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Original Article

An interactive web-based design system for rubber injection mold: Automotive rubber parts

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Abstract

This research aims at integrating a knowledge-based system and web-based technology to facilitate the rubber and rubber composite injection mold design. The system integrates both of computer-aided design and web-based management by using the application programming interface. The research processes started with gathering data and knowledge concerning on rubber injection mold design and process, with the designed framework of the system included. An example part was demonstrated in order to validate the developed system. Based on standardized procedures, the system provides counseling that is able to resolve relevant issues at the early stage of the mold design. The system can be used for both designing and training in rubber mold fabrication.

Keywords: rubber injection mold design, interactive, web-based design, knowledge-based design

1. Introduction

In the rubber industries, injection molding technique has been accepted as one of the most important processes because of its ability to fabricate in design flexibilities with dimensional accuracy, short cycle times and environmental friendliness. The design of the mold is critical in ensuring successful molding process. However, technical challenges lie in proper design of the mold and process as well as the selection of material to obtain the desirable material distribution. Rubber injection mold design involves extensive empirical knowledge about the structures and functions of the mold components. Consequently, mold designers require broad knowledge and experience to interface various parameters (Mok *et al*., 2001). Unfortunately, it is difficult to cover the rapidly growth demand of the superior products with special characteristics in the short period. The tools which can assist in the various tasks of the mold design process are required.

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Nowadays, a new paradigm to integrate web-based and predictive intelligence for manufacturing system is becoming a new benchmark strategy. It becomes usual to see that design, manufacturing, and assembly of products is taking place at different locations. There are many reports on web-based design for thermoplastic injection mold. However, rubber and rubber composite have some differences in thermoplastic properties such as temperature and viscosity of melt material. Rubber material generally requires very high pressure because of their high viscosity in the cold runner and injection unit. Improper mold design will result in incomplete products within the cavity. In principle, rubber processing consists of several steps, which the material is brought into heated molds with high pressure, undergoes chemical cross-linking to the non-recycled rubber product. Therefore, the special nature of rubber requires specific measurement with regards to flow properties, temperature control and part ejection, thus details of rubber molds need to be special.

This paper presents an interactive web-based design system for rubber injection products. The developed program consists of ten modules as follows: (1) mold base design,

(2) runner design, (3) gates design, (4) cooling design, (5) ejection design, (6) action molds, (7) classroom design, (8) mold design, (9) material data base, and (10) report analysis. These our program allows faster operation time in designing of rubber injection mold and products when compared with other programs since they were designed specifically for the rubber injection mold. In addition, the developed system can also be used to facilitate and share the rubber injection molding information and experience of interested parties in collaborative design of injection mold through internet network. The paper is organized as follows; section 2 describes conventional rubber mold design and related field of previous study on mold design. The framework of knowledge-based of mold design and interactive web-based design system are given in section 3. An example case is demonstrated in section 4. Finally, conclusion and recommendation are presented in section 5.

2. Literature Review

2.1 Conventional injection rubber mold design

Mold is normally constructed by stacking several metal plates to form a rigid body. The mold steel must be selected for the relatively high operating temperature of 170-220°C. Chrome-alloy steels with surface coating are used for part-forming sections. Plates have to be housed with various mold components in correct positions for the proper functioning of the mold. The fundamental features of an injection mold include cavity number and layout, feed system, cooling system, ejection system and mold construction (Mok *et al.*, 2008). Figure 1 shows the general strategy of mold design that expresses how interrelated the conditions are and which boundary and secondary conditions have to be met by the main functions.

2.2 Related works

2.2.1 Related works with CAD/CAE system

In order to complete a three dimensional mold design model, designers have to face with the reuse of many standard mold components, geometrical modeling and complicated assembly such as mold bases, guild pillars, ejectors, etc. Computer-aided design (CAD) of molds offers significant advantages for optimum process management which can already be taken into consideration during the concept stage (Bharti, 2010). Nevertheless, when apply a CAD system to design parts and the assembly of an injection mold two difficulties are found. First, there are about a hundred parts for a mold building, and these parts are associated with each other with different kinds of constraint in order to position the components during assembly. Second, the CAD system uses different geometrical objects from the real used objects such as screws, plates and pins in molding. It takes time to translate such information. Additionally, most computer aided design systems provide only the geometric modeling functions which facilitate the drafting operations of mold design, and do not provide mold designers with necessary knowledge to develop good mold designs. Thus, an added function to assist assembly modeling system for injection molding is required.

