ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
UDC/UDK 621.744:004.891/.896

RULE BASE REASONING IN THE KNOWLEDGE-BASED MOULD DESIGN SYSTEM

Miodrag Hadzistevic, Ivan Matin, Janko Hodolic, Djordje Vukelic, Srdjan Vukmirovic, Damir Godec, Bogdan Nedic

Preliminary notes
This paper describes knowledge-based oriented, parametric, modular, and feature-based integrated CAD/CAE system for mould design. The proposed system integrates Pro/E system with developed original module for calculation of parameters of injection moulding and mould design calculation and selection. The system interface uses parametric and CAD/CAE feature-based database to make the process of design, editing, and reviewing smoother. An example is provided to demonstrate our approach in rule-based representation. Also presented the lists of KBE techniques used for building the knowledge-based system and especially production rules reasoning.

Keywords: *knowledge-based system, mould design, production rules*

Ekspertni sustav za konstruiranje kalupa primjenom pravila zaključivanja

Prethodno priopćenje
U članku se prikazuje parametarski, modularni, integrirani CAD/CAE sustav za konstruiranje kalupa, temeljen na značajkama. Predloženi sustav integrira Pro/E s izvorno razvijenim modulom za izračunavanje parametara injekcijskog prešanja, parametara kalupa i izbor kalupa. Sučelje koristi parametarske CAD/CAE značajke iz tipsko-orijentirane baze podataka, što doprinosi jednostavnijem procesu konstruiranja, uređivanja i izmjene podataka. S obzirom na prethodno istraživanje, članak prikazuje mogućnost modeliranja sustava primjenom pravila. U članku se još predstavlja popis inženjerskih metoda koje su se koristile za gradnju sustava zasnovanog na znanju, a metoda zaključivanja na osnovu pravila proizvodnje predstavlja se detaljnije.

Ključne riječi: *konstruiranje kalupa, pravila proizvodnje, sustav zasnovan na znanju*

1 Introduction

Mould design is an intensive knowledge process involving many parameters that need to be considered in a concurrent manner [1 ÷ 3]. In order to design a mould, many important factors must be taken into consideration. These factors are mould size, number of cavity, cavity layout, runner subsystem, gating subsystem, shrinkage, ejection subsystem, etc.

Godec et al. [4, 5] have developed a CAE system for analytical mould calculation and selection. System is used for thermal, rheological and mechanical calculation and injection moulding machine (IMM) selection. Program system used matrix and production rules for decision-making process. Novak [6] has developed modules such as FEMDES, OSCAR, PROPOSE and DFPOLYMERS for decision support in engineering product design. Providing computer-aided (CA) decision support is one of the computational support techniques that proved to be effective in enabling more intelligent and less experience-dependent design performance. Their research is based on some of the most crucial areas of product design, plastic material selection, engineering process that requires additional computational intelligence in terms of selection support. Authors have integrated modules with different design aspects. Rujnic-Sokele et al. [7] presented important injection moulding parameters such as injection pressure, packing pressure, injection and packing time, and influence of packing pressure and appropriate packing pressure time on moulded part weight and dimensional stability and hardness of the moulded part. Packaging pressure and appropriate packing time have dominant influence to mass properties of ABS. Ogrizovic and Dudakovic [8] established a calculation model using MATHCAD for the gear geometry calculation. They used Pro/E modules for gear wheel CAD modelling, numerical simulation of plastic injection moulding process and CNC manufacturing. They used HASCO standard mould base library as a part of the Pro/Mold Library. The advanced geometric modelling method of CAD and calculation ability of CAE are combined closely by CAD/CAE integration technology, it is also adapted to the attributes of modern design, such as parametric design, model modification and requirement of reanalysis. Lou et al. [9] developed knowledge-based system (KBS) for mould base design. The system has module for cavity calculation, dimension calculation, calculation of the number of mould plates and IMM selection. The system used standard Pro/Mould base library. Ma et al. [10] developed standard component library for plastic injection mould design using an object-oriented approach. This is object-oriented, library model for defining mechanical components parametrically. Xu et al. [11] used Multi Model Technology (MMT) for integration CAD/CAE/CAM. This model uses object-oriented technology in the product modelling process together with feature based model technology. It means that they used single basic solid CAD model to generate all other required models in the subsequent layers of product development process. Todic et al. [12] developed integrated CAD/CAPP/CAM for plastic injection mould manufacturing using mostly RBR technique. The expert system has a module for plastic material selection and the module for machine (CNC and EDM) selection.

