Journal for Technology of Plasticity, Vol. 26 (2001), Number 1

THE FUTURE OF INJECTION MOULDING OF POLYMERS

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ABSTRACT

The injection moulding is one of the most sophisticated and very popular procedures in the production of polymeric parts. The position of the procedures of injection moulding in the main production chain has been indicated. Parts produced by these primary-shaping procedures are not only with well-defined shape and dimensions, but often also with very close tolerances. This is the main reason why is this procedure so popular. At the same time the development tendency in the production of polymeric parts shows an increasing significance in combining the structure of matter or material, processing conditions and the final properties of the product. This requires more numerous versions of the fundamental injection moulding procedure. Their description has been left out due to the great number of procedures, at least 106. In the Table 1 the most important injection moulding procedures has been given, grouped according the description of the most important characteristics of single procedures.
Keywords*: polymers, injection moulding, main production chain, product development*

1. INTRODUCTION

One of the characteristics of the second half of the last century of the last millennium was the dramatic increase in the production of natural rubber, and especially plastics. In 1950, about 1 million tonnes of plastics was produced and at the end of the century more than 150 million tonnes. [1]
The next century will be, among others, marked by a strong development of information technology and telecommunications. Particular emphasis will be on the development of biotechnology, one of two human, artificial technologies. [2] However, even in the very far future the needs of 8 or more billion people will require primarily products of common dimensions, which means macro-technical products such as passenger vehicles. It may be expected that these products will incorporate structures that belong to the field of micro-technology (10^{-6} m) i.e. nano-

technology (10^{-9} m). At the same time we must to pay attention to the pico-technology (10^{-12} m) or femto-technology (e. g. 10^{-15} s, e.g. femtolaser).

What will this development mean for the future of polymer technology and polymer engineering? These are namely the two fields of human activities that have to convert the results of research of the basic natural sciences: physics, chemistry and biology, into the material products.

The polymer production volume has to follow the foreseeable general economic growth, and the improved production procedures of polymeric materials and polymeric elements have to contribute as well to the economic and technical development. The quantitative assessment of the production future of polymeric materials (plastics and rubber) up to the year 2020 about 380 thousands tons. [3] This assessment depends on the economic-market conditions providing increase in consumption, and also on the expected improvements in the production of these materials and the procedures that will lead to new areas of application. [3]

Following the experience in previous development of the polymeric parts production, and also in the production of parts not depending on the type of material, a conclusion can be made. In the next period, regarding production of polymeric parts, no dramatic changes are to be expected. The basic production procedures of polymeric parts, such as reactive and non-reactive extrusion, calendering, coating, casting, and the main moulding procedures will retain their significance. This refers in particular to the basic procedure of injection moulding of thermoplastic melts, and advanced injection moulding procedures. The same goes for the procedures of reshaping blow

Main Production Chain in Injection Moulding

In order to transform the idea into the final product, thing, here moulding, and then to deposit the used rest of the wasted (exhausted) product, a lot of operations are needed. The concretization of the general model of production chain, with example of reactive and non-reactive injection moulding of polymeric matter and materials in the main production chain is given in Figure 1. [5]

The main production chain for making of polymeric parts by injection moulding would be in short described from the idea about the product to the disposal of the residue.