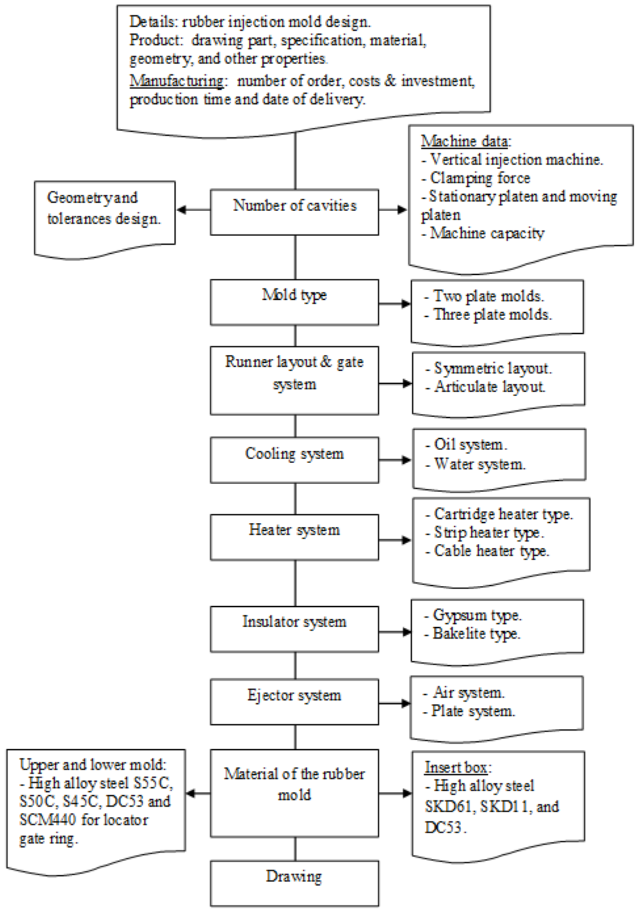


Figure 1. General process of rubber injection mold design.

A feature-based and object-oriented hierarchical representation and the simplified symbolic geometrical approach for automatic mold assembly modeling are presented by Ye *et al.* (2000). Neo and Lee (2001) presented IMOLD®, which is an injection mold design application based on a commercial 3D CAD kernel using an object-oriented programing language. The object-oriented mold component library models for incorporating different geometric topologies and non-geometric information are developed in mold design software "QuickMould" by Ma *et al.* (2003). Fuh *et al.* (2003) presented a windows-native 3D plastic injection mold design system which has been implemented on window NT by interfacing Visual C++ with SolidWork99 and API. Conventional computer aided engineering (CAE) packages are usually good at data processing for information intensive problems or at number manipulation for formulation-intensive problems. The former comprehends the computer-aided drafting and graphics, data reduction and data transformation while the latter involves numerical (or mathematical) modeling and analysis. Lee (2005) proposed a CAD-CAE integration approach that allows both design and analysis information to be specified and shared by creating the single master model containing different types of all the geometric models required for CAD and CAE. The application of CAE for cold runner system analysis of rubber injection molding is demonstrated by Rodkwan *et al*. (2007). Temperature control in rubber injection mold could be obtained by positioning of heaters through finite element analysis (Bae *et al*., 2010). The computational analysis is also applied to show different types of runners to be used between thermoplastics and rubber parts (Kyas *et al*., 2013). The better part quality could be obtained; however, designing of mold still depends on skill and experience of the mold designer.

