Development of Integrated CAD/CAE System of Mold Design for Plastic Injection Molding

JANKO HODOLIC, IVAN MATIN, MIODRAG STEVIC, DJORDJE VUKELIC
Faculty of Technical Science of Novi Sad, Department of Production Engineering, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia

Development of CAx for numerical simulation of injection molding and mold design have opened new possibilities of product analysis during the design process of plastic production. This development contributes to higher quality performance as well as to lower cost of production. The paper deals with the design of plastic products with state-of-the-art integrated CAD/CAE software for mold design. The possibility of solving problems in mold construction appeared by integrated CAx universal system with unique applications (CAE/II module) for mold parameters verification, mold calculation and selection and final mold modeling (CAD/II module). Thus, the specializated CAD/CAE system for automated mold design is successfully created.

Keywords: plastic injection molding, mold design, CAD, CAE

Injection molding is one of the most important commercial processes for the production of three-dimensional plastic articles. It is the most important process used to manufacture plastic products. More than one third of all thermoplastic materials are processed by injection molding. High cost of molds is a major disadvantage of injection process and therefore, it is used as economically as possible for high assembly line production and mass-produced parts of complex shapes that require precise dimensions and quality [1].

During the last decade many authors developed systems of mold design for injection molding as for example a program solution for automated process planning for manufacturing moulds for plastic injection molding [2] but this system lacks CAE calculation of parameters of injection moulding and mould design.

Another study developed a CAE system for injection moulding parameters calculations and methods for mould selection [3]. It enables thermal, rheologycal and mechanical calculations of molds and parameters of injection molding but it lacks integration with any universal CAx software of general use.

It was also developed a structure model of CAD/CAM/CAE system of mold design for injection molding, but its software solution has not been developed yet [4].

A collaborative integrated design system for concurrent mold design within CAD database on the WEB was built [5] and a numerical simulation of injection molding based on Helle Show flow model of non-Newtonian fluids was made [6].

A system of mold selection for plastic injection moulding enabling the manipulation with standardized mold plates was also developed [7].

It was developed a structural design system for 3D mold drawing based on functional features using a minimum set of paramweters for initial information [8, 9] . In addition it was also applicable to assign the functional features flexible before accomplishing the design of a solid model for the main parts of mold.This design system included modules for selection and calculation of mold components.

A parametric 3D plastic injection mold design system was also made [10].

A CAE analysis was used for determining the plastic material behaviour [11] . The authors use mechanical, thermal and rheologycal calculation for optimizing dimensions and analyse physical, mechanical and thermal properties of plastic materials such as shaft, which is dynamically loaded, responsible element, and they also defined the critical parameters (properties) of polymers under consideration.

A study for optimizing a system of mold cooling based on standard elements was developed. Cooling system is defined through basic standard elements and thus, when assembled , it results in a new complex standard form of cooling system oriented through parameters with integrated base of standard elements of cooling canals [12].

A CAE analysis for researching the aspects of the behaviour of polymer assemblies on mechanical stresses [13].

It was developed also the framework for collaborative design environment for injection molding simulation according to the principles of simultaneous engineering [14].

Other researcher studied the possibilities of using CA information technology for the design of optimal cooling system for injection molding and developed the methodology for optimizing cooling system based on BEM(Boundary Element Method) [15].There were also developed a moldbase system for injection molding with a base parametric, associative and feature oriented [17] and an intelligent design system for injection molding of mold plates [18].

An integrated knowledge-based system for designing mold plates and structures was also developed [19] . The system has a module for cavity and dimension calculation calculating the number of mould plates and a module for injection machine choice.Based on the numerical simulation a virtual injection molding system was built [20].

Generally, plastic injection molding design includes plastic product design and mold design as well as simulation of injection molding process. This is a complex process involving many design parameters that need to be considered in a concurrent manner [16]. The traditional trial-and-error method is costly and time-consuming. Due to the improved the optimal mold design and optimal process control in injection molding, increasing reliance

* email: hodolic@uns.ns.ac.yu; Tel. +381 21 485 2053

has been placed on the development of CAD/CAE system for designing the mold for plastic injection molding.

The main objective of this research is to develop a software system which integrates CAD/CAE components such as: 3D modeling products and molds, analysis and numerical simulation of discrete and continuos processes of plastic injection molding, designing molds and parameters of plastic injection molding.

