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An interactive modular rule-based expert system for plastic injection moulding processes (EX-PIMM) and its industrial application

By

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Abstract:

This paper presents a shop-floor application of a developed system called EX-PIMM (An Expert System for the Determination of Injection Moulding Parameters for Thermoplastic Materials). The methodology and the structure of the system were explained in detail in the previous work of author. In this study, the system was tested for an automotive product in a company. The outputs generated by the system and the workshop results are compared. The results show that EX-PIMM is an efficient and reliable system in order to determine the most suitable injection moulding machine and thermoplastic material as well as optimum number of cavities for a given job. The best machine and material were selected for the given part, which resulted in reduction in production cost and increase in production capacity.

Keywords:

Expert Systems, Reverse Engineering, Product Development, Injection Moulding Processes

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1. Introduction:

In plastic injection moulding process, a hot melted polymer (resin) is forced to flow into an empty cold cavity of desired shape, and then is allowed to solidify under a high clamping pressure. It is an effective and preferable process in plastic industry due to its ability to produce complex-shaped plastic products having good dimensional accuracy in short production times. Injection moulding process is very complex process involving many fields of science and engineering. Its complexity comes from the wide range of materials and machines. There are several parameters (such as injection pressure, clamping tonnage, shot weight, and so on) affecting the efficiency and the quality of the parts to be produced. Insufficient or wrong knowledge leads to long product development time and frequent redesign of parts. Therefore, determination of process parameters is crucial to ensure a good quality product and efficient moulding process which requires a great experience on machine and plastic material science.

Traditionally, determination of the process parameter settings for injection moulding is mainly performed by moulding personnel, and the effectiveness of the parameter setting is mostly dependent on the experience of these personnel. Their experience probably exceeds their understanding of the technology and sometimes it is hard for them to explain the reason for actions that they have taken. Furthermore, the experience is hard to acquire and transfer to other moulding personnel. Unlike traditional methods, Artificial Intelligence (AI) techniques such as Expert Systems (ES) and Knowledge-Based Systems (KBS), Artificial Neural Networks (ANN), Genetic Algorithms (GA) and Fuzzy Logic (FL) as well as Case-Based Reasoning (CBR) have recently been embodied by many researchers into injection moulding process design integrated with part and mould design [1-7], determination of initial process parameters [8-12], fault detection and diagnosis of the process [13,14], selection of suitable Plastic Injection Moulding Machine (PIMM) and plastic material as well as optimum number of cavities [15,16].

Bozdana [14] developed an interactive KBS, which is called EX-DIMP, for diagnosis of injection moulding process. It is able to define possible causes of faults occurring due to PIMM and/or resin during the process, and also provides the user with suggestions in order to eliminate such faults. A prototype KBS called EIMPPLAN-1 was proposed by Chin and Wong [2]. The system can select a suitable plastic material and generate the major injection mould design features for new product concepts. The integration of computational, graphical and knowledge-based modules was accomplished by Mok et al. [1] for mould design in injection moulding process. The system (namely IKMOULD), which is integrated within an interactive CAD-based framework, is capable of dealing with complex mould design problems by incorporating the intelligence and experience of mould designers. A monitoring ES to predict the developing trends of injection moulding operation parameters was described by Chan et al. [5]. The system also provides advice on the appropriate actions to be taken in order to ensure the quality of products and improve production rate. Practical examples of the system were also reported.

The prediction of plastic injection moulding process parameters using ANN system was discussed in [11]. The accuracy of developed network was found reliable in predicting the injection pressure and injection time for few engineering components. The use of ANN for prediction of metal injection moulding process parameters was also achieved by the same author in [12]. A neural-fuzzy model was suggested by Lau et al. [7], in which a neural network for suggesting the change of process parameters was utilised with a fuzzy reasoning mechanism for acquiring modified parameter values based on the induced parameter values from neutral network. A case-based decision support system for choosing working principles for functions of a product based on prior experiences and a diagnostic system supporting fault detection were combined in [13]. An intelligent system to obtain the magnitude of process parameters in injection moulding process was developed in [9]. CBR and rule-based systems are used to determine the first trial setting of process parameters and to suggest a set of corrective actions for possible corresponding variations in moulding, respectively. Another CBR application to determine injection moulding process parameters was developed by Kwong et al. [10].

An intelligent hybrid system called HSIM was developed by Mok et al. [8] for setting the initial parameters in injection moulding process. The system is utilises ANN, GA and CBR in order to determine a set of initial process parameters for achievement of parts without major defects. Kwong et al. [3] presented a blackboard-based approach for concurrent process design of injection moulding, which involves the considerations of product and tool design, machine selection and cost. Akin to [3], Lee et al. [4] also developed a concurrent mould design system based on knowledge-based approach which includes process modelling and re-engineering for concurrent mould design, identification of functional requirements, system modelling and implementation. Nardin et al. [6] developed simulation software for optimising the part-mould-technology system. The simulation results consist of geometrical and technological data which are used to optimise the part as well as running and cooling system of the mould in order to define optimal input values for process optimisation.