2.2.2 Related works with knowledge-based system

Mold design involves a substantial practical knowledge component about functions and structure of a mold. Mold designer experience or human heuristic knowledge and formulation-intensive knowledge are needed to complete one. Therefore, conventional computer aided design technology is insufficient for processing heuristic and empirical type of knowledge which is critical in the mold design problems. The knowledge based engineering approach was proposed to cope with the problems. The major advantage of the knowledge based engineering for mold design over conventional computer aided design systems is the explicit representation and manipulation of a body of knowledge, representing the human expertise. Lee *et al*. (2003) developed a knowledge based design aid for injection molding that accommodates manufacturability concern, as well as, requirements of products. "IKMOULD" and interactive knowledge based system for injection mold design process was presented by Mok *et al*. (2001). The similar work was intelligence-knowledge-based for plastics injection mold design process which was performed and reported by Yammada *et al*. (2002). The systems can guide the designers in selecting an appropriate mold for plastic parts based on various client specifications. The integration of CAD/CAM/CAE system and a knowledge based system was studied by Lou *et al*. (2004). The automation of mold design with the reuse of standard parts was developed by Mok *et al*. (2011). The system provided methodology to register the master model as a function of 3D CAD, standard parts and effective reuse of standard parts.

2.2.3 Related works with web-based technology

A concept to integrate web-based technology and predictive intelligence for manufacturing system becomes a new benchmark strategy for companies. The web- based technology transforms a local factory to a global enterprise. Song *et al*. (2006) explained a hybrid interference verification algorithm for web-based system for injection mold design process. Xie *et al*. (2004) illustrated two applications of IDFX (Internet-based Design of Excellence) and IDFC (Internet-based Design for Cost) systems. Objectives of their study were to provide an internet-based concurrent engineering and collaborative design platform for engineers in order to offer alternative designs with instant feedback on mold manufacture and cost. The cooperative design architecture using revolutionary internet, agent and sematic web technology was found in work done by Qiu *et al*. (2007). Based on the concept of service provision, intelligent web-agent groups act as the function of backbone to organize the service-based running of the system. Mok *et al*. (2008) offered an internet-based intelligent design system for injection molds. The architecture of the system consisted of an interactive knowledge-based mold design system embedded in an internet environment. A Java together and artificial intelligence techniques were applied to develop a networked interactive CAD system. The computational module, the knowledge based module and the graphic module were integrated within an interactive CAD-based framework. A web-based sharing system of plastic mold base design and ordering was developed by Huang *et al*. (2009), where a customer could get the design with price information. Contents of the related information and data were analyzed and expanded by IDEF0 (Integration Definition for Function Modeling) method and structured into design procedure and all sort of database. At the same time, Jong *et al*. (2009) presented a collaborative navigation system for concurrent mold design within CAD browser using Pro/Web.Link as the core tool. The system provided both concurrent engineering and collaborative design functions. The navigation system was capable of assisting designers in accomplishing 3D mold development with the use of standard component library and design decision making system. The web-based service system of injection mold design and tool technology was proposed by Jin *et al*. (2013). On the basis of analyzing function requirement of this service system, the architecture was built based on application service provider and Brower/Server (B/S) mode, and its construction was illustrated.

From the above study, several 3D CAD commercial software applications were used in mold industry. The CAD systems, which provide interference verification function, usually are very expensive and insufficient to perform collaborative works over the internet. Thus, most of the previous studies focus on increasing potential by interacting with CAD system, as well as design support system. However, only simple parts and specific designs were considered. Besides, most of integrated mold design systems involve many inter sub-systems. Such systems still require experience from designer to design a mold structure and input the necessary information into the system. As a result, some studies are too theoretical and impractical. Moreover, studies on automatic initial mold design and assembly are very limited. Therefore, an integrated injection mold design system for automotive rubber parts is proposed in this study.

3. Interactive Web-Based and Knowledge-Based System Architecture

3.1 System framework design

Since several technologies such as mold design principle and analysis, manufacturing technology, and web-based technology are required in the development of rubber mold, the developing system must be able to apply and integrate these fundamentals with target geometry. The proposed system can be demonstrated in Figure 2. Typical old design problem can be broken down into a number of sub-problems including feed systems, cooling systems, etc. Our knowledge based system accounts for such sub-problems and consists of three domains as follows.

