Int J Adv Manuf Technol (2003) 22: 387–395
DOI 10.1007/s00170-002-1514-9

ORIGINAL ARTICLE

W. M. Chan · L. Yan · W. Xiang · B. T. Cheok

A 3D CAD knowledge-based assisted injection mould design system

Received: 5 June 2002 / Accepted: 23 August 2002 / Published online: 29 May 2003

Abstract This paper presents the basic structure of an interactive knowledge-based injection mould design system (IKB-MOULD). The basis of this system arises from an analysis of the injection mould design process for mould design companies. This injection mould design system covers both the mould design process and mould knowledge management. IKB-MOULD integrates the intelligent design process and knowledge management with many developed interactive tools in a commercial solid modelling software environment.

Keywords Injection mould design · Knowledge base · Injection mould object representation

1 Introduction

In recent years the plastic product manufacturing industry has been growing rapidly. A very popular moulding process for making plastic parts is injection moulding. The injection mould design is critically important to product quality and efficient product processing. Mould-making companies, who wish to maintain the competitive edge, desire to shorten both design and manufacturing leading times by automating the design process. Thus, the development of a computer-aided injection mould design system (CAIMDS) is becoming a focus of research in both industry and academia.

Recently published papers show that research in automatic mould design focuses on individual components of the mould process. For example Ong et al. [1] and Ravi [2] focused their research on the feeding system. Wang et al. [3] focused their research on the ejection system. Others focus their research on the general design. Most research done on the general injection mould system can be classified into two areas: (a) functional, conceptual and initial mould designs; and (b) algorithms to automate mould generation.

Functional, conceptual and initial designs of the injection mould are applied mainly to the pre-mould design. Such design involves selecting a suitable mould base, arranging the cavity layout, designing the runner and designing the gate. The objective is to come up with a large number of very different product ideas for a certain requirement. Britton et al. [4] addressed injection mould design from a functional perspective by presenting the Function-Environment-Behaviour-Structure (FEBS) model. The study fostered a wide range of design alternatives. Costa and Young [5] proposed a product range model (PRM) to support the reuse of design information in variant design cases. The general structure of a PRM is defined in terms of design functions linked with sets of design solutions, interactions between potential solutions and knowledge links. Ye et al. [6] presented an approach to automatic initial design with algorithms that calculate the cavity number and automatically lay out the cavity. The initial injection mould design involves extensive empirical knowledge of the structure and functions of the mould components. Thus, a lot of researchers adopt a knowledge-based approach. Several knowledge-based systems (KBSs) were developed to advise plastic material selection, capture injection mould part design features, analyse mouldability, automate the mould design process and develop mould design for manufacture. Examples of such systems are GERES (Nielsen [7]), PLASSEX (Agrawal and Vasudevan [8]), EIMPPLAN-1 (Chin and Wong [9]), CADFEED (Ong et al. [10]), ICAD (Cinquegrana [11]), IKMOULD (Mok et al. [12]) and KBS of Drexel University (Tseng et al. [13]). However, these KBSs consider only certain aspects of the total design.

As for the automatic generation of an injection mould, a number of theoretical research works were

W. M. Chan (✉) · L. Yan · W. Xiang · B. T. Cheok
Institute of High Performance Computing, 1 Science Park Road, #01-01 The Capricorn, Singapore Science Park II, 117528, Singapore
E-mail: chanwm@ihpc.a-star.edu.sg
Tel.: +65-6-4191111
Fax: +65-6-4191280

conducted to automatically determine the parting direction, to determine the parting line, to generate the parting surface, to recognise undercut features and to generate the core/cavity. Ravi and Srinivasan [14] presented nine rules that can be used by the mould design engineer to develop a suitable parting line in the product. These rules are projected area, flatness, draw, draft, undercuts, dimensional stability, flash, machined surfaces and directional solidification. Hui and Tan [15] proposed the sweep method to form the cavity and core. The cavity and core are generated in a number of steps. Sweeping the mould part in the draw direction generates a solid. One end of the swept solid is subtracted from the first mould block. The other end of the mould block is subtracted from the mould part. The results of the above steps are subtracted with the part at the closed position to obtain the cavity and core. Shin and Lee [16] proposed a method of core and cavity development so that the side cores and corresponding core and cavity plates can be generated. This method is composed of 3 steps. The designer determines the parting line that separates the product into 2 groups of faces. Each group face has the parting surface attached to it. Then external faces are added to each group face. Shin added that a mould could be made up of many pieces in addition to the cavity, core and side cores. Hui [17] studied the mouldability of an injection mould based on an external and internal undercut analysis only for polyhedral solids. A blockage concept is presented to determine the main parting direction and a subdivision technique is developed to evaluate the geometry of an undercut. Chen et al. [18] introduced the concept of visibility maps (V-maps) of the pockets to determine the parting direction. The method did not take into account internal undercuts. Fu et al. [19] and Nee et al. [20] gave a new classification of undercuts according to the external loops and the internal loops of a moulded part. The parting direction is then determined based on the proposed parting direction criteria considering the directions, location, number and volumes of undercut features. Fu et al. [21] proposed an approach to generate the parting surface by extruding the parting line edges and create the core/cavity block using the Boolean regularised difference operation (BRDO). A methodology that generates non-planar parting lines and surfaces is presented by Nee et al. [22]. Wong et al. [23] proposed a method to determine the cutting plane of a complex shaped product. Their method uses an algorithm that slices the product. The parting line and surfaces formed by this method are planar.