This paper presents a shop-floor application of EX-PIMM (An Expert System for the Determination of Injection Moulding Parameters for Thermoplastic Materials), which is an interactive modular system in order to define the most suitable PIMM and thermoplastic resin as well as optimum number of cavities for a given job. The methodology and the structure of the system were explained in detail in the previous work of the author [16]. In this study, EX-PIMM was tested in collaboration with a company for an automotive product which is currently being produced. The outputs generated by the system and the workshop results were compared. The results obtained intensify objectives of system in terms of its efficiency and reliability for shop-floor applications. Using the generated parameters and results by the system, reduction in production cost and increase in production capacity were remarkably achieved.

2. Description and Highlights of EX-PIMM:

EX-PIMM is an interactive, modular, rule-based expert system which is constructed using Goldworks Expert System Shell. Each module has its own knowledge base containing IF-THEN type of rules which are written in LISP language, and they can work in conjunction interactively (i.e. any rule and/or information in a knowledge base of each module can be accessed and used during the execution of other modules).

EX-PIMM uses material and machine databases which are built in Lotus 123. The total number of machines and materials in databases are automatically defined when the system is activated. Currently 27 thermoplastic resins and 623 PIMMs are stored in material and machine databases, respectively. The databases can easily be extended and/or edited by the user without requiring any change in the structure of the system. Figure 1 shows the overall methodology of EX-PIMM. The system consists of three modules:

1. Module I: Determination of the feasible PIMMs for a given part and thermoplastic resin
2. Module II: Determination of the feasible resins for a given part and PIMM
3. Module III: Determination of optimum number of cavities for a given part, PIMM and resin

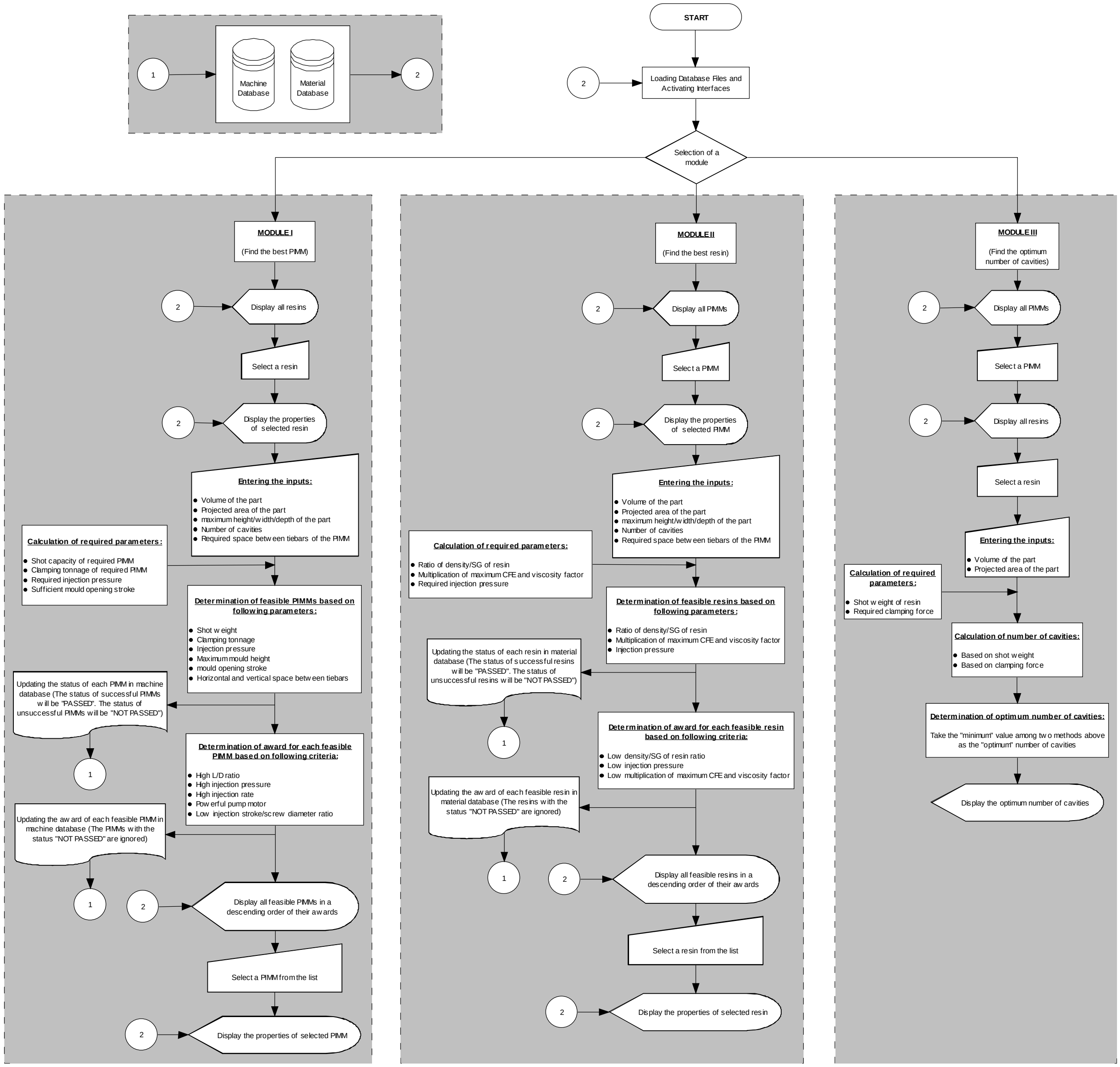

Figure 1: The overall methodology of EX-PIMM.