Model of Integrated CAD/CAE System

Architecture of integrated CAD/CAE system for automated mold design for plastic injection molding and optimised mold design is presented in figure 1. System consists of four modules, such as:

- CAD/I module for solid modeling of the part;
- CAE/I module for numerical simulation of injection molding process;
- CAE/II module for calculating parameters of injection molding and optimization of mold design and
- CAD/II module for final mold modeling.

CAD/I module is the first module within the integrated CAD/CAE system of automated mold design for plastic injection molding and mold design optimazation. This module is used for generating CAD model of plastic products. The outcome of this module is 3D solid model of plastic part with all necessary geometrical specification.

CAE/I module is utilized for numerical simulation of injection molding. Algorithm in figure 2. shows in details indispensable steps within the numerical simulation process. After importing the CAD model, material choice from the material database and definition of injection molding parameters, system automatically simulates and optimizes the number and location of incoming system. After defining best gate location, further analyses are carried out: the Plastic Flow analysis, Confidence of Fill Result derived from the Fill Time, Injection Pressure, Pressure Drop and Flow Front Temperature, time of Part Filling, presence of Welding Line, presence of Air Traps, Quality Prediction etc. All the results are illustrated using the regions of different colors on the part model. After the first iteration engineer can review the inputs and try to resolve problems. Areas on the part that show low or medium confidence of fill may need to be redesigned or a new material selected for the part to fill. After the initial operation, the next phases of redesign are the change of simple rounds, chamfers or drafts, the change of technological draft inclination of the part, the search for better injection molding parameters, the choice of best gate locations and the choice of new material. The software tells users whether a part will fill properly, where weld lines are located, and if and where air traps will appear. Information is also provided on the impact of modifications to wall thickness, gate locations, special features (such as ribs) and material choices. Using these data, engineers can quickly analyse many design alternatives to identify the one that best meets key design and injection molding parameters.

CAE/I module offers various possibilities to designers to try different part designs, materials, gate locations, and processing conditions before the final part geometry is completed. Testing the impact of these variables optimizes the design for the injection molding process before the final mold specification calculation and optimization mold design are carried out.

Each analysis is aimed at solving specific problems:

- part Analysis - It is used for testing gate location, material, and part geometry to verify that a part will have acceptable processing conditions;
- gate Optimization - It tests multiple gate locations and compares data outputs in order to determine the ideal gate location;
- part Optimization - It tests multiple thickness of the same part in order to reduce part thickness thereby minimizing cycle time and part weight.
- sink Mark Analysis - It detects sink mark locations and depths to resolve cosmetic problems before the mold is built eliminating quality disputes that could arise between the molder and the customer.