(1) Domain Knowledge: Database is used to store the knowledge of all types; knowledge from textbooks or the knowledge gained from the experience. It is necessary to provide rule or guidelines to prevent the design from conflicting with design constraints. Nowadays, there are many database management systems available in the commercial market such as Sybase, Microsoft Access 2013 and Oracle. MySQL can use easily and high performance but it also leads to generate cost investment. In this study employs MySQL 5.0.27 database to manage knowledge. The knowledge consists of modules of pre-molding process, molding layout, feed system design, cooling system design, venting design and ejector selection as shown in Figure 3. Knowledge must

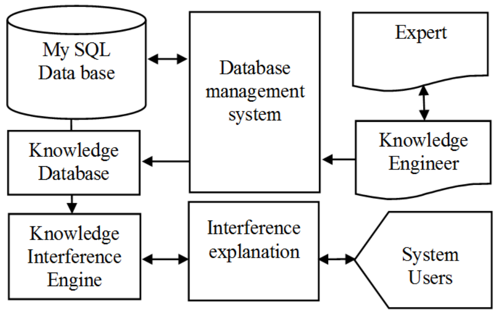


Figure 2. Structure of a knowledge-based system.

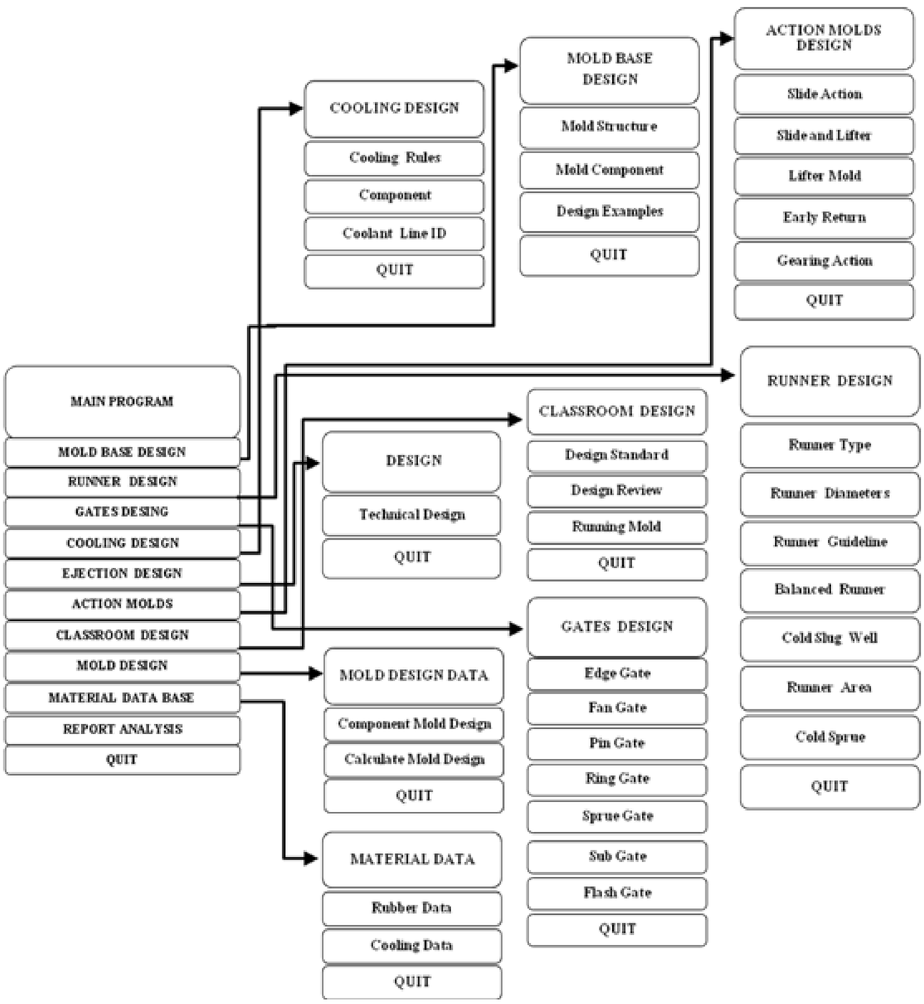


Figure 3. Architecture of knowledge-based rubber mold design.

be transformed into design and manufacturing rules. For example, the data analysis is a problem analysis part which interacts directly between user and program. It can provide the solutions depending on the question. These rules are coded by using PHP script language. They assist mold designers to avoid some unnecessary problems, and focus on the specific design of the injection rubber molds.