Current research on automatic mould design is ongoing. However, some methods can be quite theoretical and the mould design can have a complicated product geometry. Most mould development activities involve a high level of skill, a wide variety of design expertise and knowledge. Due to the fact that automatic mould development is still far beyond the current technology, it is more reasonable to provide intelligent rules or guidelines that prevent the design from conflicting with design constraints. These rules also provide interactive tools in the detailed mould design environment. This paper presents an interactive knowledge-based injection mould design system (IKB-MOULD). This system integrates the initial mould design and detailed mould design with both knowledge base and interactive commercial CAD/CAM software.

The next section of this paper outlines an analysis of the injection mould design process based on the mould designer's point of view. A later section introduces the basic structure of our IKB-MOULD for injection mould design. A case study of the injection mould design for a plastic product in IKB-MOULD is then presented. The conclusion and future work is located in the last section.

2 The injection mould design process requirement analysis

An injection mould design is composed of two steps: the initial design and the detailed design. The initial design is composed of decisions made at the early stage of the mould design, such as the type of mould configuration, the number of cavities, the type of runner, the type of gate and the type of mould base. The detailed design is composed of the insert (core/cavity) design, the ejection system design, the cooling and venting component design, the assembly analysis and the final drafting.

To develop a good CAIMDS, an analysis of 'what they have' and 'what they want' needs to be performed.

What they have:

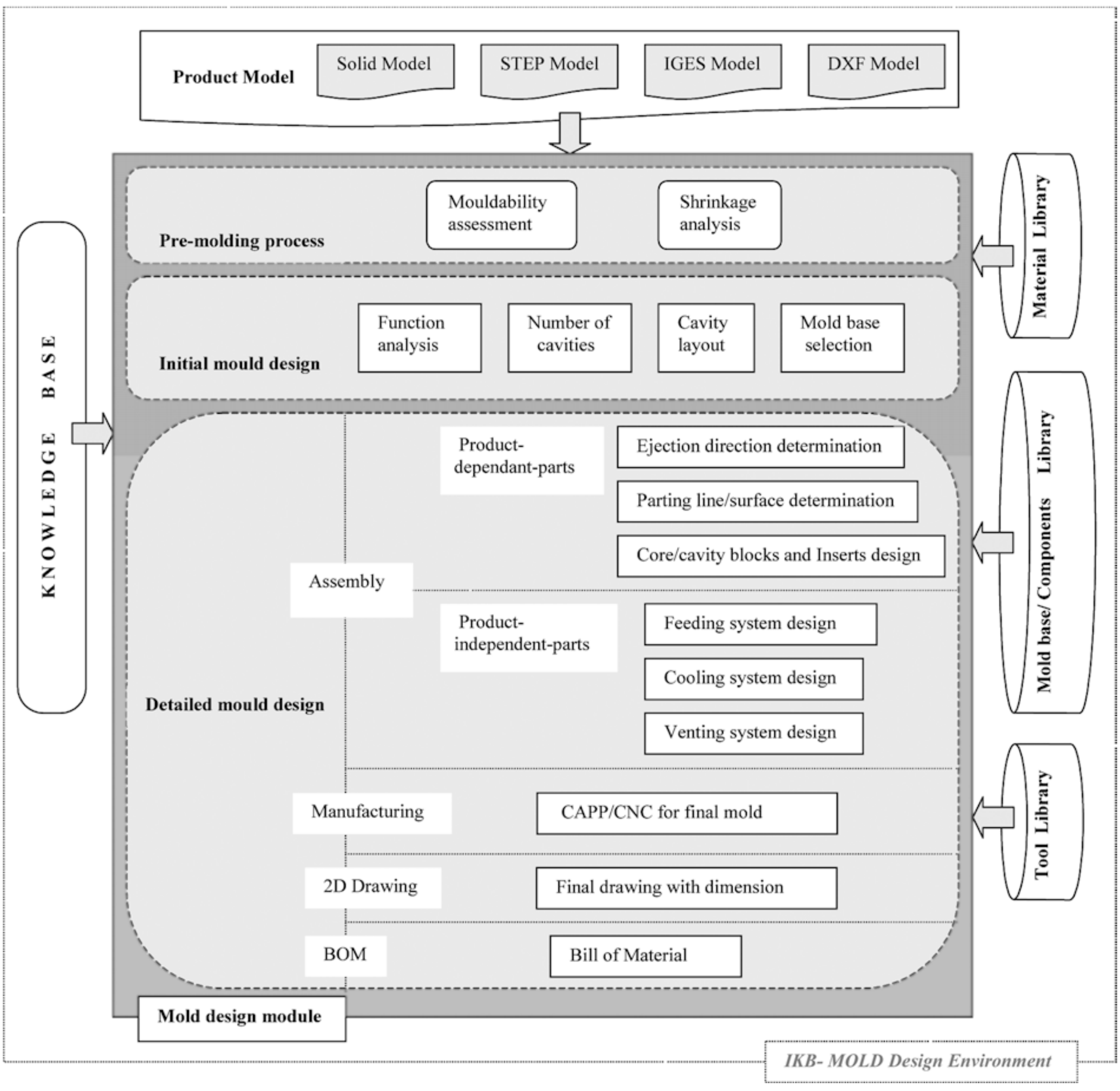
- The customer's requirements for the product. This includes the detailed geometry and dimension requirements of the product.
- An existing mould design library. This library covers the standard or previously designed components and assemblies of the mould design, for example, the mould base (the fixed half and the moving half) and the pocket (the fixed half and the moving half).
- An expert knowledge in injection mould design. Expert knowledge of both initial and detailed designs for the injection mould is obtained mainly from experienced mould designers. Such knowledge includes material selection, shrinkage suggestion, cavity layout suggestion and others.