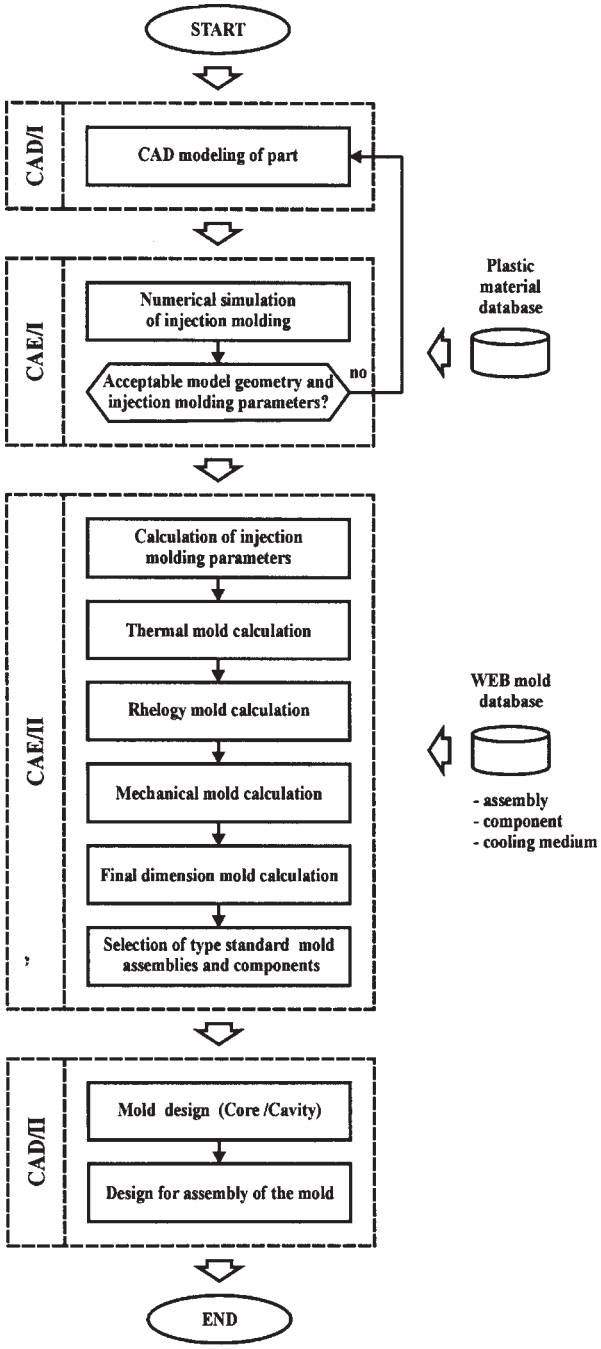

Fig. 1. Model of integral CAD/CAE system of mold design for plastic injection molding

The part molding process is heavily affected by factors of the part design. This critical parameters are outcome results of CAE/II module. The most critical of these parameters are the following:

- part thickness;
- part flow length;
- thickness transitions;
- part material;
- location of gates;
- number of gates;

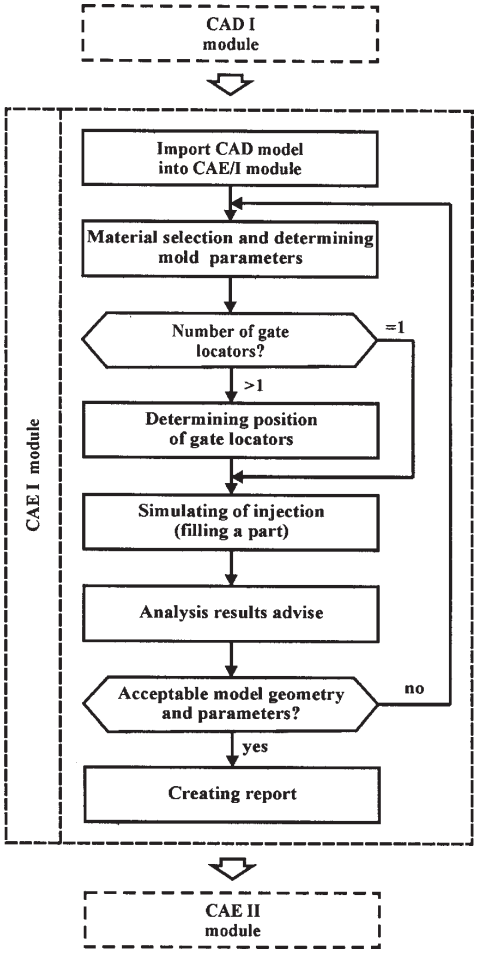

Fig. 2. Model of numerical simultation

- mold temperature;
- melt temperature.

Without injection molding simulation, the engineer lacks the insight of variable parameters change. This results in high degree of risk that the part will not mold with acceptable quality levels. The wrong part will cause high level of stress, degrade the material, cause weld lines and air traps, and engineer is short of clear insight into the problem, i.e. the parameters that created the problem. Unfortunately, molds designed without the use of injection molding simulation have to resort to the tactics of "trouble shooting". Only iterative process of optimization and change varible of the critical parameters generates optimal high quality products. Other critical data that are obtained by running the analysis includes:

- location of weld lines;
- clamp tonnage requirements;
- injection pressures;
- location of high shear rates.

CAE/II module is developed to solve the problems of mold thermal, rheological and mechanical calculations for injection molding and tool design optimisation.

Outcome CAE/I parameters such as injection pressure, mass properties, maximal melt temperature, mold temperature, injection time, cycle time, etc. are income data for CAE/II module. Outcome results of CAE/II module are optimal parameters of injection molding, geometrical and technology specifications of the mold.