(2) Library: The libraries hold information on mold bases, molding features, cooling features, standard parts and supporting tools. The features are created by using object-oriented modeling. The commercial 3D CAD system, SolidWorks 2014, provides a mold base library containing parts and assemblies of standard mold bases. The mold workpiece can have standard of dimensions to fit in the standard mold base, or it can be custom made to accommodate the geometry of the product model. The cavities, which are located inside the mold workpiece, are formed by extracting the product shapes. Thus, the product models are reserved in the CAD file.

(3) Data: Typical reference data includes product material, mold material properties, molding machine capacities, tools and process capacities. This data is available for supporting the decision making. For example, the mold of rubber brush used to absorb shocks in various parts of a vehicle depends on brush size, material and injection speed. The reference data can be obtained from the process and the rules derived from knowledge modeling.

The process of interaction among domain knowledge, library and data is illustrated in Figure 4. Knowledge is stored in the knowledge database, which is developed by using My SQL 5.0.27 and PHP Script language 5.2.6. The knowledge database is linked between database management system, knowledge database, knowledge inference engine, knowledge representations and users. The program application will be processed through the web browser: www.rubber-molddesign.com. For the developing of the program additional data can be added any time. The process according to the rules set in the application system is IF, AND, THEN and ELSE. The development of the knowledge base to support the design contains approximately 300 information of report analysis and 200 tools of supporting mold design. Once the user log in, the system prompts the user to select a product from the product library. Selecting the mold workpiece from the library will activate a knowledge rule to evaluate the selection. The evaluation rule activates the data model for selecting product and mold material parameters. The cavity number can be obtained on the product model by activating cavity number determination domain knowledge. Then, the cavity layout is performed on the mold workpiece. The feed system and venting system are selected corresponding to the rule of cavity layout design. Mold base, which contain cooling system, is selected from mold base library. The product dimension can be modified relating to the requirement of client. In addition, the program system can assist the user by suggesting alternatives or recommendations to design properly of product. For example, in the case of requiring mold design, it can recommend the number of cavity, materials, and size of machinery as shown in Figure 5.

The production rules of mold building development can be presented in the input and output of software operations. The following is an example of the rules for the determination of a mold base design of top plate dimension. Various input information such as the number of cavity, type of top plate material, dimension of workpiece and the capacity of machine is required and checked. If all the cases are converged, the dimension of top plate is obtained from the computing of software system.

IF: Mold base = top plate
AND design $\leq$ 4 cavity
AND dimension of workpiece = 66.50 x 195.50 x 37.50 mm
AND type of material = S55C, S50C: ELSE type of materials DC53
AND machine capacity $\geq$ 250 – 500 tons

THEN: Top plate dimension = 600 x 600 x 35mm.

3.2 Interactive web-based and knowledge base system architecture

The program is written by using Adobe Dreamweaver CS3, which is an programming interface to SolidWorks, Autodesk Inventor, Unigraphic NX, CATIA and other design programs. The application programming interface (API) is the function containing hundreds of directives which can be called from Visual Basic.NET, Visual Basic 6.0. Visual Basic for application, VBA, C, C#, or SolidWorks macro files. Therefore, the users (e.g., programmer and design engineer) can directly use to achieve SolidWorks functionality such as creating a line, extruding a boss, or verifying the parameters of a surface (Fuh *et al*., 2003). The program is connected to internet by using domain of www.rubber-molddesign.com. This developed web base links automatically to server. Eventually, all data base containing in server can respond to user

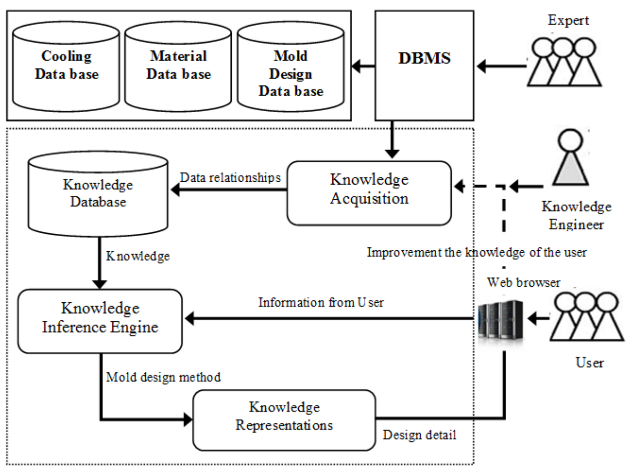


Figure 4. Process of interaction among domain knowledge and library data.