Many authors have developed CAD/CAE mould design systems for plastic injection moulding which are specially developed on modular bases and integrated with commercial system Pro/E [1, 3, 13 ÷ 18], Solid Works [19 ÷ 23], and UG [24, 25]. The knowledge-based mould design system makes possible to perform:

- 3D modelling of the parts, analysis of part design and simulation model design,

- numerical simulation of injection moulding process,
- Mould design with required calculations and IMM selection.

2 Simplified structure of the KBS

Simplified modular structure and flow chart of mould design process are presented in Fig. 1.

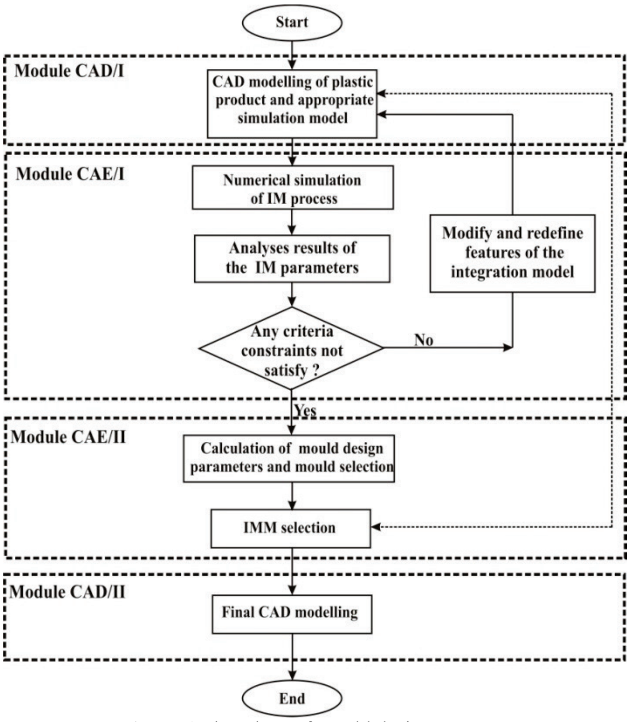

Figure 1 Flowchart of mould design process

The KBS for mould design consists of four modules, such as:

- Module CAD/I for CAD modelling of the product and appropriate simulation model,
- Module CAE/I for numerical simulation of injection moulding process,
- Module CAE/II for calculation of parameters of injection moulding and mould design calculation and selection
- Module CAD/II for final mould modelling (core, cavity and impression design and design of all residual mould components).

2.1 Module for CAD modelling of the product and appropriate simulation model (module CAD/I)

The module CAD/I is used for generating CAD model of the plastic product and appropriate simulation model. The result of this module is a solid model of plastic part with all necessary geometrical and precision specifications. Precision specifications are: project name, number, feature ID, feature name, position of base point, code number of simulation annealing, trade material name and material grade, part tolerance, machine specification such as name, daylight, maximal clamping force, distance between tie bars, shot weight for actual material, or shot weight for PS and maximal injection pressure and number of cavity. If geometrical and precision specifications are specified (given) with product model, the same are used as input to the next module, while this module is used only to generate the simulation model.

2.2 Module for numerical simulation of injection moulding process (module CAE/I)

All polymers can be processed by injection moulding. As is well known, injection-moulding process is a dynamic non-linear complex process. A typical injection moulding process consists of four stages:

- filling of the plastic material into the mould;
- packing of more material into the mould under high pressure to compensate for shrinkage of the material as it cools;
- cooling during which the plastic material solidifies;
- ejection of the moulded part from the mould.

During filling, packing and cooling, the material experiences a complex thermo-mechanical history, which leads to changes in local specific volume. While the part is in the mould, it is constrained within the plane of the part and so stresses develop in the part during solidification. Upon ejection, the relaxation of these stresses causes instantaneous shrinkage that is usually anisotropic and non-uniform throughout the moulded part. The module CAE/I is used for numerical simulation of this process by PTC Pro/Plastic Advisor software. User implements an iterative numerical simulation process for determining the mouldability parameters and simulation model specification.