CAD/II module is used for final CAD modeling of the mold (core and cavity design). This module uses additional software tools for automated creation of core and cavity from CAD model including shrinkage factor of plastic material and automated spliting mold volumes of stationary and movable plates.

Additional capabilities of CAD/II module are software tools for:

- analyzing if design part is moldable, and detect and fix problematic zones, (rounds, drafts, chamfers and quilts);
- applying a shrinkage that corresponds to design plastic part, geometry, and molding conditions which are calculated in CAE/I and CAE/II module for automation core and cavity design,;
- making conceptual CAD model for non standard plates and mold components;
- designing core and cavity inserts, sand cores, sliders, lifters, and other components that define a shape of molded part;
- populating a mold assembly with standard components such as mold base (HASCO, D-M-E, FUTABA, STRACK, DMS, EOC, MISUMI, MEUSBURGER, STRACK, PEDROTTI), and CAD modeling ejector pins, screws, and other components creating corresponding clearance holes;
- creating runners and waterlines, whose dimensions are calculated in CAE/II module [21];
- checking interference of components during mold opening and checking the draft surfaces.

Main specifications of CAD/II module are:

- specialized GUI enables instant customization of moldbases and components;
- automatic assembly of known components – „pick and place";
- all necessary clearance of holes, threads, counter bores are automatically added to plates and assemblies;
- custom components could be created, redefined, saved and reused;
- standard and nonstandard mold components are marked.

Smart Moldbase Assemblies and Components with automatic functions, such as on-the-fly customization, component sizing, placement, trimming, and clearance cut and thread creation, are provided for the following:

- complete moldbase assemblies;
- plates instance and insulation;
- multi-Cavity and Family Molds Supported;
- support Pillar Assemblies;
- latch Lock Assemblies;
- locating Rings and Sprue Bushing;
- ejector Pins, including Sleeve Ejection, Screws and Washers, Dowel Pins;
- automatic drawing, drafts and BOM creation.

As the assembly is created and optimized, software updates the BOM and assembly drawing. Drawings of all assemblies and plates, completed with hole charts, are created automatically. Drawings and BOM layouts are also customizable. Mold opening simulation, completed with slider, lifter and ejector is created automatically too. Interference can be checked automatically during the mold opening sequence.

Results and discussion

For verification of integrated CAD/CAE system for mold design, CAD model of the part is used as indicated in figure 3.