First module is used to determine all feasible PIMMs and also to select the best PIMM among them. The resin to be used is selected by the user from the list of resins which are stored in material database, and the properties of selected resin are displayed. After that, the data related to part to be produced are entered to the system by the user. The system activates the required knowledge base and runs the rules in order to generate the feasible PIMMs which can be used for the given job. The next step is to display the feasible PIMMs in descending order of their award values. The user can select any PIMM from the list on his/her desire.

Second module is similar to first module in terms of the methodology. It is used to determine all feasible resins and also to select the best resin among them. The user selects a PIMM from machine database and also provides the system with part information prior to the generation of feasible resins. Similar to first module, the feasible resins are listed according to their award values and displayed to the user. Third module is used for calculating the optimum number of cavities (i.e. maximum number of parts to be produced in a single operation) based on the part geometry, the PIMM and the resin which are defined by the user.

In EX-PIMM, the parameters related to machine/material/part are grouped separately and assigned into instances (such as "instance malzeme-1" which holds all parameters related to material). The instances are then used in the IF-THEN type of rules. Some rules which are run during execution of first module are given below. Rule 1 calculates the shot weight of the required PIMM to produce a part based on the specific gravity of the selected resin, the number of cavities and the weight (mass) of the part to be moulded. It should be noted that the weight of the part is not a direct input to the system. It is calculated by Rule 2, which is automatically requested by Rule 1. In other words, all necessary rules are automatically requested by the inference engine and executed during the run-time of EX-PIMM. For this purpose, every rule is assigned a "priority" by the system over the other rules so that the proper execution sequence of rules during run-time is enabled (i.e. Rule 2 with higher priority is executed before Rule 1 with less priority).

Rule 1: Calculation of shot weight of the machine to be required

```
(DEFINE-RULE FIND-SHOT-WEIGHT
  (:PRIORITY -70)
 (INSTANCE MALZEME-1 IS MATERIAL WITH SPECIFIC-GRAVITY ?SPECIFIC-GRAVITY)
 (INSTANCE PARCA-1 IS PART WITH NO-OF-CAVITIES ?NO-OF-CAVITIES)
 (INSTANCE PARCA-1 IS PART WITH MASS ?MASS)
  THEN
 (INSTANCE MAKINA-1 IS MACHINE WITH SHOT-WEIGHT (EVALUATE (MATH
                (((?NO-OF-CAVITIES) * (?MASS) * 1.05) / ((?SPECIFIC-GRAVITY) * 0.8))))))
```

Rule 2: Calculation of mass of part to be moulded

```
(DEFINE-RULE FIND-MASS-OF-PREFORM
  (:PRIORITY -40)
 (INSTANCE PARCA-1 IS PART WITH VOLUME ?VOLUME)
 (INSTANCE MALZEME-1 IS MATERIAL WITH DENSITY ?DENSITY)
  THEN
 (INSTANCE PARCA-1 IS PART WITH MASS (EVALUATE (MATH ((?VOLUME) * (?DENSITY))))))
```

Rule 3: Determination of feasible PIMMs

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(DEFINE-RULE FIND-ALL-FEASIBLE-MACHINES
  (:PRIORITY -140)
 (INSTANCE MACHINE-DATA IS 123-ACTION)
  THEN
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(EVALUATE (CHECK-WITH-DATA-FILE 'SHOT-WEIGHT 'H))
(EVALUATE (CHECK-WITH-DATA-FILE 'CLAMPING-FORCE 'O))
(EVALUATE (CHECK-WITH-DATA-FILE 'INJECTION-PRESSURE 'I))
(EVALUATE (CHECK-WITH-DATA-FILE 'MOULD-OPENING-STROKE 'S))
(EVALUATE (CHECK-WITH-DATA-FILE 'MAX-MOULD-HEIGHT 'T))
(EVALUATE (CHECK-WITH-DATA-FILE 'SPACE-BTW-TIEBARS-HOR 'P))
(EVALUATE (CHECK-WITH-DATA-FILE 'SPACE-BTW-TIEBARS-HOR 'Q))
(EVALUATE (DEFINE-STATUS 'W)))
```

Rule 4: Determination of award values for each feasible PIMM