What they want:

- An intelligent and interactive mould design environment. Mould design is often composed of a series of design procedures. These procedures usually require certain mould parts to be created and existing mould parts to be assembled. Such a mould design environment need not be fully automatic, especially for complicated products with many undercuts. An intelligent and interactive environment will be a good choice to integrate some useful automation algorithms, heuristic knowledge and on-line interaction by the experienced mould designer.

– Standard/previous designed components/assemblies (product-independent parts) management. Apart from the core and cavity, an injection mould has many other parts that are similar in structure and geometrical shape that can be used in other injection mould designs. These parts are independent of the plastic mould products. They are mostly standard components that can be reused in different mould designs and mould sets.
– Useful tools (including solid design and analysis calculation) in the core and the cavity (product-dependent parts) design. Geometrical shapes and the sizes of the core and cavity system are determined directly by the mould product. All components in such a system are product dependent. Also, these parts are the critical components in the mould design. Their geometrical requirements may be complicated. Thus, some tools developed to design the core and the cavity based on partial automation and partial interaction can be quite useful.
– Design for assembly. In conventional CAD/CAM systems, moulds are represented and stored as a complete geometric and topological solid model. This model is composed of faces, edges and vertices in a three dimensional (3D) Euclidean space. Such a representation is suitable for visual display and performing geometrically computation-intensive tasks such as engineering analysis and simulation. However, this form is not appropriate for tasks that require decision-making based on high-level information about product geometric entities and their relationships. Mould designers prefer a design for assembly environment instead of a simple solid model environment. This idea is also presented in Ye et al.'s work [24].

Fig. 1 The structure of the IKB-MOULD



– A design for manufacture. A complete injection mould design development cycle can be composed of the mould design and mould manufacturing process. To integrate CAD/CAM into the mould design, the manufacturing features on the mould should be abstracted and analysed for the specific NC machine. Both the process plan and the NC code should be automatically generated to enable the final designed mould to be manufactured.
– A design for engineering drawings. For many companies, the injection mould design has to be represented in the form of engineering drawings with detailed dimensions. CAD/CAM tools that are able to automatically generate these engineering drawings from the final injection mould design will be useful.

Based on the above analysis, our research focus is to develop techniques to represent 'what they have' and 'what they want'.

Representing 'what they want' is actually the representation of the knowledge and injection mould object. Developing 'what they want' means to integrate the representation with intelligent and interactive tools for the injection mould design into a completed design environment. Therefore, an IKB-MOULD is proposed for mould designers to realise the above two requirements.

3 The IKB-MOULD

The IKB-MOULD combines the use of knowledge-based and object-oriented tools with commercial solid modelling software to carry out its function. The IKB-MOULD presented in this paper begins with the plastic part to be moulded and finishes with the generation of a completed mould system with relatively detailed drawings.

Mould specification			Preliminary	L X1
			Approved	L 1
To: Manager			From: K. K. Lee	
Product design				
Part	ABA640			
Description	Connector			
Material	Zenite			
Weight	0.00 g			
Mould design				
Mould	ABA640			
Size	470 x 380			
Mould number	BAB540			
Cavity	1	Tonnage : 25		
Circuit	5	Cycle (sec) : 5		
Part				
Flow shrinkage	1.0100			
Cross flow shrinkage	1.0060			
Z-Axis flow shrinkage	1.0400			
Comments				
Prepared / Date	K. K. Lee		6 Jan 2002	
Approved / Date	L. H. Lim		10 Jan 2002	