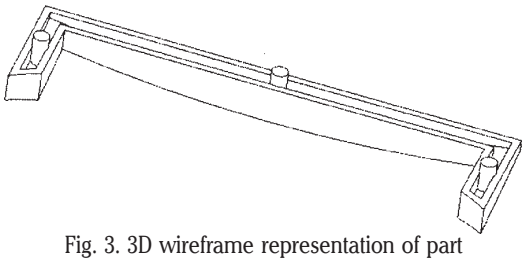

Fig. 3. 3D wireframe representation of part

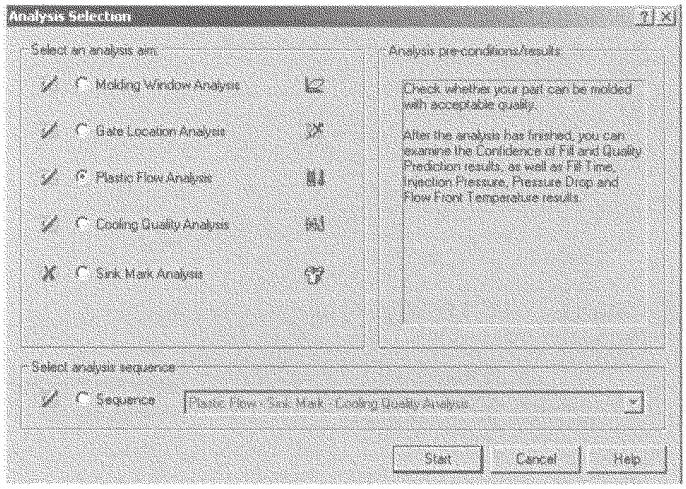

Fig.4. Dialogue box for selecting numerical simulation

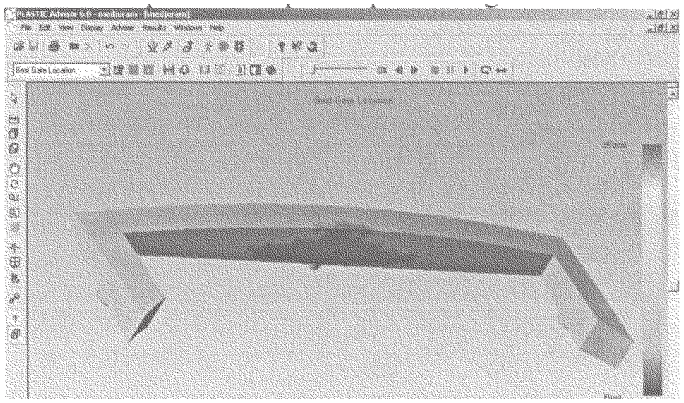

Fig.5. Best gate location in the part

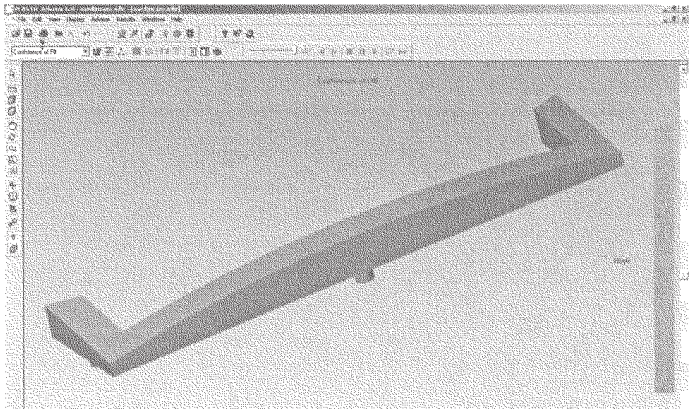

Fig.6. Calculation model of cooling time

Material Grade and Material Supplier	Acrylonitile Butadiene Styrene 780 (ABS 780), Kumho Chemicals Inc.
Max Injection Pressure	100 MPa
Mold Temperature	40 °C
Melt Temperature	230 °C
Quality Confidence	High
Injection Time	0,2 s
Injection Pressure	29,59 MPa
Clamp force Area	4,19 cm^2
Cooling time	1,9 sec
Modulus of elasticity, flow direction for ABS 780	E_1=2600 MPa
Modulus of elasticity, transverse direction for ABS 780	E_2=2600 MPa
Poison ratio in all directions for ABS 780	$v_{12}=v_{23}=v=0,38$
Shear modulus for ABS 780	G_{12}=942 MPa