```
(DEFINE-RULE DEFINE-AWARDS-OF-FEASIBLE-MACHINES
  (:PRIORITY -150)
 (INSTANCE MACHINE-DATA IS 123-ACTION)
  THEN
 (EVALUATE (SET-ORIENTATION-ROW 'MACHINE-DATA))
 (EVALUATE (FIND-BEST-MACHINE 'L-TO-D-RATIO 'F))
 (EVALUATE (FIND-BEST-MACHINE 'INJECTION-PRESSURE 'I))
 (EVALUATE (FIND-BEST-MACHINE 'INJECTION-RATE 'K))
 (EVALUATE (FIND-BEST-MACHINE 'INSTALLED-DRIVING-POWER 'V))
 (EVALUATE (FIND-BEST-MACHINE 'STROKE-TO-SCREW-DIA-RATIO 'M)))
```

The system has a special awarding facility for feasible PIMMs and resins which are generated in the first and second modules, respectively. The feasible PIMMs in the first module are awarded based on five criteria (as shown in Figure 1). An award of 20 points over 100 is given to the “best PIMM” according to each criterion in the first module. On the other hand, an award of 33.3 points over 100 is given to “best resin” for every criterion since there are three criteria in the second module (as shown in Figure 1). If there is more than one best PIMM/resin for a criterion, the award value is shared equally by those PIMMs/resins. The feasible PIMMs/resins are listed and displayed according to their award values (the PIMM/resin with the highest award value appears at the top of the list). The determination of all feasible PIMMs and their award values are shown in Rules 3 and 4, respectively. Both rules work with machine database interactively in order to read/write the necessary information from/to database. Similar to Rule 1, necessary rules containing the functions, namely “check-with-data-file” and “find-best-machine”, are automatically executed.

It should be noted that the effect of the weight and projected area of runners, the location and dimensions of gates and length of sprues are ignored in the system as their effect is assumed to be negligible. In addition, the material and life of mould as well as the orientation of cavities in the mould are not taken into consideration. The addition of these parameters into the system increases the complexity of problem and requires careful study on the design and geometry of mould. EX-PIMM does not propose any solution on design of the mould or orientation of cavities in the mould.