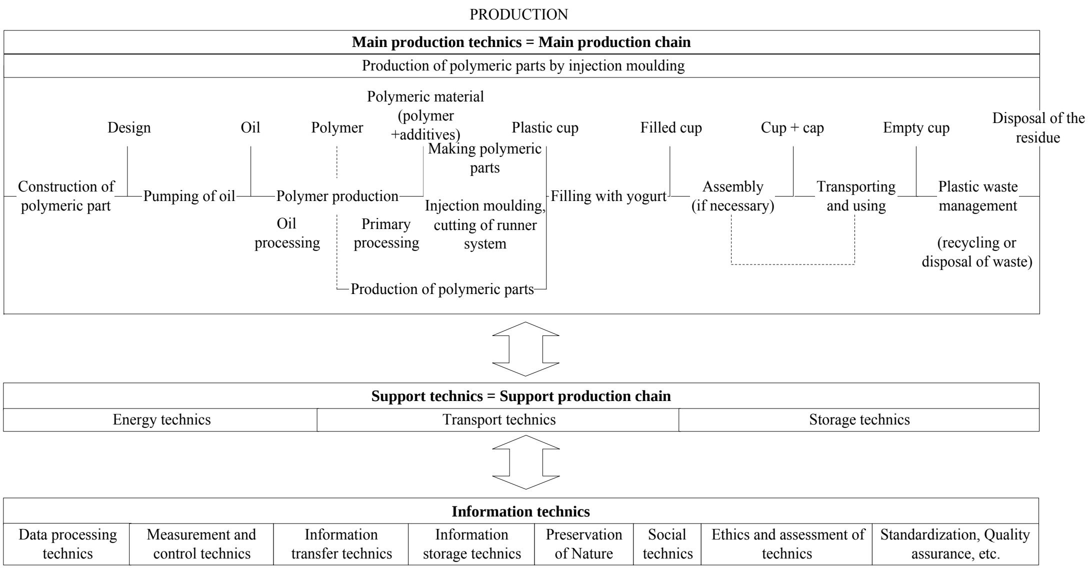

Figure 1. Concretization of general model of production chain with for making of polymeric parts by injection moulding [5]

2. PRODUCT DEVELOPMENT

There are an ever-increasing number of experts who understand the specific characteristics of the polymeric product development. This is indeed a very substantial fact, since polymers, regarding their properties from the aspect of product structure, represent a very complex family of materials.
However, certain specific characteristics in the development of a product need to be emphasised. The product requirements are becoming more versatile and they demand increasingly improved production procedures. There is an ever-deeper connection between the structure and the properties. Here, the usage or final characteristics of polymeric parts depend directly on the procedure of primary shaping, in this case of injection moulding. Therefore, apart from knowing the rules regarding product design and materials, the product designer has to have knowledge about the production procedures. At the same time, when developing a product, the product designer has to take several more independent fields of activities that directly influence the final form of the product. These include manipulatibility, suitability for assembling, and recyclability and recoverability. Special field of activity within the product development belongs to the selection of optimal polymeric material. For some details on the trends in the field of material development see e.g. [5]
In product development, there is an increasing usage of various simulation methods, primarily based on the finite element method and similar methods. Calculations, i.e. testing of products is carried out regarding mechanical and other moulded part stresses, polymer flow in the mould and the necessary duration of solidification. These simulations allow optimising of material consumption and production times.
A special field of product designer's activities that connects him at the same time with the design of the necessary mould is rapid prototyping. Prototypes can be physical or virtual. In the former case a physical model for various purposes is made. Regarding the wide scope of this relatively new field of activities, it is impossible to consider this topic in more detail.

3. PARTIALLY OVERVIEW ON INJECTION MOULDING PROCEDURES

There is an ever-increasing number of the basically variant injection moulding procedures, called mostly advanced injection moulding (AIM) procedures. It is therefore necessary to classify these procedures, at the same time encompassing the basic procedures of injection moulding.
moulding and thermoforming. The development will be directed to enhancing and variant procedures. The tendency will also be towards further improvement of procedures so as to meet the requirements regarding the production of parts not only at the macro-level, but also at the micro-level and the nano-level as well. The production of parts of changed structure will gain in significance: foam products (normal and integral), as well as reinforced products of customised (tailor-made) properties.
Having this in the mind cyclic procedure of primary shaping, injection moulding has an excellent future. This is also confirmed by the following data: the annual demand for injection moulding machines is forecasted to increase from the current sales of 60,000 units to 100,000 units in 2010. [4]
For further explanation is important to stress that injection moulding can be reactive or non-reactive. The parts can be produced at macro-, micro- and nano-level. The processed materials already contain nano-particles which, among other things, allow for very high strength and quality. The products can be compact or foamy.