Table 1
CAE/I OUTCOME PARAMETERS OF USED MATERIAL AND PARAMETERS OF INJECTION MOLDING PROCESS

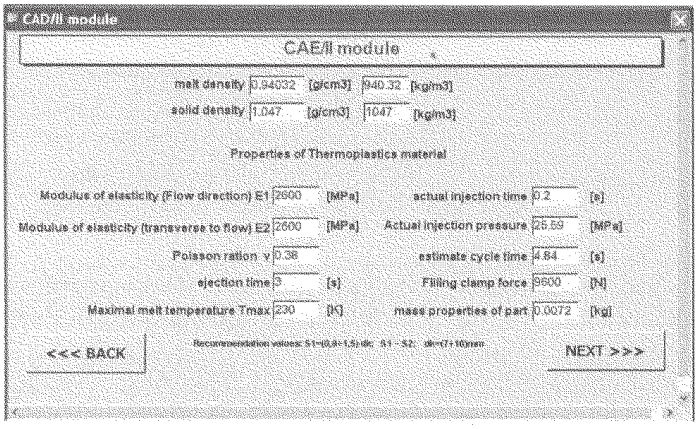

Fig.7. Inlet form of CAE/II module

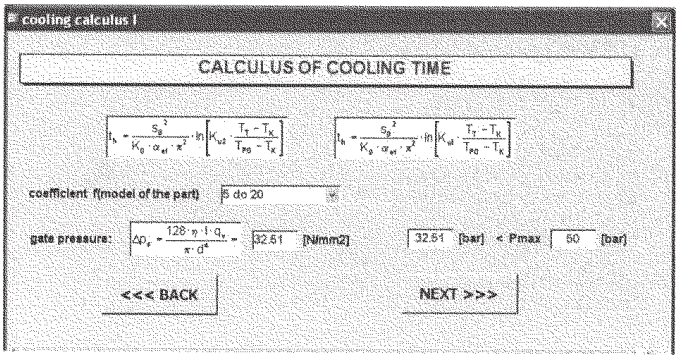

Fig.8. Form of cooling time calculation

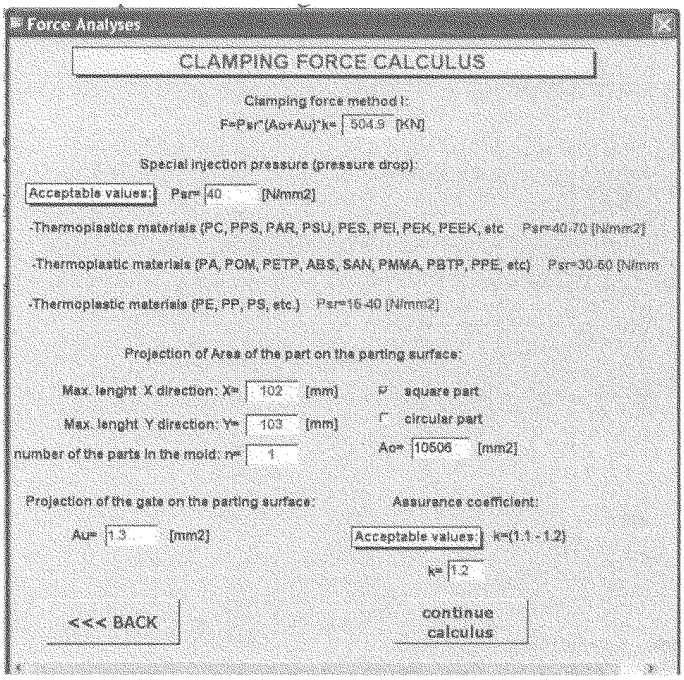

Fig.9. Clamping force calculation

Dialogue box for selecting simulation type is shown in figure 4.

CAE/I module suggests the best gate location in the model as indicated in figure 5. The figure presents the blue zone of the part as an optimal place for gate locator.

A green area is all over the part as indicated in figure 6. The green area has high confidence rate; yellow color indicates medium confidence rate, while red one shows low confidence rate. Figure 6 shows that the part is full of plastic material. It means that cavity is full of ABS.

The segment of the results (report) of CAE/I module is presented in table 1.

Inlet form of CAE/II module is presented in figure 7. There are parameters, which are needed for further calculation in module CAE/II.

Afterwards, software directs the engineer towards thermal, rheology and mechanical calculation. One of the several forms of verifying IM process condition and thermal calculus is presented in figure 8. The cooling time is influenced by the form, dimension and material of the injected part, but also by mold temperature. This is one of the most important technological parameters that influence the quality of the injected plastic material part. The injection process can be carried out within optimal conditions if the temperature of the mold is stationary and controlled.

One of the several forms of mechanical calculation is presented in figure 9. A method of calculation and verification of clamping force computed in module CAE/I is presented in figure 9.