2.3 Module for calculation of parameters of injection moulding and mould design calculation and selection (module CAE/II)

This module is used for thermal, rheological and mechanical calculations, mould sizing, and its selection. Module recommends mould-base type and all mould plates. After selection user loads appropriate mould-base assembly or each plate independently one by one.

2.4 Module for final mould modelling (module CAD/II)

This module is used for core, cavity, and impression design and design of all residual mould components. This module uses special software tools for automation creating core and cavity from simulation model including recommended shrinkage factor. This module is used for CAD design waterlines and runners, too.

3 Techniques for development KBS for mould design

Various authors use design automation techniques such as knowledge base engineering (KBE) such as (RBR - rule base reasoning, CBR - case base reasoning, PDT - parametric design template) or design optimization techniques such as traditional (NLP - nonlinear programming, LP - linear programming, GBA - gradient based algorithm, IR - iterative redesign, HR - heuristic reasoning) or meta-heuristic search such as (TS - tabu search, SA - simulation annealing, GA - genetic algorithm) and other special techniques such as (SPA - space allocation, AR - analogical reasoning, and ED - evolutionary design).

Simplified structure of the developed CAD/CAE integrated KBS for mould design is described in previous section. There are two ways of integration in the proposed KBS. The first one is integration of the module CAD/I and module CAE/I and the next one is module CAE/I and module CAE/II, see in Fig. 2. For integration of the CAD and CAE at parametric level, our research team used simple Common Data Model (CDM).

The described structure of the KBS is built using several techniques such as OOP - object oriented programming, CSP - constrain satisfaction problem, SA - simulated annealing, RBR - rule base reasoning, LP - linear programming, PSM - problem satisfaction method, IR - iterative redesign and PDT - parametric design template.

Bill of the techniques, which are used for research, and development of the KBS are presented in Fig. 2.

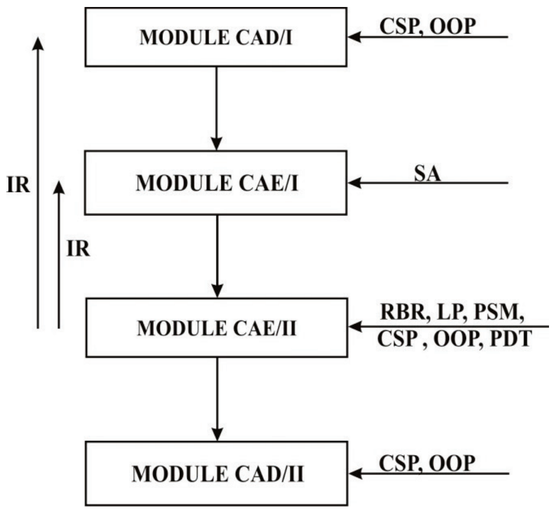

Figure 2 Order list of techniques for building the KBS

RBR is the most widely used of all the previously mentioned techniques. That is why production rule base will be presented in the next section.

3.1 Rules base reasoning in the KBS

The KBS comprises two main elements, a knowledge base and interference mechanism. The KB contains domain knowledge, which may be expressed as any combination of IF-THEN rules, factual statements, frames, objects, procedures and cases. A few of the many evaluation rules are given by expressions (1 ÷ 10).

IF x1<Fmax<x2 THEN prediction A, (1)

where are x1, x2 - empirical constraints, A - safety distance on the parting surface and Fmax - calculated clamping force [1].

Calculated length and width of the movable and fixed moulded plates are given by expressions.

Lx=X+2A, (2)

Wy=Y+2A, (3)

where are X - length, and Y - width of the simulation model.

Standard length and standard width of the movable and fixed moulded plates are given by:

IF (Lx, Wy) THEN (seral_code, basic_stand_dims_(L, W)). (4)

General evolution rules for prediction simulation model specifications are given by [1]:

IF (tunnel, plastic_material, mass) THEN prediction simulation_model_dimension (upper_tunnel, length, diameters, radius, angle). (5)

Further, the evaluation rules for mould plates selection can be implemented in an IF/THEN format, e.g.