Fig. 3 The mould specification

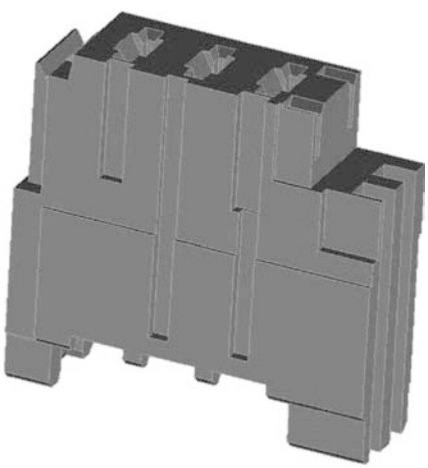


Fig. 2 The plastic product

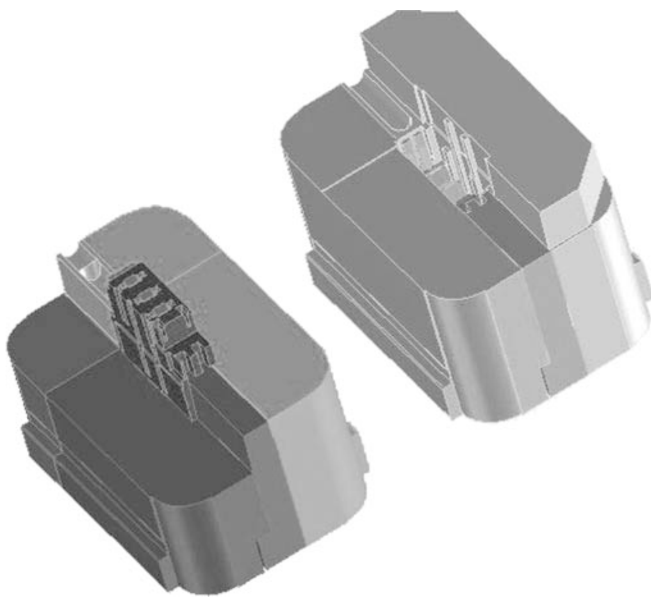


Fig. 4 The designed core and cavity inserts

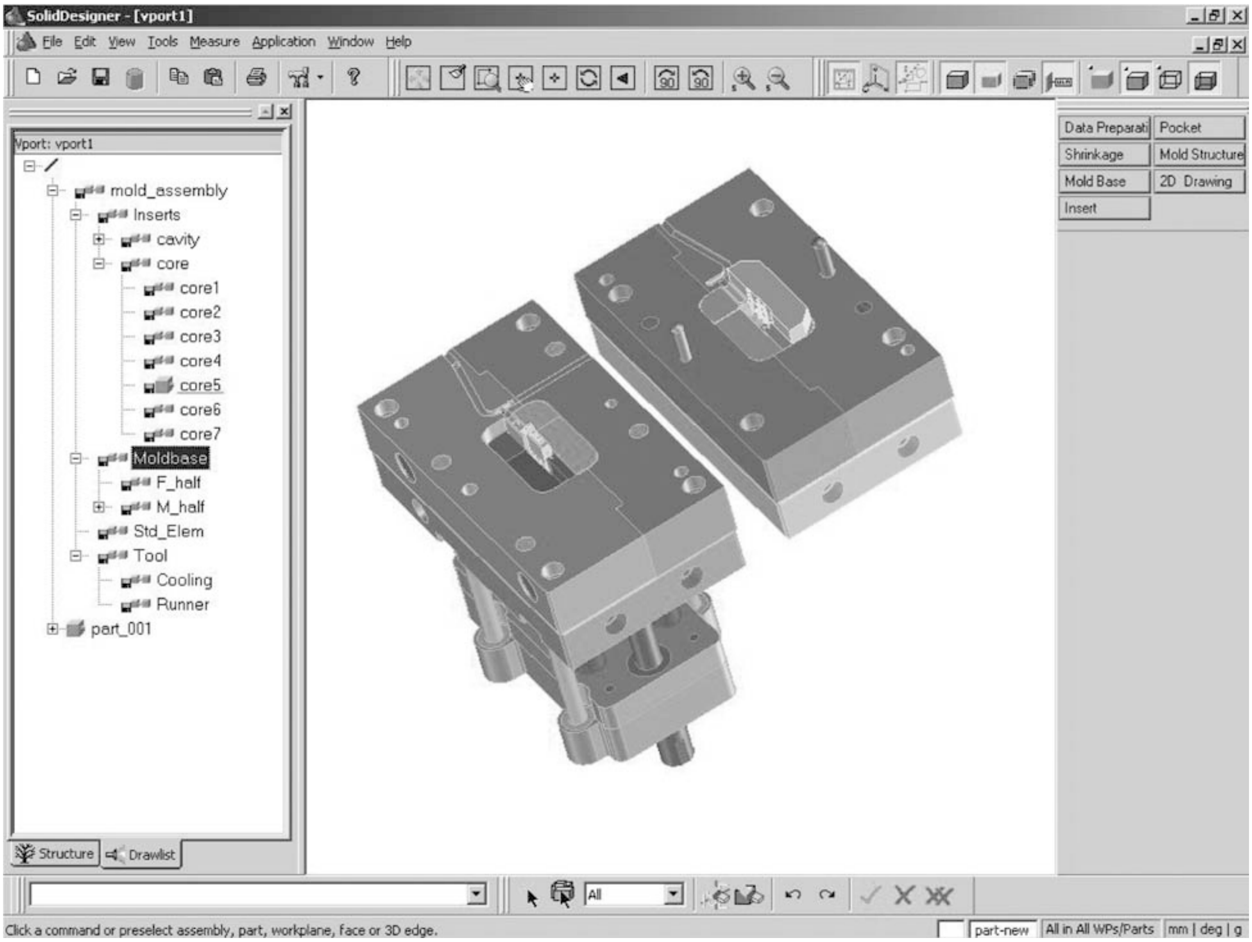


Fig. 5 The IKB-MOULD environment

Figure 1 shows the basic structure of the injection mould design process in the IKB-MOULD. The IKB-MOULD is composed of the following modules: a product model interface, a mould design module, a knowledge base and some other libraries.

3.1 The product model interface

The product model is the input to the IKB-MOULD design process. This model can be a solid, standard engineering interchange, or a surface or wire-frame model. The IKB-MOULD system provides a product model interface to accept a solid model built in different types of solid modelling software. It can directly load the product model built in SolidDesigner. If the product is developed from a CAD system that is other than SolidDesigner, then the product needs to be converted using STEP, IGES or DXF.