EX-PIMM defines and amends the errors and insufficient information before execution of the modules. In other words, the information stored in databases are automatically checked and updated when the system is activated. The following section presents an application of EX-PIMM for a part which is currently being produced by injection moulding process. The execution of each module is explained step-by-step by screen shots of the system.

3. Industrial Application of EX-PIMM:

An automotive part which is working under high pressure and temperature in the crankcase section of automobiles was chosen in order to test the system. The technical drawings of part and mould, which are provided by the collaborator of this study [17], are shown in Figure 2. Table 1 shows the inputs to be entered to EX-PIMM. The volume, the injection (projected) area and the maximum dimension of the part to be moulded are calculated from the part geometry. The horizontal and vertical distances required between the tiebars of the PIMM are also calculated based on the mould dimensions. Acrylonitrile Butadiene Styrene (ABS) is used as thermoplastic resin and a 110 tonnes (Screw A) machine made by NingBo Haitian is used as PIMM. Figure 3 shows the welcome menu of EX-PIMM. The modules appear at the top of the menu. Each module is executed using the inputs given in Table 1, and the methodology of each module is described by means of screenshots during run-time of EX-PIMM. The results generated by the system are compared with the workshop results, and discussions and recommendations are presented in the last section.

3.1. Module I: Determination of Feasible PIMMs

The list of thermoplastic resins stored in the material database is displayed so that the user can select the resin to be used. As stated in Table 1, ABS is selected from the list in Figure 4. The properties of selected resin are then displayed as shown in Figure 5. The user is able to customize the properties of resin if necessary. It is especially useful if a special resin or a resin which is not existent in the material database is requested.

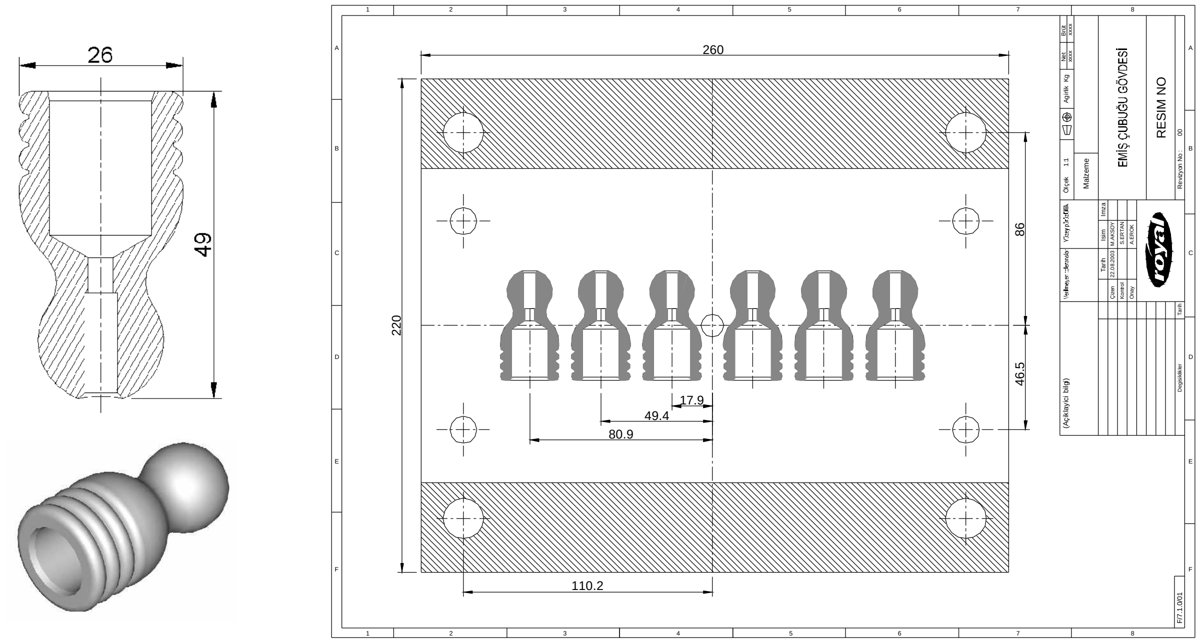

Figure 2: The technical drawings of part (top and bottom left) and mould (right)

Table 1: The input data related to part, mould, resin and PIMM