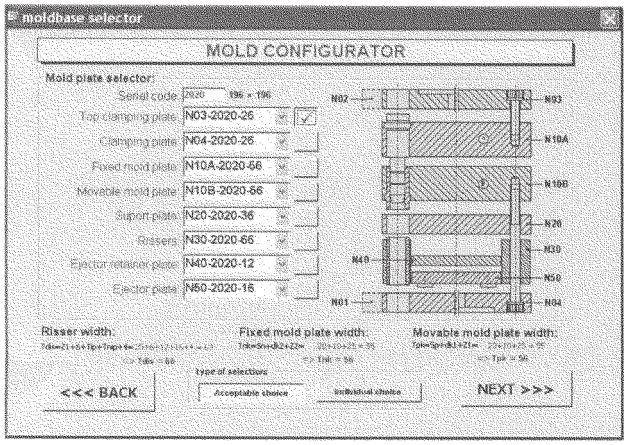

Fig.10. Form of selecting standard mold plates

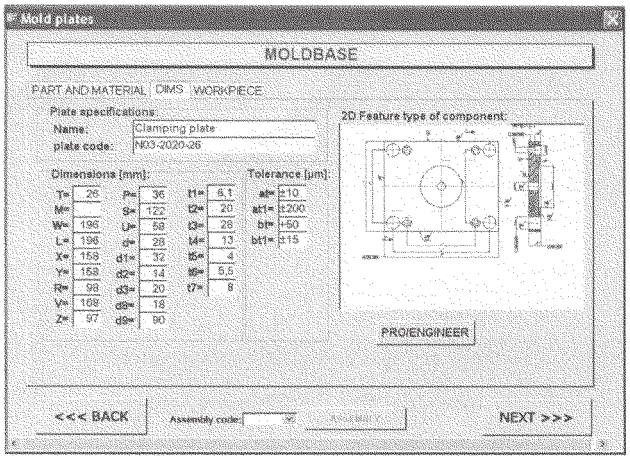

Fig.11. Form of generating solid model of clamping mold plate

Table 1
CAE/II OUTCOME OF PARAMETERS OF INJECTION MOLDING PROCESS

Cooling time	1,9 sec
Environmental Temperature	T_o=20°C
Optimal wall thickness	2,7 mm
Waterline diameter	6 mm
Contoled mold outside temperature	T_o=32,5°C
Isotropic coefficient of thermal expansion for ABS 780	$\alpha_1 = \alpha_2 = \alpha =$ $9{,}4 \cdot 10^{-0{,}05}$ 1/°C
Enthalpy of ABS on T_0=20°C	h_2=387870 J/kg
Plastification time	t_{ps}=0,15 s
Estimated cycle time	$\tau_c = 5$ s
Max mold cavity temperature	T_D=42°C

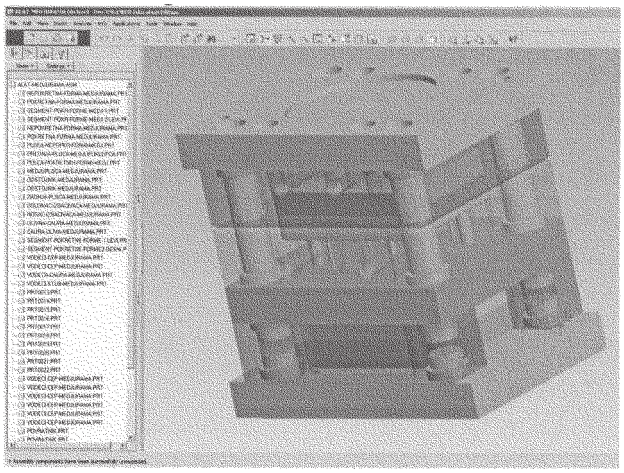

Fig.12. Completed mold assembly designed in CAD/II module

Afterwards, the user chooses mold plates from the moldbase. Form of selection of D-M-E standard mold plates is presented in figure 10. Software selects all standard mold plates due to calculation dimensions of fixed and movable mold plates. The DIN ISO standard 12165, "Components for Compression, Injection, and Compression-Injection Molds" classifies molds on the basis of the following criteria: standard molds (two-plate molds), split-cavity molds (split-follower molds), stripper plate molds, three-plate molds, stack molds and hot runner molds. According to the recommended plate choice, the dimensions of mold components are entered from database and thus, 3D model is generated. Dimensions of the mold component (for example clamping plate) are presented in figure 11.Segment of the outcome results of CAE/II module is illustrated in table 2.

After dimensioning and selecting mold components, CAE/II module generates 3D model of the fixed and movable plate without cavity. Geometry mold specifications which are calculated in CAE/II module, automatically integrate into CAD/II module; the assembly model of the mold, with all necessary mold plates, is the final result of CAD/II outcome, as indicated in figure 12.

Conclusion

The paper presentes the process design of plastic parts production by means of Pro/Engineer software system and specially developed application of mold design. As the production results show that the analyses performed during the process design are correct, the integrated CAD/CAE system proves to be a confident software tool. All described modules of CAD/CAE system are 3D solid-based, feature oriented, associative and modular. Plastics flow simulation in CAE/I allows engineers to determine optimal critical parameters. CAD/II module enables engineers to capture their own unique design standards and best practices directly within the mold assemblies and components. Module for calculation of mold specification and parameters of injection molding (CAE/II) improves design efficiency and reduces mold design error and provides relevant geometry and technology data inevitable for complete mold design. Furthermore, the standard components library (CAD/II) ensures consistency in mold development and reduces the time and manufacturing cost of standard components. Developed specialized program solution, i.e. integrated CAD/CAE system, enables the automation of a large number of activities in plastic parts design (DFX).