IF (serial_code, guided_ejector_plates=YES) THEN recommendation (N01, N02, N10A, N10B, N30, N40, N50), (6)

IF (serial_code, guided_ejector_plates=NO) THEN recommendation (NO3, N04, N10A, N10B, N30, N40, N50), (7)

IF (serial_code) AND (guided_ejector_plates=YES) THEN TRUE (N, B, R, SF) AND THEN recommendation (SB, GEB), (8)

IF (serial_code) AND (guided_ejector_plates=NO) THEN prediction (SB, GEB) AND clamp_slots (dimensions, HOLE IDs), (9)

IF SO=TRUE THEN NO thread_holes (HOLE UDFs, RADIUS ID, base_point_dx,dy,dz, THREAD COSMETIC IDs), (10)

where (N, B, R, SF, S, SO) are mould based types.

The mould-based types are:

- N-type mould kit integrates interchangeable plates complete with components but not assembled.
- B-type consists of N-type mould base, which is assembled.
- R-type mould base consists of B-type mould base with four return pins.
- SF-type consists of R-type mould base with sprue bushing, locating ring and sprue puller pin.
- S-type mould kit consists of 2 mould plates N10A, N10B, 3+1 leader pins (FSN) and 3+1 leader pins leader pin bushings (FBN) and,
- SO-type is S-type without screw holes.

The SO-type is instance designed from general S-type using EMX software. Instances without thread_hole features are defined as (Yes/No) feature in Family Table receptively Pro/TABLE. Family table cells are related to MS Excel for next calculation. The evaluation rules for green quality prediction can be implemented in an

IF/THEN format by expressions (11, 12) which are given in Tab. 1.

An area of the quality prediction result is acceptable, only if all of these expressions are true.

Table 1 Expression for green quality prediction

Description	Expression
The flow front temperature (T) is between the minimum (T_{min}) and maximum (T_{max}) recommended temperatures for the plastic material in the DB.	$T_{min} < T < T_{max}$
The pressure drop (p_{drop}) is in the range between 0 % and 80 % of the maximum injection pressure (p_{max}).	$p_{drop} < 0{,}8p_{max}$
The cooling time (t) is less than 1,5 times the average cooling time for the part (t_{av}).	$t < 1{,}5t_{av}$
The shear rate (τ) is less than the maximum recommended shear rate in the material record (τ_{max}).	$\tau < \tau_{max}$
The shear stress (σ) is less than the maximum recommended shear stress in the material record (σ_{max}).	$\sigma < \sigma_{max}$

The gate location analysis indicates an optimal location if the flow of material is balanced. Confidence of fill result shown displays the probability of a region within the cavity filling with plastic material. The quality prediction result measures the expected quality of the simulation model's appearance and its mechanical properties. The fill time result shows the flow path of the plastic through the simulation model. The pressure drop result displays the drop in pressure from the injection point to the selected point, at the moment that point was filled. The injection pressure result displays the pressure at the injection point at the moment each point was filled and the flow front temperature result displays the plastic material melt temperature at each point at the time it was filled. The evaluation rules (11, 12) are part of module CAE/II and controlled number of iteration in the module CAE/I. These rules must be accepted too.

IF (the average of the length and width of a local region, and average wall thickness S_o < 1/4 of average of the length and width of a local region is true) THEN ($SA_x = SA_{opt}$) (11)

and

IF (thickness is less than one quarter of this average) ($SA_x = SA_{opt}$), (12)

where SA_x is actual code number of numerical simulation iteration and where SA_{opt} is simulation code which is passed.

Of course, for real moulded parts, it is time-consuming to apply the above rule to each wall. However, it is often possible to look at the entire part or simulation model and decide whether or not it is suitable to be taken through the module.

4 Case study

The simplified theoretical framework of RBR is presented in previous sections. The KBS was entirely tested on a real case study. The system was tested on the test assembly product, which consists of the lower and upper part. Shaded solid model of tested assembly is presented in Fig. 3.