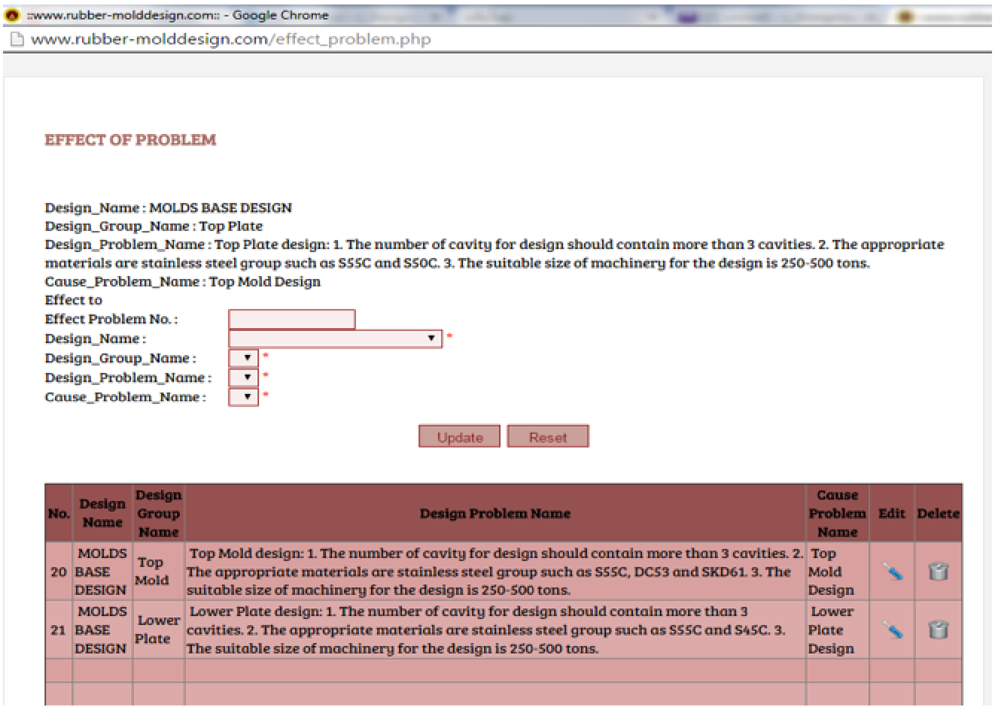


Figure 5. Suggesting alternatives or recommendations to design problems of product by using the developed program.

through user interface which presents the result in form of explanation and graphics as shown in Figure 6.

Nowadays, however, there is no program that can be used as a tool to assist rubber injection mold design. Therefore, commercial programs are still required to help the mold design with limitation of available software program and functions. The performance of the software created in comparison to other commercial products is summarized in Table 1. It can be seen that the tools containing in the commercial rubber injection mold design still lack the information of rubber material such as rubber properties, types and shapes of rubber products. In addition, the knowledge database of rubber injection mold, program tutorials, and setting guidelines are not included.

4. Implementation and Case Study

The program architecture developed was able to dissociate the database for supporting the design in two parts. The first part of the program has been designed by containing the knowledge base to provide recommendations or suggestions according to a written statement format of program rules. The second part has developed a program that can connect to commercial applications. The structure in this part consisted of the standard parts used for mold design including which covered the three groups of rubber injection mold design depending on structural complexity of molds that was simple, medium and high structural complexity. The users can neglect or cancel the standard mold part containing in the developed program, and create the new parts by using with

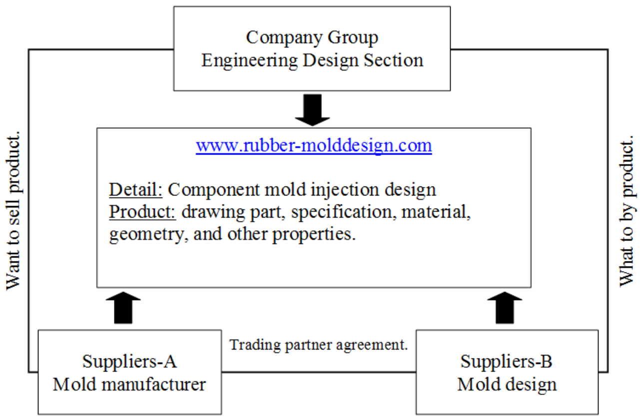


Figure 6. E-rubber design and manufacturing systems.

