Chapter 6

Computer-Aided System for Multi-Cavity Die-Casting Die-Design

Previous chapters in this thesis discuss development of three systems for computer-aided design of important activities of the multi-cavity die-casting die-design. These three systems are: (i) cavity layout design of a multi-cavity die-casting die (ii) core, cavity and side-core design, and (iii) gating system design for a multi-cavity die-casting die. These systems perform important activities for a die-casting die-design. Although the three developed systems and their modules are independent of each other, yet the information generated by one system is useful for the other. For example, the information about design of cavity layout is used for generating the super-core and super-cavity of a multi-cavity die.

One of the objectives of this thesis is to integrate different activities of the multi-cavity die-casting die-design to fully exploit the potential of an integrated system. Benefits of such an integrated system include seamless flow of data from one step to another, fewer design iterations, lower lead time, and lesser development cost.

In this chapter an integrated computer-aided system for multi-cavity die-casting die-design is presented. The system named Multi Cavity Die Designer integrates three systems, namely (i) cavity layout design of a multi-cavity die-casting die (ii) core, cavity and side-core design, and (iii) gating system design for a multi-cavity die-casting die. Multi Cavity Die Designer system that has been presented in this chapter handles major activities of the multi-cavity die-casting design in a computer-aided environment,
namely cavity design, cavity layout design, core, cavity design and side-core design, and gating system design.

However, the design of cooling and ejection systems, which are also important activities in a die-casting die design, have not been dealt in the proposed system.

Rest of the chapter is divided into the following sections. Section 6.1 discusses architecture of Multi Cavity Die Designer. Section 6.2 discusses modules and graphic user interface (GUI) of the proposed system. Section 6.3 discusses two case studies taken from the industry. Section 6.4 presents a discussion on the integrated system presented in this chapter. Lastly, Section 6.5 discusses conclusions drawn from the research work presented in this chapter.

6.1 Architecture of Multi Cavity Die Designer

The system architecture of Multi Cavity Die Designer is shown in Figure 6.1. The system is developed as an add-on application of SolidWorks software [13] by using its API functions [81]. The integration of the developed system with SolidWorks and the information required for extraction have been discussed in the Appendix-IV. Advantages of developing a system that uses the platform of a commercial CAD modeler like SolidWorks is that the native file of the part model can be used as input, and the output, which is again in the native file format may directly be utilized for further downstream applications, such as die manufacturing and inspection.

The developed system has five modules, namely data initialization, cavity design, cavity layout design, core, cavity design and gating system design. Each module is divided into sub-modules which perform different activities of the die-casting die-design. Furthermore, the proposed system is supported by various databases, such as die-casting machines, die-casting alloys, and standard die-bases. The system makes use

149
of the die-design knowledge at various stages that has been acquired from reliable sources including the die-casting industry and published literature. Figure 6.1 shows the architecture of the developed system. Following paragraphs briefly discuss modules of the developed system whereas their detailed description is provided in Section 6.2.

- **Data initialization** module is used to upload the part CAD model to the system and to extract part details from it.

- **Cavity design** module is responsible for applying shrinkage and draft allowances to the die-cast part CAD model.

- **Cavity layout design** module determines optimal but feasible number of cavities. It uses die-design knowledge for placing the cavities in the die-base after taking into account the die-casting part design and manufacturing resource considerations.

- **Core, cavity and side-core design** module generates core and cavity block with side-cores for a multi-cavity die-casting die.

- **Gating system design** module determines parameters of important elements of the gating system for a multi-cavity die-casting die. Subsequently, it uses the parameters to generate CAD model of the complete gating system for a multi-cavity die.

### 6.2 Modules of Multi Cavity Die Designer

As discussed previously the computer-aided system for multi-cavity die-casting die-design, which has been named *Multi Cavity Die Designer* consists of five major modules. Following paragraphs discuss the modules of the developed system.

First module, namely *data initialization* deals with loading of the part model and input of the process data. The CAD model of the part is first taken as input using graphic user interface (GUI) of the system. A snapshot of the GUI of the system is
given in Figure 6.2. The user needs to set the co-ordinate system to orient the part model in such a way that the parting direction of the part is along the Y/-Y axis. The feature information of the part geometry such as volume, length, width and height are extracted by the system for downstream activities.