3.2 The mould design module

The injection mould design process of the mould design module in IKB-MOULD covers the pre-moulding process, the initial mould design and the detailed mould design.

3.2.1 The pre-mould process

Product mouldability is evaluated in this pre-mould process. Some issues to be considered are material thermal expansion, the plastic flow direction and the product draft angle. The system not only allows experienced mould designers to define the shrinkage of the product model, but also to recommend product shrinkage using the material library. This material library is a material database that stores information about the material's viscosity, temperature sensitivity, and degree of differential shrinkage. Based on the generic type of material used, IKB-MOULD system retrieves the material shrinkage rate from the material library. Once shrinkage is determined, the product model is reconstructed to account for material shrinkage that occurs during the mould operation.

3.2.2 The initial mould design

Mould specification is done in the initial stage of the injection mould design. The requirements of the plastic component are specified at this stage. Decisions made at this stage include a functional analysis, the number of cavities, the cavities layout and the type of mould configuration. The initial design plays an important role in the mould design. Once the initial design stage is completed,

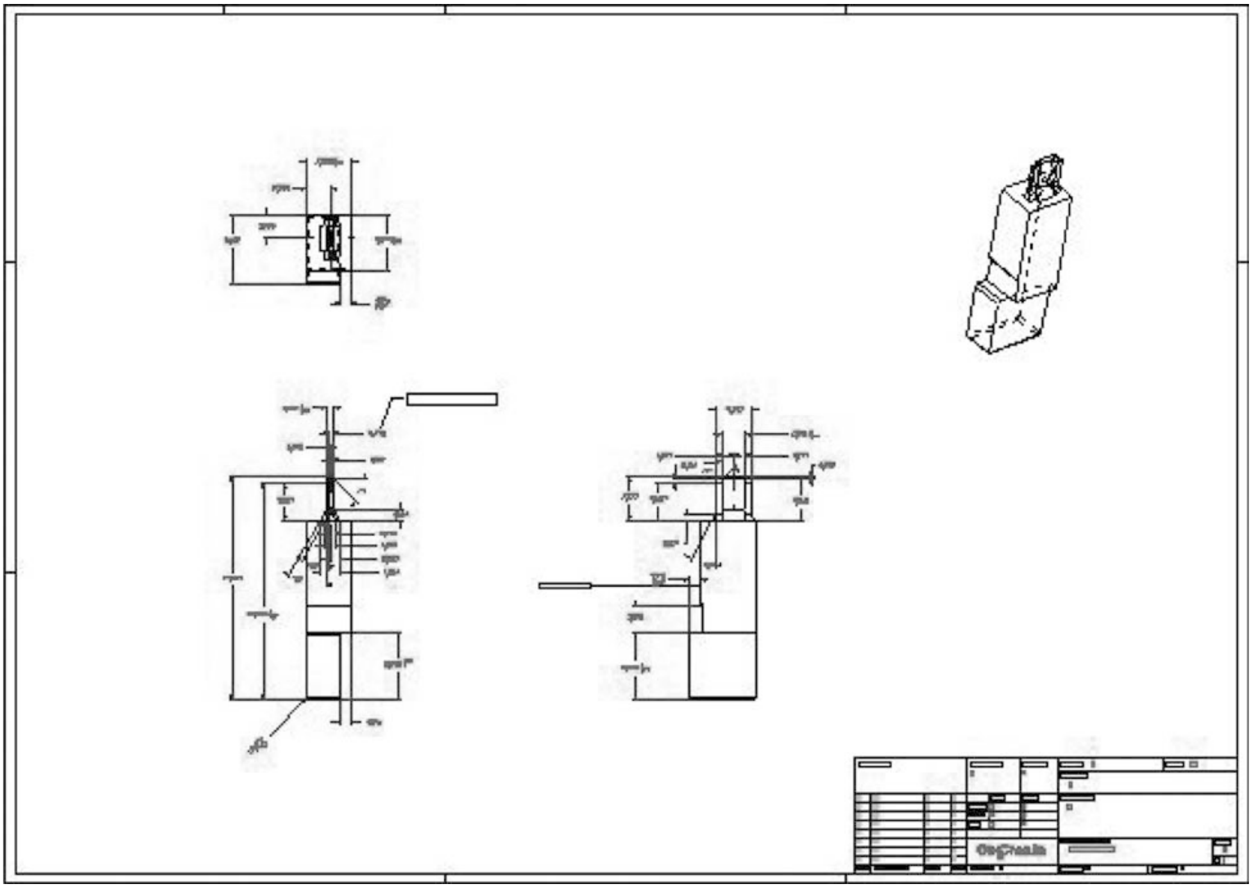


Fig. 6 The insert 2D drawing

the mould structure is determined. Such an initial design is usually the guideline for the mould quotation, the mould base ordering and the detailed mould design.