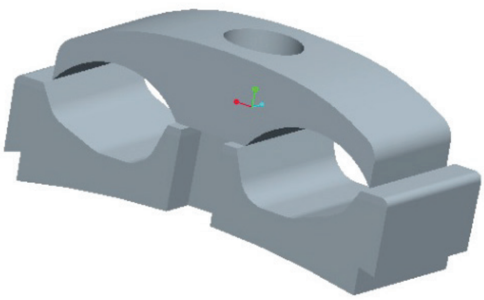

Figure 3 Test assembly

The appropriate simulation model after SA procedure is presented in Fig. 4. The green regions of the simulation model show high confidence of fill as indicated in Fig. 5.

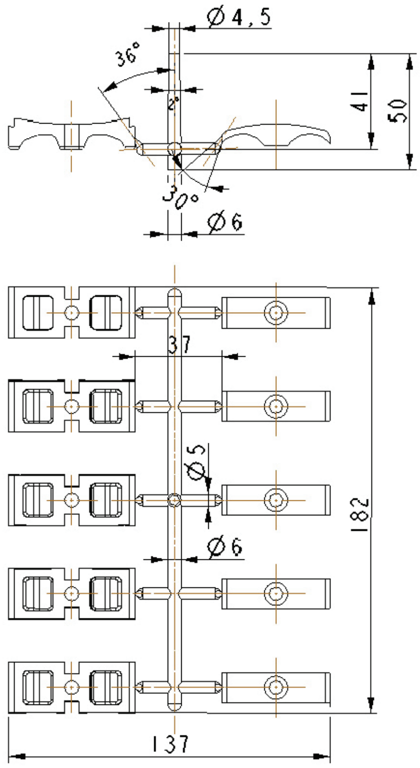

Figure 4 Simulation model

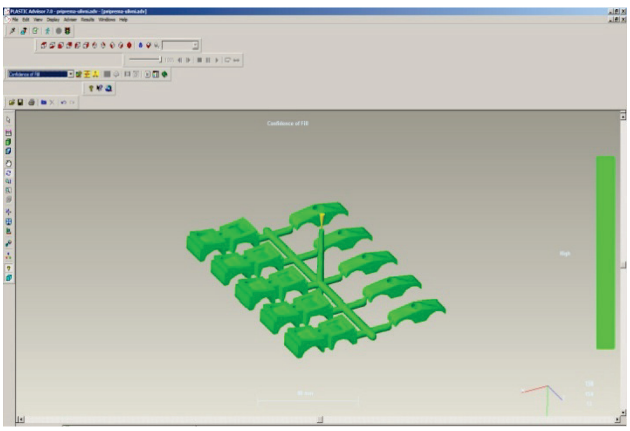

Figure 5 Confidence of fill

Part of the output results from module CAE/I, which are used for final calculation into the module CAE/II are shown in Tab. 2.

Table 2 Part of the output results from the KBS

Material grade and material supplier	ABS 728B, BASF
Max injection pressure	100 MPa
Injection pressure	21,37 MPa
Maximal melt temperature	300 °C
Mould temperature	40 °C
Melt temperature	240 °C
Injection time	2,11 s
Recommended ejection temperature	91 °C
Modulus of elasticity, flow direction	2600 MPa
Modulus of elasticity, transverse direction	2600 MPa
Shear modulus for ABS 728B	946 MPa
Density in liquid state	0,93656 g/cm^3
Density in solid state	1,045 g/cm^3
Max sink marks estimate	0,01 mm
Environmental temperature	20 °C
Waterline diameter	9 mm
Optimal wall thickness measuring between waterline and cavity	27 mm
IMM name and manufacturer	370s by ARBURG
Maximal IMM clamping force	700 kN
Calculated clamping force	456,4 kN
Mass of the tested assembly	11 g
Mass of the simulation model	62 g
Number of cavity	5