4.1. Classification of injection moulding procedures [6]

The classification criteria for injection moulding procedures are numerous and diverse. One of the classifications of injection moulding procedures is regarding the type of material. These are the procedures of primary shaping of polymeric matter and materials, metals and ceramic compounds, or combinations of different matters, like ceramic and thermoplastics or metals and thermoplastics. According to the necessary chemical reaction, it is possible to make a classification into reactive and non-reactive[1] injection moulding procedures. Reactive procedures process all the thermosets and rubber compounds and some thermoplastics. Regarding physical state of matter, we distinguish procedures of injection moulding of liquids and solid particles. In the injection moulding of liquids it is possible primary shaping of melts, dispersions and very low viscous compounds. Injection moulding can transform materials with or without reinforcing fillers. Injection moulded parts can be compact or cellular. The cellular ones can be with integral (structural) skin or normal foams. Special groups of injection moulding are the procedures with the aim of giving the part the necessary surface quality. According to the pressure in the cavity, the injection moulding procedures can be high and low pressure ones. [7]

The basic procedure of injection moulding of polymeric materials is injection moulding of thermoplastic melts. The result is a compact part. This procedure is beyond the interest of this paper.

Wishing to provide those interested with the information about the number and diversity of injection moulding procedures, mostly of the procedures known up to now (around 80) are listed in Table 2 in paper [7]. Based on this Table a shorter version, only with main groups of injection moulding has been worked out for this occasion (Table 1).

Table 1

PROCEDURE	**Primary shaping**	**Pressure in cavity**	**State of matter**	**Art of matter**	**Physical state of matter**	**Product can be**
HIGH PRESSURE PROCEDURES						
Injection moulding of thermoplastic melts	N + (FC)	H	MT (+ R)	TP, TPR	M	C (+R)
Co-injection (sandwich) injection moulding	N	H	MT	TP	M	C
Multi-component injection moulding	N	H	MT	TP + ···	M	C
Lost-core injection moulding	N	H	MT(or MA)	TP	M	C
Injection moulding with double injection	N	H	MT (or MA)	TP	M	C
Encapsulation of prefabricated parts made from different materials by injection moulding	N	H	MT	TP + M	M	CO + C
Special procedures of injection moulding of thermoplastics	N (+ RS)	H	MT	TP (+ M)	M	C (+ C0)
Injection moulding with decoration in mould	N	H	MT	TP +L(or M)	M	C (+ CO)

[1] Later in the text only the syntagm injection moulding will be used for non-reactive injection moulding.

Injection moulding of thermosets	*R*	H	MA	TS	M (or D)	C (+ CO)
Special procedures of injection moulding of rubber compounds	R	H	MA	R	M	C
Special procedures of injection moulding of other matters and materials	N	H	MA	M (or CE) *TP	M	C or SI
LOW PRESSURE PROCEDURES						
Fluid injection moulding	N + FP (+FW/FL)	L	MT	TP	L or M	C or I or SH or F
Other low pressure procedures	N (+ FC) or R	L	MT	TP	M or D	C or SI/F
Reaction injection moulding procedures	R (+ FC)	L	MA	TS, (+ R) TP, R, C, TS	L or M or S	I or C (+ CO), SI
Multi-component reaction injection moulding (MC-RIM)	R	L	MA	TS	D, L	F

