INJECTION AND MICRO INJECTION OF POLYMERIC PLASTICS MATERIALS: A REVIEW

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Abstract: The explosive development of plastics industry due, on one hand the emergence of many new polymers with very different characteristics, on the other hand improves their processing technologies. Injection and micro-injection with extruder, calendaring, are the main training techniques for plastics.Injection molding is the most popular method for producing plastic products because of its high productivity and the manufacturability for making various complex shapes also is a widely used, complex but highly efficient technique for producing a large variety of plastic products, particularly those with high production requirement, tight tolerance and complex shapes.
The paper begins with an introduction on the evolution of obtaining and processing of plastics by injection and follow with injection and micro-injection process presentation with issues such as: process scheme, injection stages, worms and mold displacement, plastification phases, comparison of conventional and modular mold development process. Following factors that influence the presentation, grouped into: input factors (process factors), factors related to material structure and machine and output factors. Also are presented and factors affecting precision molded parts. The main results from the literature refer to: standard deviation vs melt temperature, microgenetic algorithm for locate an optimal solution, weld line strength response to different gate size, weld line V notch profile and principle that the flow front shape influences the V notch; bubble size according to the residence time, microscopic images and roughness; creep strain at different mold temperatures, strategy for optimizing the cooling channels. Other part of the paper refers to analysis of injection and micro-injection using different software. Thus for the beginning is presented the virtual reality environment for plastic injection molding. The main simulation are as follow: filling time, flow simulation, product ejection, gate positions, runner system, cooling channel position, cavity surface temperature profile, warpage and comparison of fibre orientation distribution. Specific properties of plastics products allow a high quality and high reliability to use in various industrial fields such as electronic engineering, aerospace and automotive industry, electrical industry, food industry, industry objects household etc.
Key words: injection, micro-injection, polymeric-plastics materials, finite element analise

1. INTRODUCTION

Plastics are made from polymers and are produced in the temperature at which they become plastic in order to obtain the finished product. Polymer macromolecules are composed of groups of atoms that are repeated more or less ordered along the chain. Macromolecules of interest in terms of technology are those whose molecular weight exceeds 10,000.
In view of their technical utilization of plastics are classified considering the thermomechanical behavior, which takes into account the variation of deformation of a polymer material under constant load, depending on temperature. Thus there are the following groups of polymers: thermoplastics, elastomers and duroplast.
The explosive development of plastics industry due, on one hand the emergence of many new polymers with very different characteristics, on the other hand improve their processing technologies, the rapid expansion resulted in the last 20 years of plastics applications, the emergence of numerous produced from synthetic polymers or modified natural, artificial metals or other materials shortages, which have invaded the artificial environment evolving lives, decisively influencing socio-economic development, [2].
Plastics are some of the most important and widely used materials in the industrialized world. Defined as solid, synthetic, organic polymer materials, plastics are easily formed into almost any shape desired. They have a wide range of physical properties—strength,

rigidity, opacity, color, toughness, hardness, ductility, heat tolerance, thermal and electrical conductivity, etc., and can thus be used in a variety of products and applications. The properties of plastics are so diverse that they can be and are substituted for metals in which case they are called “engineered materials” and, when formed into fibers, substitute for natural fibers like silk and wool, [45].

Plastic products are created by the molding, forming, and shaping of solid or liquid resins. Two types of resins are used in the manufacture of plastics—thermoplastics and thermosets. Thermoplastic resins can be heated and formed repeatedly, but thermoset resins, once heated and formed, cannot be remelted. The process of melting a thermoset resin irreversibly alters the internal linkages of the polymers, making it difficult to recycle products made from the thermoset plastic. In contrast, thermoplastics are generally suitable for recycling.

Plastics occupy a very important role although in recent years has reduced oil and gas extraction, primary sources of raw materials used in manufacturing plastics.

The first industrial plastics were obtained between 1927-1950, so that in the last 70 years over 80% of surrounding has been replaced by products made of plastic, [1].

Cellulose was present on the Earth when there were trees and plants as the main constituent of plant cell walls. Because of this there is no specific date for its discovery, appeared before human birth. Recognition of cellulose as a main constituent of plant cell wall was in 1838 due to findings Anselme Payen french botanist who first isolated from wood pulp. That was understood structure. Currently polysaccharide cellulose is the most widespread in nature and is under the guidance of scientists producing real changes in the processing, use and plant genetics, [3].

Although obtaining cellulose derivatives was attributed to Professor Christian Shonbein Swedish, English inventor Alexander Parkes and American entrepreneur John Wesley, basically, the latter is considered the father of the plastics industry.

Based on metal injection machine, patented in 1870 by John Smith and Jesse Locke, Hyatt brothers made and patented in 1872 the first machine injected molding.

This was the first and most important step in achieving development and plastics processing industry. Since then they have taken many steps, big and small but what is most important is that it has developed plastics processing industry so that today 80% of products manufactured in the world have incorporated at least one polymeric material landmark, [2].

The highlights of the evolution of obtaining and plastics processing industry are presented in Table 1.