Fig. 6.1: System architecture of Multi Cavity Die Designer
The geometrical information of the part, such as projected area, wall thickness, and longest part depth is the only information to be provided by the user. Thereafter, as shown in Figure 6.3, the process data window prompts the user to input the information.
related to lot size, delivery date, material, die cost and number of undercuts and their position.

The *Cavity Design* module is responsible for applying shrinkage and draft allowances to CAD model of the die-cast part. The shrinkage allowance depends upon the material of the die-cast part. The draft allowance also depends on many factors related to the part material and its geometry. *Multi Cavity Die Designer* maintains a material database which along-with the die-casting process information is used for selecting appropriate shrinkage and draft allowances. The user has an option, either to accept values of the shrinkage and draft allowances suggested by the system or to provide other values of the allowances to suit the requirements. The selected values of the shrinkage and draft allowances are applied to CAD model of the die-cast part. The *cavity design* module is discussed in detail in Chapter 3 of the thesis.

The *Cavity Layout Design* module determines the number of cavities, selects the feeding system, decides layout pattern of the cavities, selects the die-base and orients & places the cavities. The number of cavities is determined by considering comprehensive factors of delivery date, production cost, selected machine and part geometrical limitations. The feeding system and layout pattern is then selected using die-casting die-design knowledge. Lastly, the cavities are oriented and placed by considering different factors, such as undercut position and recommended clearances. The nearest standard die-base size available in the database is selected taking into account the layout of the cavities. Output from this module is CAD model of the containing box enclosing all the cavities with applicable clearances. The details of the cavity layout design has already been presented in Chapter 3 of the thesis.
The *Core, cavity and Side-Core Design* module is responsible for computer-aided design of core, cavity and side-cores for a multi-cavity die. First of all, the parting line is identified interactively by the user by selecting the edges on the part CAD model. This is followed by creation of shut-off surfaces by the user in case the part model has through holes. The system generates the parting surface by extruding the parting lines. CAD models of core and cavity even for a multi-cavity die can be generated in this module. Similarly, if the part has undercut features, the side-cores are also generated by the system. The details of the core, cavity and side-core design has already been discussed in Chapter 4 of the thesis.

The *Gating System Design* module is responsible for determination of gating system parameters, generation of CAD model of the gating system elements, and placement of these elements in the die. The design guidelines for various gating system elements, such as gate, runner, overflow and biscuit are available for designer’s ready reference. Lastly, the gating system design is evaluated for the desired level of performance by filling simulation to ensure complete filling of the cavity in the stipulated time. The details of the gating system design has already been provided in Chapter 5 of the thesis.
6.3 Industrial Case Studies

*Multi Cavity Die Designer* system is tested on a number of die-cast parts including those having undercut features. To demonstrate the capabilities of the developed system, results obtained from the system for two industrial die-cast parts are presented in the following case studies.

6.3.1 Case study 1: Carburetor lower-half

The die-cast part taken in this case study is an automotive part shown in Figure 6.4, which is lower half of the carburettor. The characteristics of this part are: aluminium alloy material, one undercut feature, and envelope size of 70.5 mm x 58 mm x 42 mm (Length x Breadth x Height).

Fig. 6.4: Carburetor lower-half (a) Solid model (b) Wireframe model
Fig. 6.5: The cavity layout design for the carburetor lower-half

Fig. 6.6: Multi-cavity core and cavity along-with side-cores for the carburetor lower-half
Results generated by *Multi Cavity Die Designer* for this case study are presented in Figure 6.5. The system generates a cavity layout arrangement in which undercuts are on outer side of the die. The number of cavities determined by the system for this case study is three and the layout pattern is half-circular with bottom feeding system. Size of the die base calculated by the system is 484.5 mm x 455.5 mm x 122 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system is 496 mm x 496 mm x 150 mm. CAD models of super-core, super-cavity and side-cores generated by the system in this case are presented in Figure 6.6 in an exploded view.

