Standard Element Cost Data

In injection moulds and pressure die-casting dies many times accessories are used which are available in market as Standard elements. Hot Nozzles and Hot manifolds are used to avoid material wastage in feeding system. Some accessories are used in ejection system to ensure that ejector pins are retracted back before mould is closed. The standard spring-loaded latches ensures sequential opening of the mould. Standard locators are used to maintain precise alignment of core and cavity side. All these accessories need not have to be manufactured in tool room. These accessories are purchased as standard elements

45

from suppliers. Hence to take care of the cost of the standard element, purchase cost data of these standard elements is collected. At the time of estimating mould cost, estimator need to take into account requirement of standard elements and then refer the purchase data for cost of standard element.

6.4 Overhead Cost

Apart from direct material and direct labour cost, indirect cost in terms of overheads is associated for manufacturing any sort of product. This overhead includes most of the Fixed cost elements like plant and machineries, salaries of staff and other common services used by manufacturing shops. Typically, overheads are assumed as certain percentage of direct material and direct labour cost. For tool room under study for this cost model, the overheads include the common services like hardware's, stores, purchase section, staff salaries, plant maintenance etc. The overhead percentage will change for other tool rooms depending upon consideration of common services under overheads.

Chapter 7

Cost Model

We have seen estimation of different cost elements of injection moulds and pressure die-casting dies. In this chapter all these elements are consolidated to get total cost injection mould or pressure die-casting die.

7.1 Structure of Cost Model

Total cost of injection mould or pressure die-casting die is divided into following five elements:

1) Mould Base cost: This is derived from volume of mould base. To calculate mould base volume mould base size is derived. By using decision table, size of mould base is calculated from component size and mould construction type. Equation (4.1) gives this cost element.

2) Basic Mould cost: This is cost of manufacturing and assembly of mould inserts. This cost is derived from regression equation which uses geometric details of component like volume, surface area etc. and mould construction parameters like no. of cavities, parting line type etc. Equation (5.2) and (5.3) gives this cost element.

3) Mould insert material and treatment cost: Raw material and heat-treatment cost is calculated from per kg rate and weight of mould insert. Mould insert weight is calculated from mould insert sizes derived from decision tables. Surface treatment cost is estimated by using surface area of component having aesthetic requirement and rate of this process. Equation (6.1) and (6.2) gives this cost element.

4) Standard Element cost: This is cost of standard elements purchased from market. The cost of standard element required for mould or PDC is taken from database of cost of these purchased elements.

5) Design cost: Design cost of mould or PDC is calculated as percentage of total mould cost excluding overheads. Equation (6.3) gives this cost element.

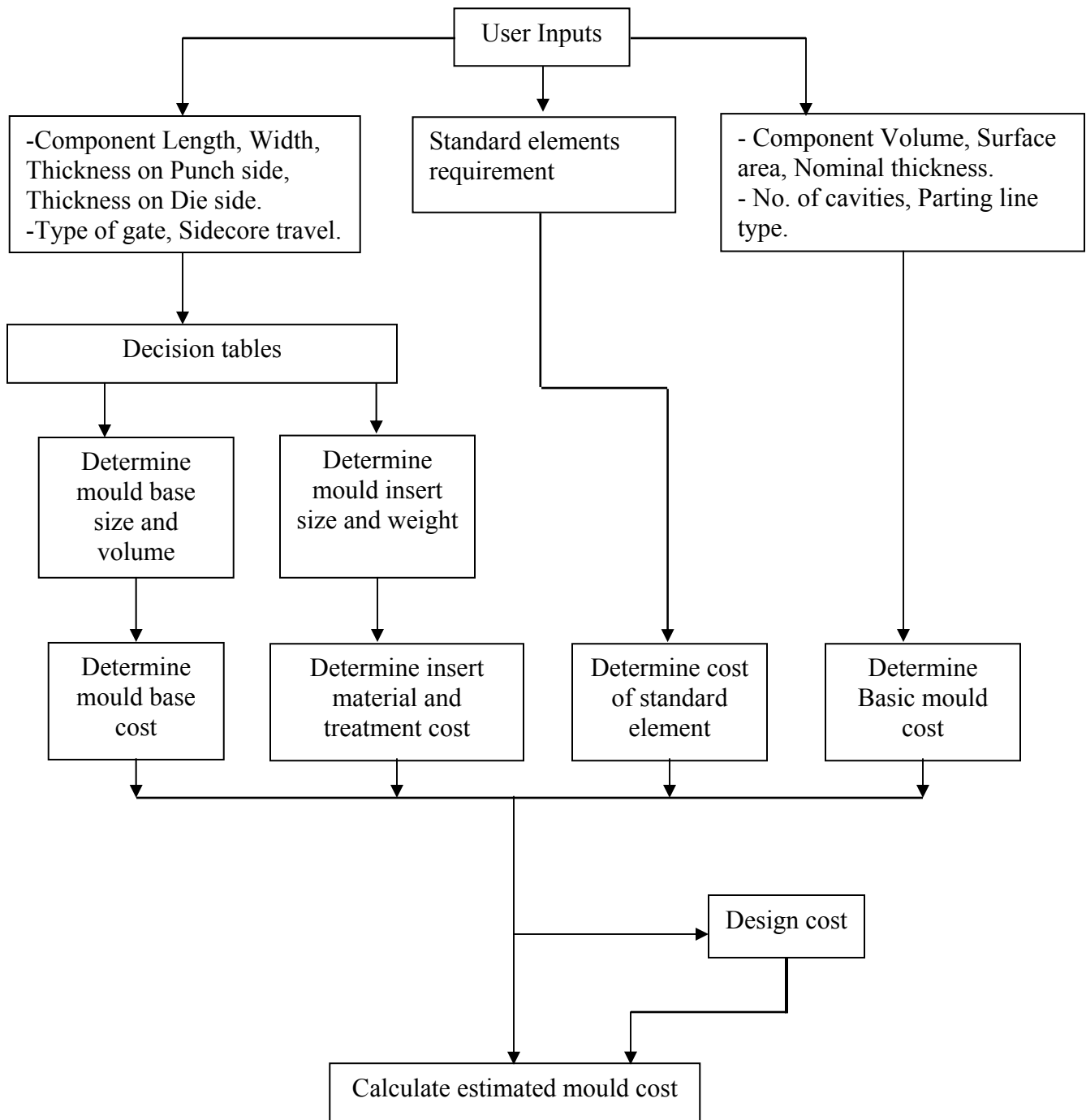Following diagram indicates the flow chart of the cost model:

Figure 7.1: Flow chart of cost model

7.2 Inputs for Cost Estimation

The cost model developed here needs following inputs from users:

1) *Component size:* Length, width and thickness of component. The thickness is further divided into Punch side and Die side. It is expected that cost estimator has basic knowledge of mould and PDC design from which he can decide overall parting plane which decides depth of component in Punch side and depth of component in Die side.

2) *Mould details:* The cost estimator should decide gate location of the component to be moulded. The decision is to be taken whether gating would be from side or at centre. Most of the time functional requirement of component decides this. The no. of cavities will be decided in consensus with customer based on quantity requirements. Estimator also needs to decide parting line type. Parting line type is of three types: straight, stepped and complex. Effect of no. of side cores will be considered while deciding parting line type. Estimator has to consider internal cut-bearing faces while deciding parting line type. It is also expected that estimator will find out need of Standard elements required for mould or PDC for which cost estimation is done. In case component has got undercuts, which requires mould with sidecore construction, then sidecore travel has to be considered.

3) *Component geometric data:* Apart from length, width and thickness of component estimator need to find out component surface area, volume and nominal thickness. Nowadays all products are designed using 3D design software. Therefore estimator can find out surface area, volume and nominal thickness very quickly using component 3D model.

All the above mentioned inputs for cost model can be given by estimator having primary knowledge of injection mould and pressure die-casting die design. It doesn't call for diversified experience in tool and die making. Thus the developed cost model fulfils aim to avoid expertise in die making to do cost estimation.