– The determination of the cavity number. The number of cavities can be determined using an empirical formula that considers different factors. These factors are the period of delivery, the minimum cost, the product precision quality requirement or the machine technical data such as the maximum shot capacity and the clamping force (Menges [25]). Ye et al. [26] determined the cavity number based on a mixed consideration of three factors: machine technical data, minimum cost and delivery date.
  Often mould designers determine the cavity number based on their experience and suggested empirical calculations with consideration to different factors.
– The determination of the cavity layout. The cavity layout of an injection mould usually includes the layout pattern and orientation of each cavity in the mould. The layout pattern depends on the cavity number. A balanced layout pattern is commonly adopted for multiple cavities, such as two-cavity, four-cavity and eight-cavity. Orientation of the cavity affects the position and orientation of the gate system. In other words, cavity orientation and gate location should be balanced.
– The determination of the mould base. The projection area of the cavity layout along the ejection direction can be used to determine the minimum mould base size. The IKB-MOULD has a mould base library that stores many standard mould bases (the fixed half and the moving half).

Design rules and expert knowledge in the initial mould design process are regarded as heuristic knowledge incorporated into the IKB-MOULD. After the initial design, a mould specification can be generated.

3.2.3 *The detailed mould design*

In the detailed mould design, the IKB-MOULD is developed for three different and useful applications for use by the mould design companies: the design for assembly, the design for a 2D drawing and the design for BOM.

(1) The design for assembly. An injection mould is a mechanical assembly that is composed of the product-independent and product-dependent parts. Design of the product-dependent parts is based on the geometry extracted from the plastic product. This extraction can be realised by integrating some automation algorithms and expert knowledge. The design of product-independent parts is based on the designer's experience and catalogue information.

Tasks in the detailed injection mould design may be interrelated with many of the injection mould objects' design elements. Therefore, the final detailed mould design can be regarded as a design composed of the injection mould objects. Representation of an injection mould object and the knowledge used for detailed mould design is explained in a later section. Based on that representation, an assembly tree can be automatically generated and modified during the detail mould design.

(2) The design for manufacture. This module is developed mainly for the CAPP/CNC of the final designed mould. In process planning, the sequence of machining processes to manufacture the designed mould is a complicated task and requires manufacturing knowledge. Manufacturing features needed to be abstracted from the final designed mould and a relative sequenced process has to be generated based on knowledge stored in the knowledge base. In addition, a tool library for the specific NC machine is used to automatically generate the NC code for the manufacturing process. Detailed design of the manufacture module in the IKB-MOULD is not presented in this paper.

(3) The design for the 2D drawing. With the help of an application-programming-interface (API) provided by the commercial solid modelling software, most 2D drawings of parts can be obtained from the solid model. Some intelligent tools need to be developed for generating detailed dimensions.

(4) The design for the bill of material (BOM). Similar to the design for the assembly in the detailed mould design, all properties of the designed injection mould objects can be traced. A tool can be developed to automatically generate the BOM.

3.3 Knowledge base and libraries

3.3.1 Knowledge representation

Knowledge for an injection mould design is gained mainly through experience and handbooks. Each module of the mould design process needs to be supported by the knowledge base. Knowledge involved in the mould development can be represented in terms of design rules: IF (conditions) THEN (design solution).

Some design rules in the IKB-MOULD used to determine the ejector pin size from both the catalogue library and design experience are represented as follows:

$$\begin{aligned} Rule\ 1:\ & IF && ejector\_pin\_type\ is\ Straight\ circular\ type \\ & AND && ejector\_pin\_size = 1.0\,mm \\ & THEN && ejector\_pin\_head\_dia = 3.0\,mm, \\ & && ejector\_pin\_head\_thick = 4.0\,mm \end{aligned}$$

$$\begin{aligned} Rule\ 2:\ & IF && ejector\_pin\_type\ is\ Step\ type \\ & AND && ejector\_pin\_size = 0.4\,mm \\ & THEN && ejector\_pin\_head\_dia = 2.0\,mm, \\ & && ejector\_pin\_head\_thick = 4.0\,mm, \\ & && ejector\_pin\_step\_dia = 0.5\,mm, \\ & && ejector\_pin\_step\_lengh = 20.0\,mm \end{aligned}$$

$$\begin{aligned} Rule\ 3:\ & IF && ejector\_pin\_type\ is\ Rectangular\ type \\ & AND && ejector\_pin\_size = 1.8 \times 3.0\,mm \\ & THEN && ejector\_pin\_head\_dia = 15.0\,mm, \\ & && ejector\_pin\_head\_thick = 4.0\,mm, \\ & && Ejector\_pin\_step\_dia = 10.0\,mm, \\ & && ejector\_pin\_step\_lengh = 20.0\,mm \end{aligned}$$

$$\begin{aligned} Rule\ 4:\ & IF && Mouldbase = TRUE \\ & AND && Core\_insert = TRUE \\ & THEN && Ejector\_pin\_length \\ & && = (z\ co-ordinate\ of\ product \\ & && \quad ejection\ point\ at\ core) - (z\ co\text{-} \\ & && \quad ordinate\ of\ ejector\ back\ plate\ base) \end{aligned}$$

In the IKB-MOULD, knowledge rules are stored in groups that are associated with the design tasks. Many design tasks in the mould design module are shown in Fig. 1. To implement each task, some injection mould objects need to be determined using the knowledge base. Consider, for example, the feeding system design task in the detailed mould design. Some injection mould objects such as runners and gates are to be defined. The detailed runner design has a set of design solutions that can be applied; for example, runner types can be circular or trapezoid.

3.3.2 The library

The IKB-MOULD also has useful libraries that support the injection mould design module. Three types of libraries are the material library, the mouldbase/components library and the tool library. The material library stores the detailed material properties and the shrinkage rates of 38 different materials. The mouldbase/components library stores all standard mouldbases and other components used in the detailed mould design. The tool library is reserved mainly for automatic NC code generation and to store tooling information such as feed rate and speed. All libraries can be expanded to meet the user's requirements.