Figure 6.7 shows a snapshot of the graphic user interface (GUI) of the proposed system in *SolidWorks* platform. The system first performs the P-Q² check, which is shown at the bottom of the gating design parameter window. The part application type is selected as *Engineering*; gate type is *Fan* and runner type is *Trapezoidal* with flow angle of 45°. The determined filling time is 0.027 sec, gate area is 21.6 mm² and gate height is 1.2 mm respectively, which are well within the industry recommended range. The runner parameters determined by the system are also within the recommended range. The industry recommended range for each of the gating parameters is also displayed for ready reference of the user. CAD model of the gating system generated by the system is presented in Figure 6.8.

Opinion of the die-casting experts was taken on the system generated gating system design. The experts gave positive feedback on the gating system design, although cosmetic changes were required.
Fig. 6.7: A snapshot of the GUI of the gating system design

Fig. 6.8: Generated CAD model of the gating system for the carburetor lower-half

Furthermore, to validate the gating system design, metal filling simulation using a die-casting process simulation software was conducted. The filling pattern results for the case study part at 4 time intervals (out of the available 245) during filling are shown
in Figure 6.9. Simulation results of the filling and solidification were found to be satisfactory. Based on the filling pattern also, the die-casting experts gave positive feedback on the success of the gating system design generated by the system.
6.3.2 Case study 2: Fuel pump cover

The die-cast part taken in this case study is an automotive part named fuel pump cover, which is shown in Figure 6.10. The characteristics of this part are: aluminium alloy material, two undercut features in the selected parting direction and envelope size of 83.72 mm x 72.5 mm x 29 mm (Length x Breadth x Height).
This part has two undercuts, which are shown as undercut “1” and undercut “2” in the Figure 6.10; undercut “2” is positioned at an angle of 125° with respect to undercut “1”. Side-core mechanism for undercut “1” can be arranged along one side of the die-base plate, but for undercut “2” the side-core mechanism can’t be arranged along the other side of a rectangle shaped die-base plate; rectangular shaped die-bases are generally used in the industry. In such cases two solutions are possible: (i) to cut a part-shaped die-base plate as per requirement of the side-core mechanism for undercut “2”, and (ii) to perform machining of the die-cast part after it is ejected from the die. The interaction with the industry experts revealed that the solution (i) is not preferred in the industry due to higher cost and lower acceptance of a non-rectangular die-base. Therefore, undercut “2” is removed from the die-cast part CAD model and would be created by machining after on the solidified die-cast part.
Fig. 6.11: The cavity layout design for fuel pump cover

Fig. 6.12: Multi-cavity core and cavity along-with side-cores for fuel pump cover
Results generated by *Multi Cavity Die Designer* for the case study are presented in Figure 6.11. The number of cavities determined by the system for the fuel pump cover case study is four and the layout pattern is series with bottom feeding system. Size of the die base calculated by the system is 514 mm x 392.44 mm x 109 mm. The die layout generated in this case study is also satisfying the condition of minimum die-base size requirements. The standard die-base size selected by the system is 546 mm x 546 mm x 150 mm. CAD models of super-core, super-cavity and side-cores generated by the system in this case are presented in Figure 6.12 in an exploded view.

Figure 6.13 shows a snapshot of the graphic user interface (GUI) of the proposed system in *SolidWorks* platform. The system first performs the P-Q^2_ check, which is shown at the bottom of the gating design parameter window. The part application type is selected as *Engineering*; gate type is *Fan* and runner type is *Trapezoidal* with flow angle of 45°. The determined filling time is 0.035 sec, gate area and gate height are 27.72 mm^2 and 1.2 mm respectively, which are well within the NADCA recommended range. The runner parameters determined by the system are also within the recommended range. The NADCA recommended range for each of the gating parameters is also displayed for ready reference of the user. Final CAD model of the gating system is presented in Figure 6.14.