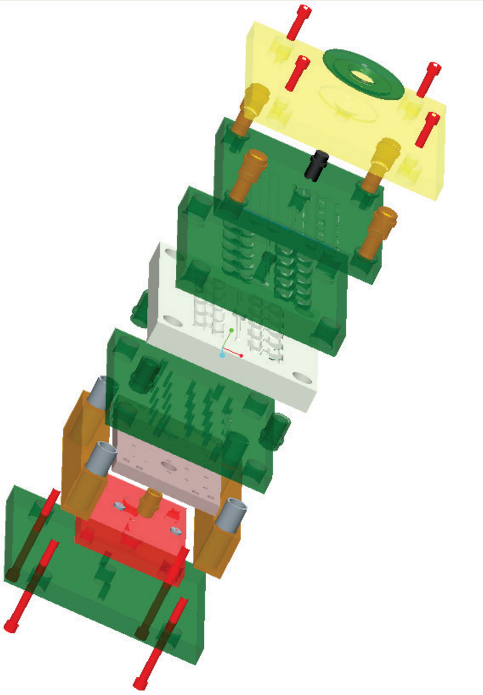

Figure 6 Competed model of the mould assembly

The module CAE/II recommends all the required models of the mould plates such as (N03-2530-26, N04-2530-26, N10A-2530-66, N10B-2530-66, N20-2530-36, N30-2530-66, N40-2530-16 and N50-2530-26). The final model of the mould assembly (L=246 mm, B=296 mm, H=286 mm) is presented in Fig. 6.

5 Conclusion

The KBS for mould design is based on Pro/E system and uses specially designed and developed modules for plastic injection mould design. The described proposed simplified evaluation rules are used for mould base or/and plates selection, simulation model design and green quality prediction confirmation. Manufacture of the tested moulded assembly confirms that the production rules and RBR method are correct.

Future research will be directed towards three main goals. The first is to develop KB and interference engine with adequate subroutine for automated IMM selection from database. Another line of research is usage of other AI methods, e.g. CBR method. Finally, the development of the KBS especially module CAE/II could be focused on developed features and relations for design of fully automated screw selection and fully automated leader pins selection using feature-based modelling, object-oriented programing, based on black-board architecture and D-M-E standard.

Acknowledgment

Results of the investigation presented in this paper are a part of the research realized in the framework of the project TR-035020, financed by the Ministry of Education and Science of the Republic of Serbia.

6 References

[1] Matin, I.; Hadzistevic, M.; Hodolic, J.; Vukelic, D.; Lukic, D. A CAD/CAE-integrated injection mold design system for plastic products. // International Journal of Advanced Manufacturing Technology. 63, 5-8(2012), pp. 595-607.
[2] Chen, D-C; Chen, W-J; Lin, J-Y; Jheng, M-W;Chen, J-M. Finite element analysis of superplastic blow-forming of Ti-6Al-4V sheet into closed ellip-cylindrical die. // International Journal of Simulation Modelling. 9, 1(2010), pp. 17-27.
[3] Slavkovic, R.; Arsovski, S.; Veg, A.; Jugovic, Z.; Jovicic, A; Ducic, N. Casting process optimization by the regression analysis applied on the wear resistant parts molding. // Tehnicki Vjesnik - Technical Gazette. 19, 1(2012), pp. 141-146.
[4] Godec, D.; Sercer M.; Osrecki, G. Design of Mould for Injection moulding of moulded part with internal thread. // Tehnicki Vjesnik - Technical Gazette. 16, 1(2009), pp. 53-62.
[5] Godec, D.; Krsnik, I.; Sercer, M. Od ideje do gotovog proizvoda. // Polimeri. 31, 2(2010), pp. 71-76.
[6] Novak, M. Computer aided decision support in product design engineering. // Tehnicki Vjesnik - Technical Gazette. 19, 4(2012), pp. 743-752.
[7] Rujnic-Sokele, M.; Sercer, M.; Vlasic, N. Influence of packing pressure phase on ABS moulded part properties. // Tehnicki Vjesnik - Technical Gazette. 17, 3(2010), pp. 67-72.
[8] Ogrizovic, M.; Dudakovic, M. The technique of quick designing of casting panel for plastic gear wheel injection. // Tehnicki Vjesnik - Technical Gazette. 17, 2(2010), pp. 251-254.
[9] Lou, Z.; Jiang, H.; Ruan, X. Development of an integrated knowledge-based system for mold-base design. // Journal of Material Processing Technology. 150, 1-2(2004), pp. 194-199.