7.3 Validation of Cost Model

Cost model developed here is validated for single cavity Injection Mould made for component shown in following figure 7.2. This mould is manufactured very recently by tool room under study for development of cost model.
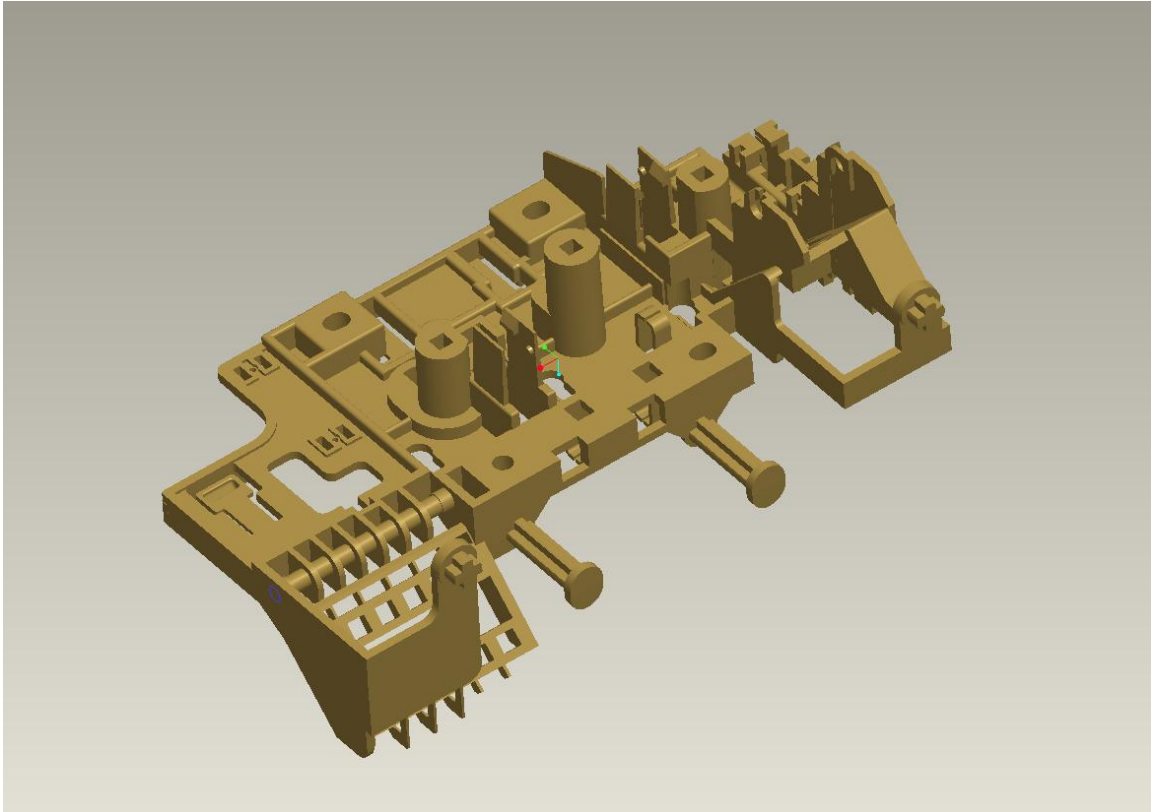

Figure 7.2: Component used for validation

The component details are as mentioned below:

Length (L) = 139 mm

Width (W) = 239 mm

Height (H) = 88 mm

Nominal thickness (T avg.) = 3 mm

Depth in punch (Hp) = 56

Depth in Die (Hd) = 32

Volume = 1.5080×10^5 mm^3

Surface Area = 1.1956×10^5 mm^2

Details of the mould are as follows:

> No. of cavities = 1
>
> Parting line type = Complex
>
> Parting line factor = 9
>
> Gating = Two drop hot runner system

As seen in figure 7.2, the component has many areas where we need to provide metal to metal cut bearings. Though component doesn't have any undercuts which requires sidecore, the internal parting and external parting is complex. For feeding of the component this mould has two drop hot runner system. Therefore component will be placed at mould centre. As this mould contains many cut-bearing faces it is advisable to use conical locators between punch and die to maintain perfect alignment of the same. Hence hot runner system and conical locator are Standard elements required for this mould.

The cost estimation of this mould done as per flow chart mentioned in figure 7.1. From component mould insert and mould base size is derived using decision tables mentioned in Chapter Four. The calculation of the same are as mentioned below:

Mould insert length,

> $L_i = L + 2$ (Max. 40 or 0.6 H_p or 0.6 H_d)
>
> $L_i = 139 + 2 (40)$
>
> $L_i = 219$
>
> $L_i \approx 220$ mm

Mould insert width,

> $W_i = W + 2$ (Max. 40 or 0.6 H_p or 0.6 H_d)
>
> $W_i = 239 + 2 (40)$
>
> $W_i = 319$
>
> $W_i \approx 320$ mm

Punch insert thickness,

$$Hpi = Hp + 30$$
$$Hpi = 56 + 30$$
$$Hpi = 86 \text{ mm}$$

Die insert thickness,

$$Hdi = Hd + 25$$
$$Hdi = 32 + 25$$
$$Hdi = 57 \text{ mm}$$

Hence we get mould insert size as follows:

Punch insert: 220 x 320 x 86 mm

Die insert: 220 x 320 x 57 mm

Mould base length,

$$Lm = Li + 2 \text{ (Max. 60 or Hpi or Hdi)}$$
$$Lm = 220 + 2 \text{ (86)}$$
$$Lm = 392$$
$$Lm \approx 400 \text{ mm}$$