4 A case study

So far, the detailed mould design modules have been presented in the previous section. In the IKB-MOULD, the implementation of those modules is realised in a

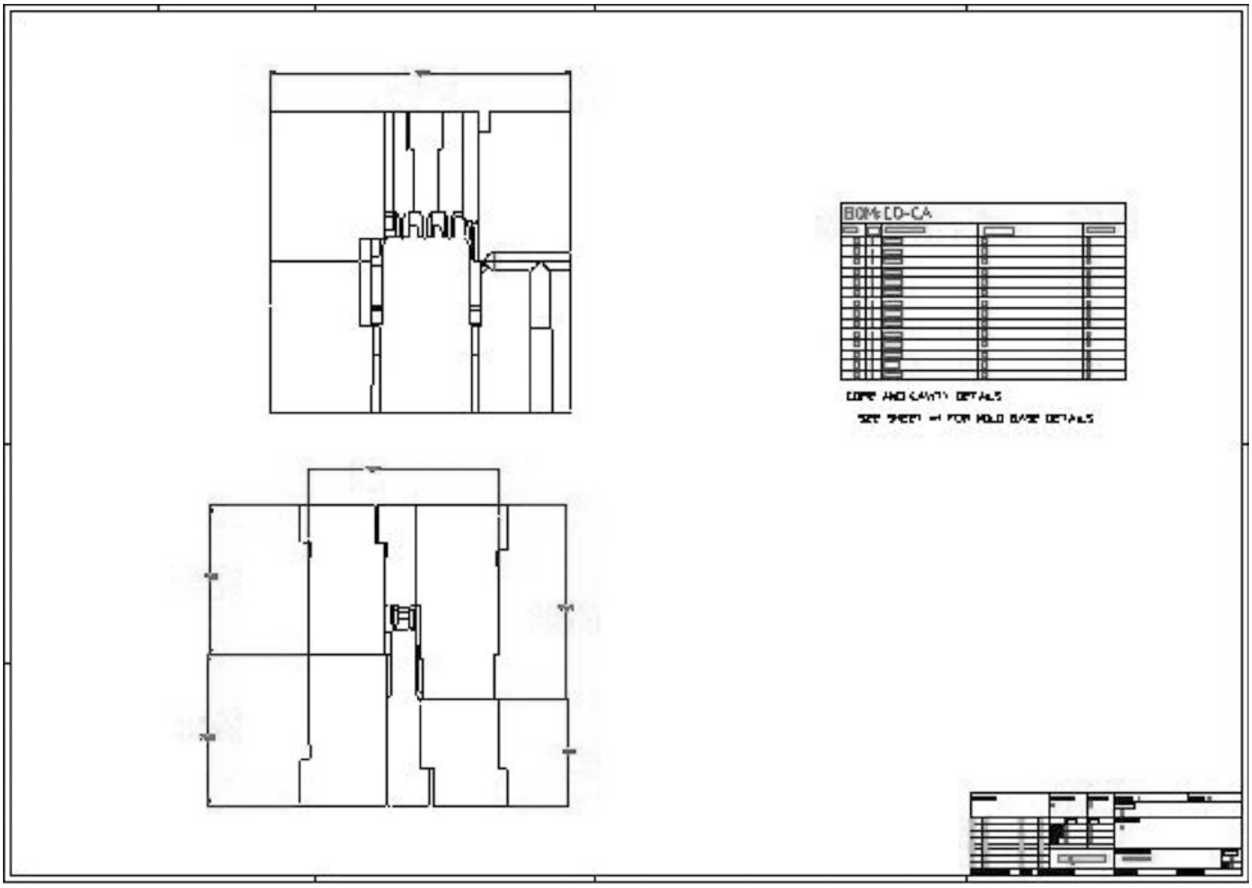


Fig. 7 The assembly 2D drawing

commercial 3D solid modelling environment—SolidDesigner. SolidDesigner provides a user-friendly API. Using this API, an intelligent and interactive design environment for injection mould design is developed. There are many useful menus, tool buttons, dialogues and commands.

Figure 2 shows a plastic product. With the help of the intelligent and interactive tools provided by the IKB-MOULD, an injection mould is designed to mould this plastic product.

Mould specification is done during the initial mould design. Figure 3 shows the mould specification of this product. The material used is Zenite. Using the material library, the relative shrinkage rate in three directions is recommended to reconstruct the product model to account for material shrinkage during the mould operation. Some other mould information, such as the mould base, the number of cavities, the mould size, etc., can be found in the mould specification.

The critical design in an injection mould lies in the core/cavity insert. Due to the complicated structure of the product, there are many inserts in the core and the cavity. Figure 4 shows the designed core and cavity inserts. The designed core inserts with the product are displayed on the left side and the designed cavity inserts are displayed on the right side of Fig. 4.