Primary shaping: FC – foaming with chemical blow agent, FP – foaming with physical foaming blow agent, FW – foaming with water, alcohol etc., FL – foaming with liquid, N – non-reactive, R- reactive, RS – reshaping; **Pressure in cavity**: H - high pressure procedure, L – low pressure procedure; **State of matter**: MA – matter, MT – material, R –reinforcement filler; **Art of matter:** CE – ceramics; L – label, M – metals, R – rubber, TP – thermoplastics, TPR – thermoplastic rubber, TS – thermosets; **Physical state of matter**: D - dispersion, L - low viscous compounds, M – melt, S – solid; **Product can be**: C- compact, CO – composite, F – cellular, I – Integral (structural) foam, R – reinforced, SI –sintered, SH – skin+hollow

4.2. Most important advanced procedures of injection moulding of thermoplastic melts, other polymers or metals and ceramics with polymers as binder [6, 8]

The biggest group of advanced injection moulding consists of the procedures dedicated to transform the thermoplastic melts into moulding. Due to a great number of procedures, only the most important groups of injection moulding procedures will be mentioned. These are: co-injection (sandwich) injection moulding, and multi-component injection moulding, lost-core injection moulding encapsulation of prefabricated parts made from different materials by injection moulding, injection moulding with decoration in mould, gas- and liquid- assist injection moulding, reaction injection moulding procedures and special procedures of injection moulding of other matters and materials.

5. CONCLUSION

The production of polymeric products increased over the last 50 years by 150 times with a tendency for continuous growth. This intensive development was accompanied by the development of the necessary procedures. This is confirmed by the contents of Table 1. It is impossible to describe within one single text, e.g. only the injection moulding procedures. However, a very important conclusion can be made. Based on the works regarding systemic analysis of injection moulding [9, 10] a general model of injection moulding was developed and it is described in detail in the work. [6] It is precisely this great number of the basically similar procedures, which requires new syntheses that have to enable the understanding of connections and similarities among these procedures.

Acknowledgement

Author would like to thank the Ministry of Science and Technology of the Republic of Croatia for the financing of the project Optimization of Fractal Production of Polymeric Parts*. He would like to thank the junior researcher Dipl. Ing. Maja Rujnić-Sokele for her helps in designing of this text.*

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INJEKCIONO PRESOVANJE POLIMERA

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REZIME

Injekcijsko presanje jedan je od najusavršenijih i vrlo popularnih postupaka u proizvodnji polimernih dijelova. Otpresci načinjeni tim postupkom preoblikovanja odlikuju se ne samo potrebnim oblikom i dimenzijama već i visokom preciznošću.

U uvodnom dijelu rada ukazuje se na veliki značaj koji ima proizvodnja plastike u svijetu. To se ilustrira podatkom da je produkcija gume i plastike u drugoj polovici prošlog stoljeća dramatično porasla. godine 1950 ta produkcija je iznosila 1 milijun tona a na kraju stoljeća više nego 150 milijuna tona. Postupku injekcijskog presanja polimera predviđa se velika budućnost, što se potvrđuje i predviđanjima da će prodaja strojeva za ovaj postupak porasti sa sadašnjih 60.000 na 100.000 jedinica u 2010 godini.

Određen je položaj postupka injekcijskog presanja u glavnom proizvodnom lancu. Data je konkretizacija generalnog modela proizvodnog lanca na primjeru reaktivnog i ne-reaktivnog injekcijskog presanja polimernih tvari. Objašnjava se glavni proizvodni lanac za proizvodnju polimernih tvari injekcijskim presanjem.

Naglašavaju se specifične karakteristike razvoja proizvoda u ovoj oblasti. Zahtjevi proizvoda su sve rigorozniji i raznovrsniji, sve je veća povezanost između strukture materijala i karakteristika proizvoda. Konstruktor dijela stoga mora poznavati ne samo pravila konstruiranja nego i sam proizvodni postupak.

U okviru razvoja proizvoda rabe se različite metode simulacije, prije svega metoga konačnih elemenata. Simulacijom se obuhvaćaju mehaničke osobine, naprijezanja, tok polimera te potrebno vrijeme solidifikacije. Ovakve simulacije omogućuju optimizaciju potrošnje materijala te vremena izrade.