Mould base width,

$$Wm = Wi + 2 \text{ (Max. 60 or Hpi or Hdi)}$$
$$Wm = 320 + 2 \text{ (86)}$$
$$Wm = 492$$
$$Wm \approx 500 \text{ mm}$$

Mould base height,

$$S.H. = Hdh + Hph + Hs + 35$$

Where,

$$Hdh = Hdi + 30$$
$$Hdh = 57 + 30 = 87 \text{ mm}$$

$$Hph = Hpi + 50$$
$$Hph = 86 + 50$$
$$Hph = 136 \text{ mm}$$

$$Hs = Hp + 56$$
$$Hs = 60 + 56$$
$$Hs = 116 \text{ mm}$$

Therefore S.H. $= 87 + 136 + 116 + 35$

S.H. $= 374 \text{ mm}$

As this mould has got two drop Hot runner system, we need to add manifold thickness of 128 mm in the S.H. calculated above.

Therefore mould base height $= 374 + 128$

Mould base height $= 502 \text{ mm}$

Hence size of mould base $= 400 \times 500 \times 502 \text{ mm}$

Thus we get size of mould base and mould insert from decision table. Now cost of the mould base and cost of raw material and heat-treatment of mould insert is calculated using equations (4.1) and (6.1) mentioned in Chapter Four and Chapter Six. As component doesn't have any aesthetic requirement the cost of surface treatment is not considered here.

A] Mould base cost $= 34187 + (3.22 \times \text{Mould base volume in cc})$

$$= 34187 + [3.22 \times (400 \times 500 \times 502) \times 10^{-3}]$$

Mould base cost $= 3, 57,475$ Rs.

B] Mould insert material and Heat-treatment cost $=$ (per kg rate of material $+$ per kg rate of Heat-treatment operation) X

$$\left\{[(Li \times Wi)(Hpi + Hdi)] \times 7.85 \times 10^{-6}\right\}$$

$$= (580 + 375) \times \left\{[(220 \times 320)(86 + 57] \times 7.85 \times 10^{-6}\right\}$$

$$= 75471.28 \text{ Rs.}$$

$$\approx 75,470 \text{ Rs.}$$

C] Cost of Standard elements used = Cost of Hot- runner System + Cost of Conical locators

$$= 4, 86,000 + (4 \text{ X } 700)$$

Standard element cost = 4, 88,800 Rs.

D] Basic Mould cost:

Basic mould cost is calculated by using equations (5.2) and (5.3) mentioned in Chapter Five. The calculations are mentioned below.

Cost per Volume (Rs/mm3) = C_0 + C_1 (Volume Ratio)$^{1/3}$ + C_2 (Area Ratio)^2
- C_3 { (S.A.)$^{1/2}$ / (Volume)$^{1/3}$ } + C_4 Parting line factor
- C_5 No. of additional cavities – C_6 Nominal Thickness.

Where,

$$\text{Volume Ratio} = \frac{\text{Volume of Bounding Box}}{\text{Volume of component}}$$

$$\text{Volume Ratio} = \frac{88 \text{ x } 139 \text{ x } 239}{1.5080 \text{ x } 10^5}$$

Volume Ratio = 19.3862

$$\text{Area Ratio} = \frac{\text{Surface area of component}}{\text{Surface area of cube having equivalent component volume}}$$

$$\text{Area Ratio} = \frac{\text{Surface area of component}}{6 \text{ x (component volume)}^{2/3}}$$

$$\text{Area Ratio} = \frac{1.1956 \text{ x } 10^5}{6 \text{ x } (1.5080 \text{ x } 10^5)^{2/3}}$$

Area ratio = 7.0331

Therefore,

$$\text{Cost per Volume} = C_0 + C_1 (19.3862)^{1/3} + C_2 (7.0331)^2$$
$$- C_3 \left\{(1.1956 \times 10^5)^{1/2} / (1.5080 \times 10^5)^{1/3}\right\} + (C_4 \times 9)$$
$$- (C_5 \times 0) - (C_6 \times 3)$$

Cost per volume = 12.4609 Rs/mm3   (Values of C_0 to C_6 are as mentioned in Appendix)

Hence,

Basic mould cost (Rs.) = Cost per Volume (Rs. / mm^3) x Volume of component

x No. of cavities

$$= 12.4609 \times (1.5080 \times 10^5) \times 1$$

$$= 1879103.72$$

Basic mould cost ≈ 18, 79,104 Rs.

E] Design Cost:

Design cost is calculated as percentage of other cost using equation (6.3) mentioned in Chapter Six. The calculation for design cost is mentioned below.