Solid Work functionality creating such as core holder, insert box, ejector plate and bottom insulator. Both programs (i.e., the developed program and Solid Work) work and encourage together in the mold design process which Solid Work served to extract the data from the developed program for use at all. The system operation stream was processed corresponding to the flow diagram in Figure 7.

In order to validate the system, grommet rubber mold was designed. The 3D model was created by SolidWorks2014 software as shown in Figure 8. The first step was identification of the geometric entities and their relationships. In CAD system, molds are typically represented and stored as a complete geometric and topological solid in term of faces, edges and vertices in three dimensional (3D) Euclidean

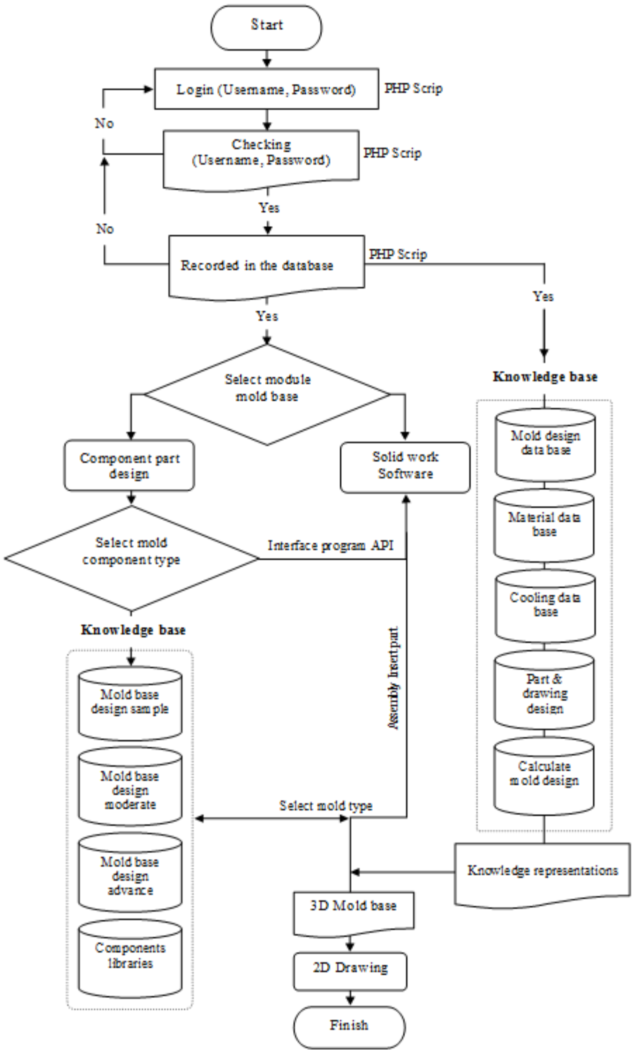


Figure 7. Interactive rubber injection mold design of the developed system operation.

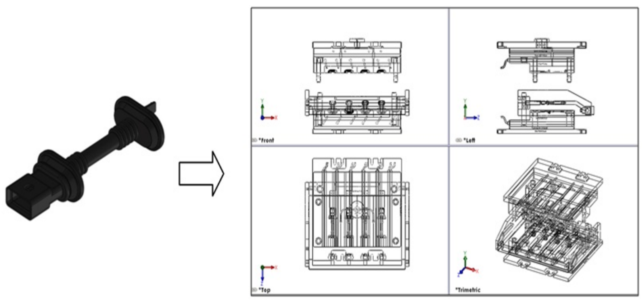


Figure 8. Grommet rubber part and its 2D CAD rubber mold design drawing.

spaces. Two types of material including Ethylene Propylene Diene Monomer rubber (EPDM) and natural rubber (NR) were identified. The dimension of rubber part was set to 66.50 mm (width) x 37.50 mm (height) x 195.50 mm (length) with the mass of 57.07 grams. Machine capacity and production rate were set to 250-500 tons and 16,000 pieces per month, respectively.