Opinion of the die-casting experts was taken on the system generated gating system design for the fuel pump cover case study. The experts gave positive feedback on the gating system design, although cosmetic changes were required. One of the suggested changes is to place overflow wells along three sides of part model to avoid formation of cold-shuts and removal of entrapped air.
To validate the gating system design metal filling simulation using die-casting process simulation software was conducted. The filling pattern results for the case study
part at 4 time intervals (out of the available 420) during filling are shown in Figure 6.15. Simulation results of the filling and solidification were found to be satisfactory. To verify the design of the gating system, opinion of die-casting experts was also taken on the filling pattern. Based on the filling pattern also, the die-casting experts gave positive feedback on the success of the gating system design generated by the system.
Fig. 6.15: Snapshots of filling pattern of cavities at different time steps (a) at 0.604s (b) at 0.610s (c) at 0.621s (d) at 0.640s

It is worth mentioning that in both the case study parts discussed above, the number of cavities determined by the system is sufficient to meet the delivery time. Although more number of cavities could have been geometrically possible for the case study parts, same is not explored by the system to make proper use of manufacturing resources, namely the die casting machines.
6.4. Discussion

Industrial case studies discussed in this chapter demonstrate the capabilities of the system in an industrial scenario. The systems developed as a part of this thesis and discussed in Chapter 3 to Chapter 6 would definitely give an edge to the die-casting industry. Normal practice in the die-casting industry is to do various die-design tasks manually that requires lot of involvement of the die-casting experts. There are a number of rules, which are based on industry best practices or guided by the prevailing physics of the process that need to be followed for designing a die. What makes the process even more cumbersome is the availability of different alloys for the die-cast parts, wide range of machines and other parameters, such as the number of cavities in a die.

Another issue worth discussing is the availability of alternative solutions for die-design. Although the proposed system applies best practices and scientific rules used by the die-casting industry, their actual implementation may vary due to personal opinion or preferences of a die-casting expert. Therefore in addition to providing die-design solutions based on the acquired knowledge-base, the proposed system is provided with enough flexibility for the user to choose his/her preferences. This aspect of the proposed system makes it highly acceptable to the industry.

Development of the proposed system on the platform of existing CAD software also makes it more acceptable in the industry. This aspect of the developed system makes CAD models of the die components generated by the system directly acceptable to the computer-aided manufacturing (CAM) systems that use the same CAD platform.

The developed systems when combined with automated parting direction and parting line determination [24, 96-99] can increase its capability manifold, bridging the existing gaps in design-manufacturing integration of the die-casting process.
6.5 Conclusions

A computer-aided system named *Multi Cavity Die Designer* for multi-cavity die-casting die-design has been presented. The presented system is developed as an add-on application of *SolidWorks* software. The API toolkit of *SolidWorks* along-with VB.NET programming is used to develop this system. Sample code of the developed system is given in *Appendix-III*. Proposed system is an effort to integrate die-casting die-design application into existing CAD software. Use of databases of alloy, machine, clearances and standard die-bases, along-with die-casting die-design rules makes this system least dependent on the die-design expert; the system alongside reduces lead time for producing a die-cast part.

The developed system uses CAD model of the die-cast part in *SolidWorks* native file format and performs following activities:

(i) Determine shrinkage and draft allowances, and apply the same to the part CAD model.

(ii) Determine cavity number and layout pattern of the cavities in a semi-automated manner taking little information from user.

(iii) Determine the minimum size of the die-base plate that can accommodate all the cavities with usual clearances. It selects the nearest available standard size die-base size.

(iv) Generate core, cavity and side-core for a multi-cavity die.

(v) Determine parameters of different elements of the gating system and generate their CAD models.

To demonstrate the capabilities and effectiveness of the integrated system in an industrial environment, results for two typical parts taken from the die-casting industry
were presented and discussed. The case study parts have been selected from the die-casting manufacturing industry and keeping in view their geometrical complexity, and variations in size and shape.

To validate design of the die, metal filling simulation were carried out using die-casting process simulation software. Opinion of the die-casting experts on the system generated results and filling pattern was also taken. Based on the simulation results and their experiences, the experts opined that the system generated die-design is satisfactory, although it required cosmetic changes.

The developed system is a major step towards automated design of a multi-cavity die-casting die. Major benefits of using the developed system for design of a multi-cavity die is significant time saving, less dependency on the die-casting expert and consistency in decision making. With the development of the proposed system design-manufacturing integration of the die-casting process seems achievable as automated design of a die is a bridge that needs to be built.