Design cost = 0.2 x (Mould Base cost + Mould insert raw material & Heat-treatment cost

+ cost of standard elements + Basic mould cost)

$$= 0.2 \times (3, 57,475 + 75,470 + 4, 88,800 + 18, 79,104)$$

$$= 560169.8$$

Design cost ≈ 5, 60,170 Rs.

Therefore estimated cost of mould,

Estimated mould cost = Mould Base cost + Mould insert raw material & treatment cost +

cost of standard elements + Basic mould cost + Design cost

$$= 3, 57,475 + 75,470 + 4, 88,800 + 18, 79,104 + 5, 60,170$$

Estimated mould cost = 33,61,019 Rs.

This estimated cost doesn't include overheads. Overheads are to be added over this estimated cost as per norms of tools rooms.

As this mould is manufactured recently by tool room under study for the development of cost model data regarding actual cost incurred is collected. The actual cost incurred for making this mould is Rs. 36,41,744.

Following table shows summary of the results:

Cost	Value in Rs.
A) Mould base cost	3,57,475
B) Mould insert raw material & treatment cost	75,470
C) Standard elements cost	4,88,800
D) Basic mould cost	18,79,104
E) Design cost	5,60,170
Estimated mould cost (A+B+C+D+E)	**33,61,019**
Actual mould cost	**36,41,744**

Therefore we can calculate error in cost estimation as follows: -

$$\text{Estimation error} = \frac{\text{Estimated cost} - \text{Actual cost}}{\text{Actual cost}}$$

$$\text{Estimation error} = \frac{33,61,019 - 36,41,744}{36,41,744}$$

$$\text{Estimation error} = -7.7\%$$

The estimation error is – 7.7%, which is OK. This fulfils one of the objectives of project to get cost estimation within 10% error.

Chapter 8

Conclusion

Cost estimation of injection moulds and pressure die-casting dies is important for product costing and decision making. Higher estimates may lead in loosing orders while lower estimation will affect profitability. Hence accurate cost estimation needs to be done. At present it is time consuming and needs expertise in mould making. Availability of such experts in tool rooms is becoming difficult. Hence need is felt to develop a method which can give quick estimation and can be used by less experienced engineer having basic knowledge of injection moulds and pressure die-casting die design.

8.1 Summary of Work Done

The main objective of this project was to develop cost model which will give accurate estimated cost of injection moulds and pressure die-casting dies in less time and by user who has basic knowledge of die design. To achieve this objective mould cost is divided into five elements and individual element cost is estimated as mentioned below:

- From component size and mould specifications, mould base size is derived using decision tables. The regression analysis is done to get mould base cost using mould volume.

- From component size and mould specifications mould insert size and weight is derived using decision table. By using per kg rates, the cost of mould insert raw material and heat-treatment is estimated. Cost of required surface treatment is considered here.

- Cost of standard elements is estimated by using consolidated data of purchased elements.

- Basic mould cost is estimated by using regression equation which gives cost per volume. The geometric data of component like volume, Surface area, nominal thickness along with mould specifications like no. of cavities, parting line type is used to get cost per volume

- Design cost is calculated as percentage of sum of other four cost elements.

The estimated cost is addition of these entire five cost element. The cost model developed is validated for recently manufactured mould. The inputs required for the cost model are taken from CAD model and mould or die specification sheet, which doesn't call for expertise in mould or die making. It is observed that the cost model developed gives quick and accurate estimates without involving experts in die making.

8.2 Limitations and Future Scope

The cost model developed here has following limitations:
- This cost model developed is dependent on kind of product tool room is handling. The regression equation will change if it to be used for other tool room. But any other tool rooms can use the approach adopted here.
- As this cost model uses data from 3D model, in case of unavailability of same it will be difficult to get details like volume and surface area of component. Hence cost estimation for components having only drawing will require additional efforts of finding out volume and surface area.

Future work can be done in following areas to make estimated cost more accurate and useful:
- The design cost is considered here as fixed percentage of total cost. This may not be true for multi-cavity moulds. It is possible to derive equation to find out exact percentage by using parameters like no. of cavities, no of sidecores etc.
- Cost estimator need to get data about volume, surface area etc. using 3D software and then use the same for estimation. It may be possible to develop software, which will read the inputs required for this cost model. With minimum inputs like no. of cavity, gate position and component orientation the software will be in position to give estimated cost of injection mould or pressure die-casting die.

APPENDIX

This appendix consist the data used for regression analysis to derive basic mould cost. It consist component 3D views with overall sizes, volume, surface area, nominal thickness and details of Table 5.1 to Table 5.3 with correlation factors in equation 5.2.

Being confidential, this data is available with Prof. B. Ravi, Mechanical Engineering Department.

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