Volume of the part:	12.095 cm^3
Projected area of the part:	5.054 cm^2
Maximum height/width/depth of the part:	4.9 cm
Horizontal distance between tiebars:	220.4 mm
Vertical distance between tiebars:	172 mm
Number of cavities:	6
Material:	Acrylonitrile Butadiene Styrene (ABS)
Machine:	NingBo Haitian, 110 tonnes, screw A (HTF-110A)

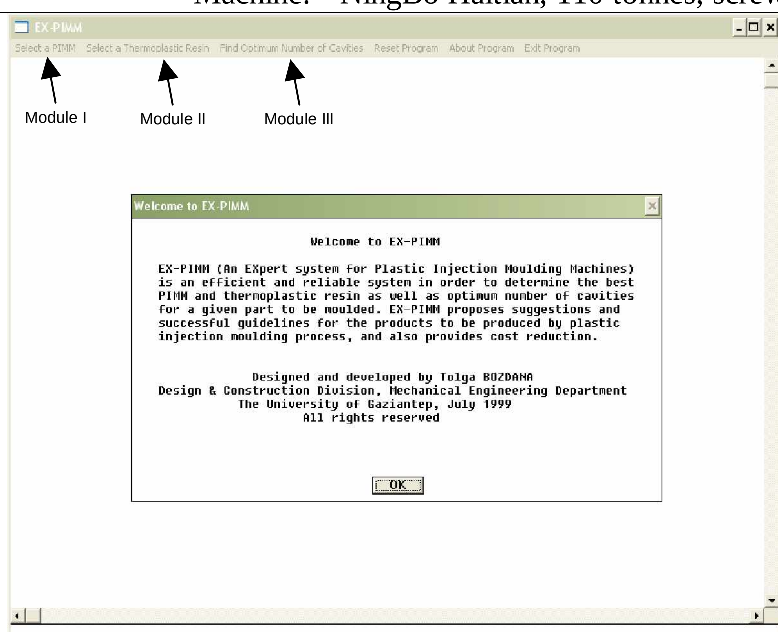

Figure 3: Welcome menu of EX-PIMM

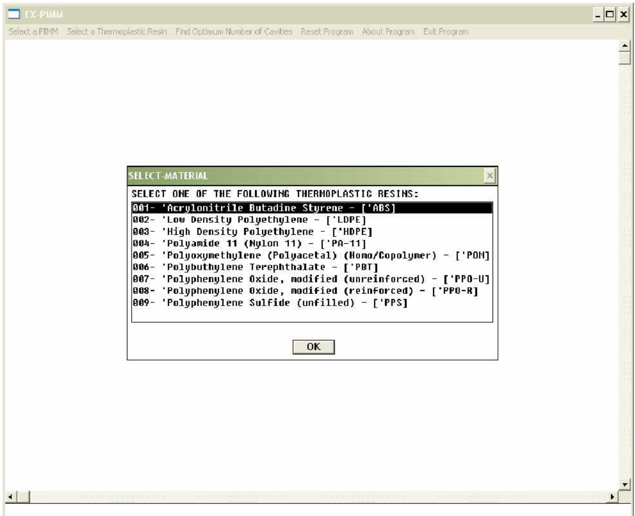

Figure 4: Select a resin

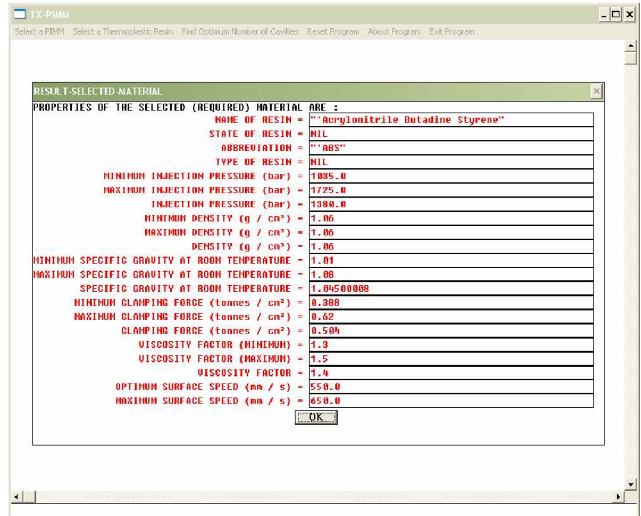

Figure 5: Display properties of selected resin

The next step is to provide the system with necessary data related to part and mould, which are given in Table 1, as shown in Figure 6. The first three and the last two parameters are calculated from the geometry of part and mould, respectively. After that, the system starts generating the results by activating and running necessary rules in knowledge base and databases. The list of feasible PIMMs in the descending order of their award values are then displayed to the user in Figure 7. The value in brackets in front of each PIMM is the award of value of that PIMM. Any PIMM can be selected in this list since all the PIMMs are satisfactory for the given job. Finally, the properties of the selected PIMM are displayed to the user as shown in Figure 8.

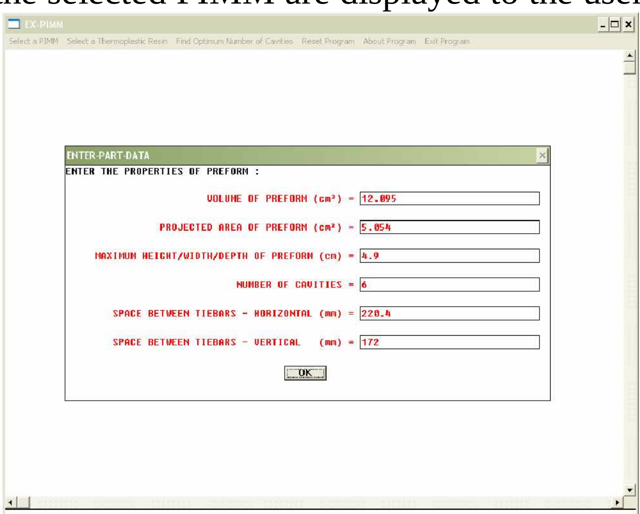

Figure 6: Enter part information

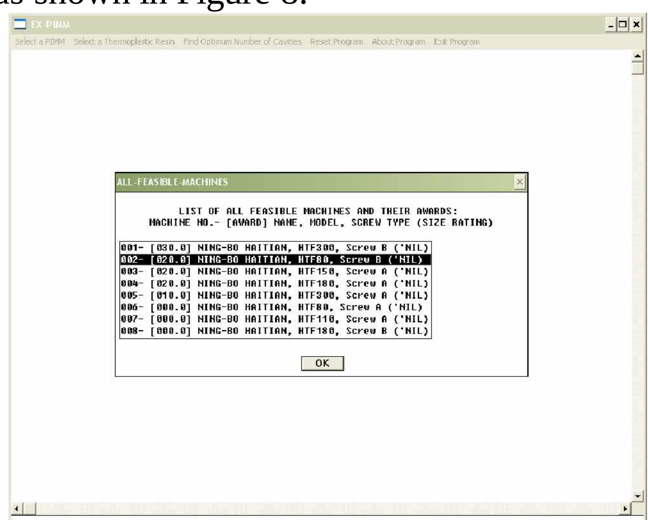

Figure 7: Display feasible PIMMs

<u>3.2. Module II: Determination of Feasible Resins</u>

The methodology of second module is similar to that of first module. The user is asked to select a PIMM from the list in Figure 9 and the properties of selected PIMM are displayed on screen as shown in Figure 10. As in the case of first module, the user can change value of any parameter. Prior to the generation of results, the parameters related to part and mould are required to be entered to the system as shown in Figure 11. The values of the parameters automatically appear in the table in Figure 11 since they are already entered to the system. It should be noted that horizontal and vertical distances between the tiebars of the selected PIMM are automatically