References

1.FETECAU. C., STAN, F. Mat. Plast., **44**, nr. 3., 2007, p. 180
2.TODIC, V., LUKIC, D., STEVIC, M., MILOSEVIC, M., Mat. PLast., **45**, nr. 4., 2008, p. 381
3.GODEC, D. Doprinos sustavnosnom razvoju kalupa za injekciono prešanje plastomera, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia, MSc Thesis, 2000, p. 146

4.KOVLJENIC, B., IVANOVIC, R., PUZOVIC, R., POPOVIC, M. The state and perspectives of CAD/CAM/CAE application in plastic products and corresponding tools design, Proceeding of 29th JUPITER conference, Mechanical Engineering Faculty, Belgrade, 2003, p. 2.47
5.JONG, W. R., WU, C. H., LIU, H. H., LI, M. Y. A collaborative navigation system for concurrent mold design, The International Journal of Advanced Manufacturing Technology, **40**, nr. 3-4, 2009, p. 215.
6.FETECAU, C., COSMA L., STAN, F. Mat. Plast., **44**, nr. 2, 2007, p. 163
7.LOW, M. L. H., LEE, K.S. Application of standardization for initial design of plastic injection moulds., International Journal of Production Research, **41**, nr. 10, 2003, p.2301
8.LIN, B. T., CHANG, M. R., HUANG, H. L., LIU, C. H.: Computer-aided structural design of drawing dies for stamping processes based on functional features, The International Journal of Advanced Manufacturing Technology, doi: 10.1007/s00170-008-1670-7, Accepted: 11 July 2008 (Article in press).
9.LIN, B. T., CHAN, C. K., WANG, J. C. A knowledge-based parametric design system for drawing dies, The International Journal of Advanced Manufacturing Technology, **36**, nr. 7-8, 2008, p. 671
10. KONG, L., FUH, J. Y. H., LEE, K. S., LIU, X. L., LING, L. S., ZHANG, Y. F., NEE, A. Y. C. A Windows-native 3D plastic injection mold design system, Journal of Materials Processing Technology, **139**, nr. 1-3, 2003, p. 81
11. MAICAN, E, BAYER, M., TABARA A. I., BALASOIU, V.., Mat. PLast., **45**, nr. 2, 2008, p. 184
12. LI, C. L. A feature-based approach to injection mould cooling system design, Computer-Aided Design, 33, nr. **14**, 2001, p. 1073
13. VODA, M., BORDEASU, I., MESMACQUE, G., CHITAC, V., TABARA, I. Mat. Plast., **44**, nr. 3, 2007, p. 254
14. CHUNG, J., LEE, K.: A framework of collaborative design environment for injection molding, Computers in Industry, **47**, nr. 3, 2002, p. 319
15. QIAO, H. A. systematic computer-aided approach to cooling system optimal design in plastic injection molding, International Journal of Mechanical Sciences, **48**, nr. 4, 2006, p. 430
16. HADAR, A., BORDEASU I., MITELEA I., VLASCEANU D. Mat. Plast., **43**, nr.1, 2006, p.70.
17. HUANG, J. M., JOU, Y. T., ZHANG, L. C., WANG, S. T., HUANG, C. X: A web-based model for developing: A mold base design system, Expert Systems with Applications, **36**, nr. 4, 2009, p. 8356
18. MOK, C. K, CHIN, K. S, LAN, H. An Internet-based intelligent design system for injection moulds, Robotics and Computer-Integrated Manufacturing, **24**, nr. 1, 2008, p. 1
19. LOU, Z., JIANG, H., RUAN, X. Development of an integrated knowledge-based system for mold-base design, Journal of Materials Processing Technology, **150**, nr. 1-2, 2004, p. 194
20. ZHOU, H., SHI, S., MA, B. Virtual injection molding system based on numerical simulation, The International Journal of Advanced Manufacturing Technology, **40**, nr. 3-4, 2009, p. 297
21. ANTON, L. E., BORDEASU, I., TABARA, I., Mat. Plast., **45**, nr. 2, 2008, p. 190

Manuscript received: 24.04.2009