Figure 5 shows the final designed mould in the entire IKB-MOULD environment. The left window shows the assembly tree of the injection mould design. This assembly tree lists the mould base, inserts (core and cavity inserts), tools (including feeding and cooling systems) and standard elements (including ejector pins). The assembly tree is automatically generated from the injection mould objects' relationship based on the proposed object representation. The entire mould can be viewed in whole or in part by selecting the visibility button of each injection mould object in the assembly tree. The final design injection mould base moving half is displayed in the current IKB-MOULD environment. The middle window in Fig. 5 shows the designed core inserts fitted into the standard moving half of the mould base plate. The designed cavity inserts are fitted into the mould base fixed half. Ongoing work is being performed for the IKB-MOULD to develop many useful tools that generate 2D engineering drawings from the designed injection mould. Figure 6 shows the final 2D drawing of one of the core inserts. Figure 7 shows the assembly 2D drawing of the designed mould with the BOM. All 2D drawings for the injection mould can be automatically generated based on the designed 3D mould in the IKB-MOULD.

5 Conclusions and future work

This paper presents an intelligent and interactive injection mould design system. Based on the analysis of the injection mould design process, the representation of the mould design and the integration of an intelligent and interactive environment have to be solved to provide a better injection mould design system. An IKB-MOULD is developed accordingly. The IKB-MOULD integrates the knowledge representation with many developed tools in a commercial solid modelling software environment. Such software can speed up the injection mould design process and facilitate a design standardisation.

The current version of the IKB-MOULD supports design-for-assembly for the injection mould design. This version only provides the 3D-injection mould design and has some automation to generate 2D drawings. To integrate the CAD/CAM, future work will be focused on design-for-manufacture. In other words, the NC code of the final injection mould design should be automatically generated.

References

1. Ong SK, Prombanpong S, Lee KS (1995). An object-oriented approach to computer-aided design of a plastic injection mould. J Intellig Manufact 6:1–10
2. Ravi B (1997) Intelligent design of gating channels for casting. Mater Sci Technol 13:785–790
3. Wang Z, Lee KS, Fuh JYH et al. (1996) Optimum ejector system design for plastic injection moulds. Int J Comput Appl Technol 9(4):211–218
4. Britton GA, Tor SB, La YC et al. (2001) Modelling functional design information for injection mould design. Int J Prod Res 39(12):2501–2515
5. Costa CA, Young RIM (2001) Product range models supporting design knowledge reuse. In: Proceedings of the IMECHE, Part B: J Engin Manufact 215(3):323–337
6. Ye XG, Lee KS, Fuh JYH et al. (2001) Automatic initial design of injection mould. Int J Mater Prod Technol 16(6–7):592–604
7. Nielsen EH, Dixon JR, Simmons MK (1986) GERES: A knowledge based material selection program for injection molded resins. Comput Engin ASME 1:255–261
8. Agrawal D, Vasudevan PT (1993) PLASSEX: an expert system for plastic selection. Adv Polym Technol 12(4):419–428
9. Chin KS, Wong TN (1996) Knowledge-based evaluation for the conceptual design development of injection moulding parts. Engin Appl Art Intellig 9(4):359–376
10. Ong SK, Prombanpong S, Lee KS (1995) An object-oriented approach to computer-aided design of a plastic injection mould. J Intellig Manufact 6:1–10
11. Cinquegrana DA (1990) Knowledge-based injection mould design automation. Disseration, University of Lowell
12. Mok CK, Chin KS, Ho JKL (2001) An interactive knowledge-based CAD system for mould design in injection moulding processes. Int J Adv Manufact Technol 17(1):27–38
13. Tseng AA, Kaplan JD, Arinze OB et al. (1990) Knowledge-based mold design for injection molding processing. In: Proceedings of the 5th International Symposium on Intelligent Control, Philadelphia, PA, September 1990
14. Ravi B, Srinivasan MN (1990) Decision criteria for computer-aided parting surface design. Comput Aid Des 22:11–18
15. Hui KC, Tan ST (1992) Mould design with sweep operations—a heuristic search approach. Comput Aid Des 24(2):81–91
16. Shin KH, Lee K (1993) Design of side cores of the injection moulds from automatic detection of interference faces. J Des Manufact 3:225–236
17. Hui KC (1997) Geometric aspects of the mouldability of parts. Comput Aid Des 29(3):197–208
18. Chen LL, Chou Sy, Woo TC (1993) Parting directions for mould and die design. Comput Aid Des 25(12):762–768
19. Fu MW, Fuh JYH, Nee AYC (1999) Undercut feature recognition in an injection mould design system. Comput Aid Des 31:777–790
20. Nee AYC, Fu MW, Fuh JYH et al. (1997) Determination of optimal parting direction in plastic injection mould design. Annal CIRP 46(1):429–432
21. Fu MW, Fuh JYH, Nee AYC (2001) Core and cavity generation method in injection mould design. Int J Prod Res 39(1):121–138
22. Nee AYC, Fu MW, Fuh JYH et al. (1998) Automatic determination of 3-D parting lines and surfaces in plastic injection mould design. Annal CIRP 47(1):95–98
23. Wong T, Tan ST, Sze WS (1998) Parting line formation by slicing a 3D model. Engin Comput 14:330–343
24. Ye XG, Fuh JY, Lee KS (2000) Automated assembly modelling for plastic injection moulds. Int J Adv Manufact Technol 16(10):739–747
25. Menges G (1986) How to make injection moulds. Hanser, Leipzig
26. Ye XG, Lee KS, Fuh JYH et al. (2001), Automatic initial design of injection mould. Int J Mater Prod Technol 16(6–7):592–604