taken since these values are used for the calculations instead of the values given in Figure 6. Similar to first module, the system generates and displays the list of all feasible resins in descending order of their award values as seen in Figure 12. Finally, the properties of selected resin are displayed to the user as shown in Figure 13.

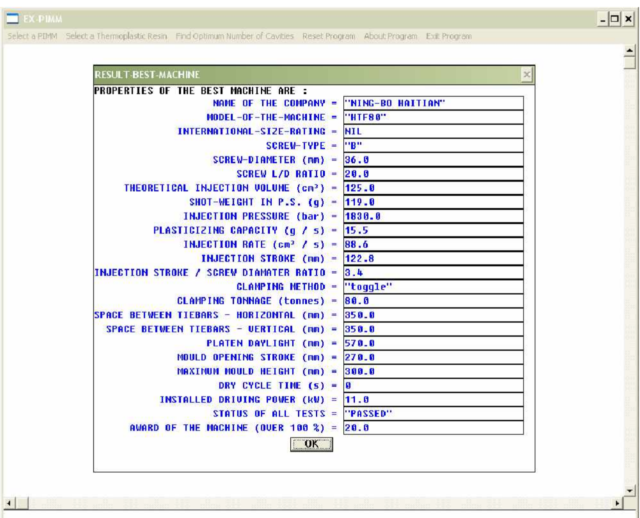

Figure 8: Display properties of selected PIMM

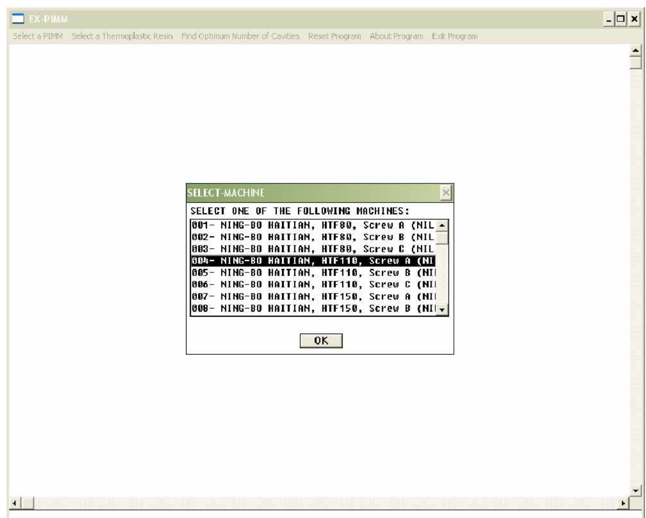

Figure 9: Select a PIMM

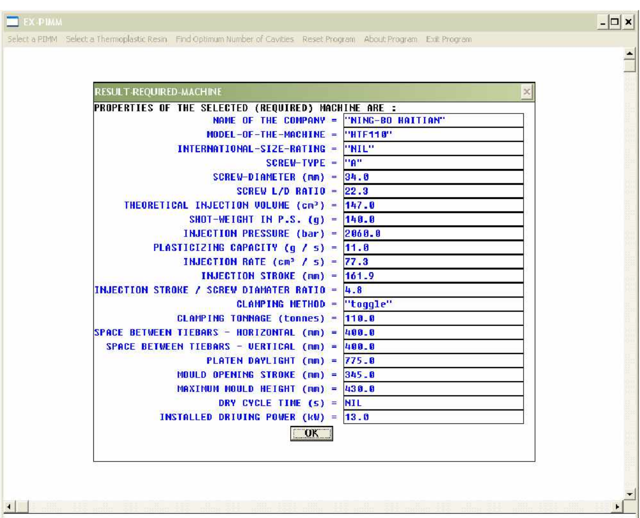

Figure 10: Display properties of selected PIMM

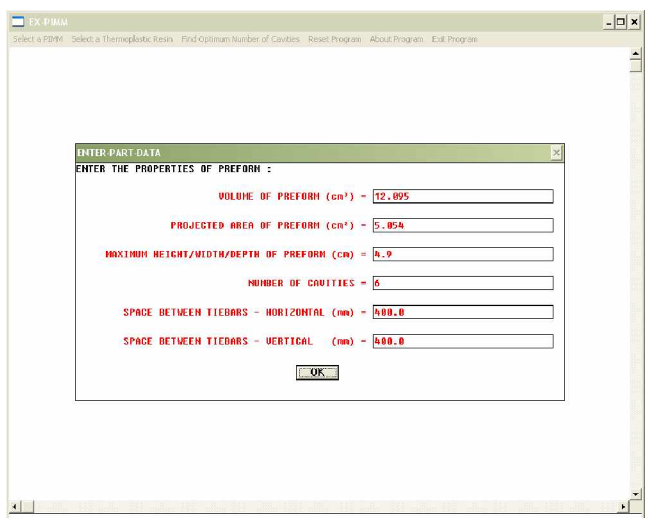

Figure 11: Enter part information

3.3. Module III: Determination of Number of Cavities

This module is used for calculating the optimum number of cavities (i.e. the maximum number of parts to be produced in a single operation) according to given resin and PIMM. For this purpose, the user is prompted to select the desired resin (Figure 4) and PIMM (Figure 9). After that, the required data are entered to the system as shown in Figure 14. The first two parameters are entered by the user since the rest of parameters are calculated automatically by the system and/or directly taken from related databases. Finally, the result is displayed on the screen in Figure 15.

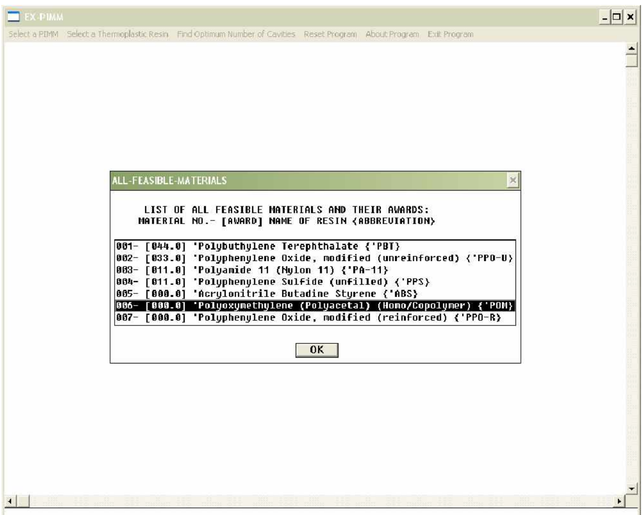

Figure 12: Display feasible resins

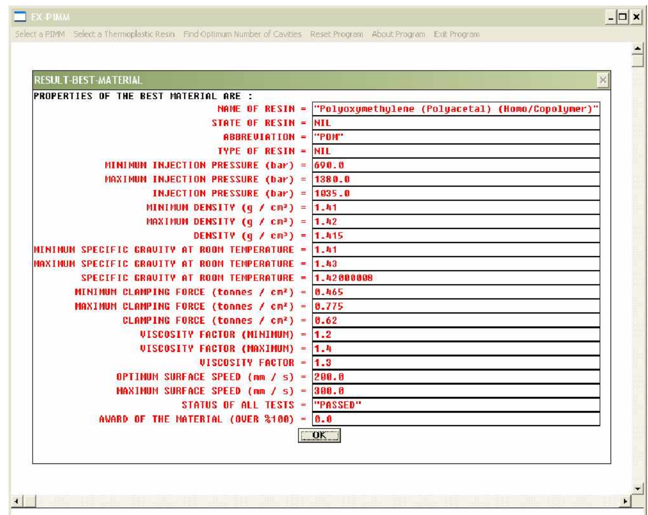

Figure 13: Display properties of selected resin

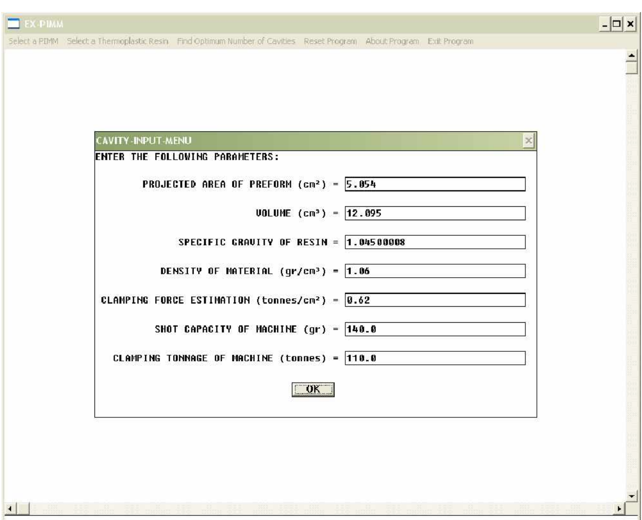

Figure 14: Enter part information

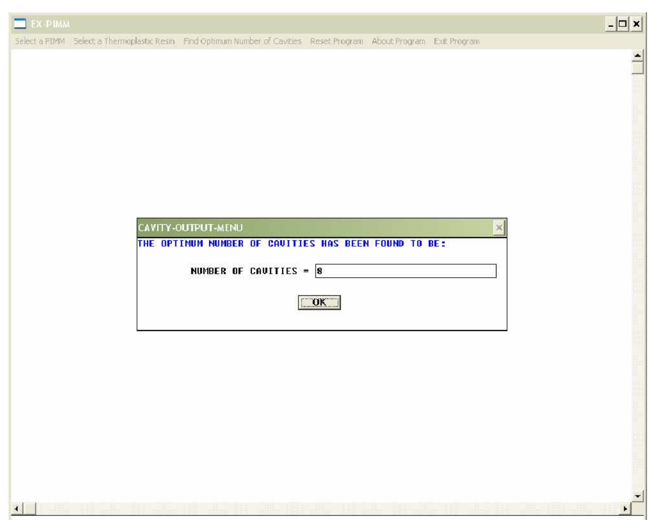

Figure 15: Display the result

4. Discussion and Conclusions:

The results generated by the system and their comparison with company results are summarised in Table 2 (The values in brackets show the award values of PIMMs and resins). Prior to EX-PIMM, HTF-110A was being used in the company. After first module of EX-PIMM, HTF-80B is now being used successfully to produce the same part. Since a smaller-tonnage PIMM (HTF-80B) as compared to a bigger-tonnage PIMM (HTF-110A) is now being used, a 4.5% reduction in production cost was achieved without changing the mould and resin.