[10] Ma, Y. S.; Britton, G. A.; Tor, S. B.; Jin, L. Y. Associative assembly design features: concept, implementation and application. // International Journal of Advanced Manufacturing Technology. 32, 5-6(2007), pp. 434-444.
[11] Xu, X. Y.; Wang, Y. Y. Multi-model technology and its application in the intregration of CAD/CAM/CAE. // Journal of Materials Processing Technology. 129, 1-2(2002), pp. 563-567.
[12] Todic, V.; Lukic, D.; Stevic, M.; Milosevic, M. Integrated CAPP System for Plastic Injection Molds Manufacturing. // Materiale Plastice. 45, 4(2008), pp. 381-389.
[13] Huang, J. M.; Jou, Y. T.; Zhang, L. C.; Wang, S.; Huang, C. X. A web-based model for developing a mold base system. // Expert System with Application. 36, 4(2009), pp. 8356-8367.
[14] Jong, W. R.; Wu, Ch.; Liu, H. H.; Li, M. Y. A collaborative navigation system for concurrent mould design. // International Journal of Advanced Manufacturing Technology. 40, 3-4(2009), pp. 215-225.
[15] Lin, B. T.; Chang, M. R.; Huang, H. L.; Liu, C. H. Y. Computer-aided structural design of drawing dies for stamping processes based on functional features. // International Journal of Advanced Manufacturing Technology. 42 (2008), pp. 1140-1152.
[16] Low, M. L. H.; Lee, K. S. Application of standardization for initial design of plastic injection moulds. // International Journal of Production Research. 41, 10(2003), pp.2301-2324
[17] Park, H. S.; Dang, X.P. Structural optimization based on CAD/CAE Integration and metamodeling techniques. // Computer Aided Design. 42, 10(2010), pp. 889-902.
[18] Hodolic, J.; Matin, I.; Stevic, M.; Vukelic, D. Development of Integrated CAD/CAE System for Mold Design for Plastic Injection Molding. // Materiale Plastice. 46, 3(2009), pp. 236-242.
[19] Deng, Y. M.; Edwards, K. L. The role of materials identification and selection in engineering design. // Materials and Design. 28, 1(2007), pp. 131-139.
[20] 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 Material Processing Technology. 139, (2003), pp. 81-89.
[21] Lee, S. H. Feature-based non-manifold modeling system to integrate design and analysis of injection molding products. // Journal of Mechanical Science and Technology. 23 (2009), pp. 1331-1341.
[22] Lee, S. H. A CAD-CAE Integration Approach Using Feature-Based Multi-Resolution and Multi-Abstraction Modelling Techniques. // Computer-Aided Design. 37, (2005), pp. 941-955.
[23] Mok, H. S; Kim, Ch. K; Kim, Ch. B. Automation of Mold designs with the reuse of standard parts. // Expert Systems with Applications. 38, 10(2011), pp. 12537-12547.
[24] Yin, C. G.; Ma, Y. S. Parametric feature constraint modeling and mapping in product development. // Advanced Engineering Informatics. 26, 3(2012), pp. 539-552.
[25] Zhou, H.; Shi, S.; Ma, B. A virtual injection moulding system based on numerical simulation. // International Journal of Manufacturing Technology. 40, (2009), pp. 297-306.

Authors' addresses

Dr. Sc. Miodrag Hadzistevic
University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
E-mail: miodrags@uns.ac.rs

Dr. Sc. Ivan Matin
University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
E-mail: matini@uns.ac.rs

Dr. Sc. Janko Hodolic
University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
e-mail: hodolic@uns.ac.rs

Dr. Sc. Djordje Vukelic
University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
E-mail: vukelic@uns.ac.rs

Dr. Sc. Srdjan Vukmirovic
University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
E-mail: srdjanvu@uns.ac.rs

Dr. Sc. Damir Godec
University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture
Ivana Lucica 5
10000 Zagreb, Croatia
E-mail: damir.godec@fsb.hr

Dr. Sc. Bogdan Nedic
University of Kragujevac
Faculty of Engineering
Sestre Janjic 6
34000 Kragujevac, Serbia
E-mail: nedic@kg.ac.rs