Step 1: Enter the system: Enroll and log in the program web server from internet and select function menu. After that, mold design was selected from library.

Step 2: Select analysis menu or design menu: Operator or engineering designers can use design functions such as component mold design from the menu of mold design in library. Next, desirable subpart design functions in component mold design types were chosen in order to allow the program building the complete mold. For example, in the case of building mold of grommet rubber product, designers must first select component mold part design; advanced types which have the most complex shape of product and mold. After that, the series of mold part were chosen in the order as described in Table 2.

Step 3: Mold dimension adjustment: In the program, the dimension of mold base was fixed well for automotive mold containing 4 cavities with the machine capacity in a range of 250-500 tons. However, all parts were easily modified. Nevertheless, all item parts of mold in the program as described in Table 2, for instant, runner, top plate, cooling plate and so on, can adjust the dimension of the mold base design as needed. Finally, the complete injection mold design is done with 3D CAD.

Step 4: Transforming 3D CAD to 2D CAD drawing: The injection mold design 3D CAD can be transformed to be 2D CAD by working through SolidWorks software operation or other software program. The complete 2D CAD drawing obtained is shown in Figure 8. From above system operation, the program was tested by 30 skilled workers with on the job experience in rubber injection mold design for 3-5 years. It was found that the developed program can decrease the average time for spending on rubber grommet design from 48 to 25 hrs corresponding to commercial program and developed program, respectively, or 47.92 percent decreasing. Moreover, the average satisfaction score of the rubber injection mold design program from the evaluation of users was 4.43 points from 5 points representing 88.67 percent with standard deviation of 0.46.

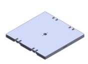
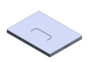
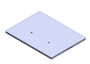
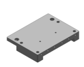
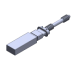
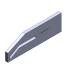
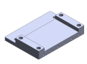
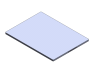
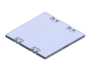
5. Conclusions

The development and practice of a prototype an interactive web-based system for injection mold design used for producing automotive rubber parts has been described in this paper. The architecture of the system consists of an interactive knowledge base mold design system embedded in a program interactive web-based system. A data base solution together with artificial intelligence techniques is presented in modular structure for accessing the knowledge base, and by this ensuring its further development and extension. In practice based on the rubber grommet design, the developed system can integrate different kinds of knowledge, guide an engineers' design, and improve their design efficiency resulting to decrease operation time of 47.92 percent which was

Table 1. Comparison of commercial mold designs.

Software Program	Software Data							
	Rubber Properties	Plastics Data	Cooling Data	Rubber Part Data	Knowledge system KBS	Online Software	Learning Software	Copyright
URMD	☆		☆	☆	☆	☆	☆	
Autodesk Mold Flow		☆	☆					☆
CAD MOLD	☆	☆	☆					☆
Mold Wizard		☆	☆					☆
IMOLD Program		☆	☆					☆
Solid work Design		☆						☆
Solid work Simulation		☆						☆
Solid work Plastics		☆	☆					☆

Table 2. Component part design of grommet rubber mold.

Item	Name	Picture	Material	Quantity
1	Locator gate ring		SCM440	1
2	Top plate & runner layout		S55C	1
3	Cooling plate & runner layout		S55C	1
4	Top insulator		Gypsum	1
5	Top mold		S55C	1
6	Core holder		S55C	1
7	Insert box		SKD61	4
8	Ejector plate		S55C	2
9	Lower mold		S55C	1
10	Bottom insulator		Gypsum	1
11	Lower plate		S50C	1

spent for product designing. With the development and support of the network technology, web-based technology, collaborative technology and other related technology, rubber injection mold design application on the web-based platform and the software features are available on the network. The program can be easily, effectively and economically utilized by small and medium rubber injection mold manufacturing companies.

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