Before EX-PIMM, ABS was being used as resin. According to customer reports in the company, ABS was causing problems and complaints from the customers in Europe due to its deformation temperature which is lower than desired. After second module of EX-PIMM was executed for this purpose, Polyoxymethylene (POM or Polyacetal) was selected since it has a higher deformation temperature as compared to ABS. POM was tested and approved by the company and also acknowledged by the customers.

Table 2: The summary of results generated by EX-PIMM versus factory results

Module	Inputs			Outputs	
	Machine	Material	No. of Cavities	After EX-PIMM	Before EX-PIMM
I	-	ABS	6	HTF-80B [20]	HTF-110A [0]
II	HTF-110A	-	6	POM [0]	ABS [0]
III	HTF-110A	ABS	-	8	6
III	HTF-80B	POM	-	7	-

Third module emerged that eight parts (instead of six) could be produced using the same PIMM and resin (namely HTF-110A and ABS, respectively). This result was not tested in the factory since it requires changes in the size and design of the mould. However, our collaborator already confirmed the possibility and reliability of producing eight parts in a single operation using HTF-110A and ABS, which will result in a 25% increase in production capacity in each operation (i.e. a huge potential increase in annual production capacity). EX-PIMM was also used to find the optimum number of cavities using HTF-80B and POM; production of seven parts in one operation can be accomplished successfully.

The results prove the reliability and efficiency of the system in shop-floor environment. EX-PIMM is a practical and beneficial system enabling the user to define the most suitable PIMM and resin as well as maximum possible number of parts to be produced. Its machine and material databases can easily be edited and extended by the user, which does not need any modification in structure of the system. The potential benefits of EX-PIMM are particularly significant when a new part is being designed and produced since it guides the engineers in determining the right PIMM and resin for a given job.

Thereby, EX-PIMM provides considerable improvements such as cost reduction, higher production capacity and shorter production time prior to and/or during design/production stages.

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