Table 1. Evolution of obtaining and processing of plastics [2, 4, 5, 6]

No.	Period of time	Author(s)	Contributions
1	1735-1744	Charles Marie de la Condamine-Franta	He participated from 1735-1744 in a scientific expedition to Peru to measure terrestrial meridian. Down the Amazon River gum trees found in the heart of tropical forest and noted the remarkable qualities of juice that flowed from it.
2	1844	Charles Goodyear-USA	Working on a method of treating gum India, fell a few drops of a mixture of gum rubber and sulfur on a hot disk. He obtained the first patent but had to lead a struggle with a large number of counterfeit and succeeds only in 1852.
3	1860	Charles G. William-Anglia	He made the first step in obtaining synthetic rubber separating isoprene
4	1880, 1884	G. Bouchardot-Franta, Tilden-Anglia	First industrial successes were recorded. Production of synthetic rubber (elastomer) really began during the Second World War to replace natural rubber.
5	1865	P. Schutzenberger, G.V. Nandin	They tried to cellulose esterified with acetic acid.
6	1873	-	Was finding the first acrylic acid ester.
7	1898	H. Schnell	It was discovered polycarbonate industrial process for Bayer company who sold the first product on the market as the Makrolon name.
8	1897	Frencsman, Grenvesse	Were prepared for the first time polifenilensulfura
9	1901	Rohm	Begin the first studies on polymethyl methane.
10	1903	C. F. Cron si L.J. Weber	Patents acetobutariatul cellulose.
11	1907	Leo Baekeland -USA	Discover bakelite.
12	1908	Jacques Brandenberger	Invent manufacture of cellophane, transparent new packaging.
13	1908	Hermann Staudinger	He realised the first study on polymer synthesis.
14	1921	Eichengrun si Bucholz	They designed a machine for cellulose acetate injection.
15	1925	-	Kodac and Rhone Poulenc companies made studies for cellulose production.
16	1930	Waldon Semon	A new material made from waste. The process transforms PVC found in a plastic flexible and durable.
17	1933	R.O. Gibson-Anglia	He created a new plastic, polyethylene from ethylene gas.
18	1933	Wulff-Germania	Put up getting polystyrene.
19	1933	-	Rohn & Haas Company introduced the first methyl polymethacrylate.
20	1934	Wallace H. Carothers	Synthetic fibers appear.

No.	Period of time	Author(s)	Contributions
21	1934	Firma DuPont	Polyvinyl fluoride material was introduced.
22	1935	Firma Farbenindustrie	Was patented styrene-acrylonitrile material.
23	1935	Fawett si Gobson-Anglia	They obtained low density polyethylene.
24	1937	Wallace H. Carothers	Nulonul was patented.
25	1938	Roy J. Plunkett	He realised a successful polymerization of tetrafluoroethylene naming new Teflon material.
26	1939	-	Industrial fabrication of low density polyethylene
27	1939	Firma DuPont -USA	Begin selling nylon.
28	1940	U.S. Ruben	He produced the first acrylic-nitrile-butadiene-styrene.
29	1940	Regnault	Industrial production of polyvinyl chloride began.
30	1941	Carothers, Whinfeld, Dickson	They started the study of linear polyesters.
31	1947	Firma ICI	Starts of industrial production of low density polyethylene.
32	1953-1954	Karl Ziegler	Appears the high density polyethylene
33	1954	Giulio Natta-Italia	He obtain new synthetic polypropylene.
34	1958	Firma DuPont	He produced the first polyacetal.
35	1960	Firma DuPont	Produced the linear polyethylene.
36	1961	Firma Penn Salt Chemicals	The first industrial-scale production of polyvinyl fluoride.
37	1964	Allan Hay	He found polifenilenoxidul.
38	1965	-	It was introduced in manufacturing the polysulphones.
39	1970	Robert Jarvik si Willem Kolff	They made the first artificial heart in plastic, aluminum and synthetic fibers called Dacron.
40	1970	Firma Celanese	The material released polibutilenterftalat.
41	1970	Joseph L. Wirt	He discovered material called polyetherimides.
42	1970	-	Liquid crystal polymers have appeared.
43	1981	Gerard Eleens	He realised the synthetic material family (Peba) used in the manufacture of sports equipment.
44	1986	Firma Mitsui Petrochimical-Japonia	It is found polimetilenpentena.
45	1991	Firma Solvey	A mixture made from poliarilamida and polypropylene.
46	1994	Compania Cincinnati-Milacron	Sells for first time computer controlled injection machines in the United States of America.

Specific properties of plastics products allow a high quality and high reliability to use in various industrial fields such as electronic engineering, aerospace and automotive industry, electrical industry, food industry, industry objects household etc. At the beginning of the century plastics industry grows more pronounced with assured markets on all continents. Most dynamic development of this industry is registered in China exceeded production in Europe and North America.

The specific characteristics of plastics will lead the development of a high quality product with great performance and reliability technology. In the past 50 years the production of plastics has doubled every five years, so it is estimated that in 2010 world production will be 390 million tons, [1, 11, 13]. In 2002, the U.S. industry producing machinery for processing plastics has created 1.4 million new jobs and sales of machinery and equipment were USD 300 billion. In 2006 sales volume increased by 9.4% (Equipment Statistics - Annual Report. The Society of the Plastics Industry, Inc.. - SPI).

Injection and micro-injection with extruder, calendaring, are the main training techniques for plastics. The process for injection has really only one disadvantage, namely, high cost of injection molds, for which, through the production process is economical only if a series of manufacturing large enough. Disadvantage that has led researchers to pay particular attention to modeling and simulation of the injection process to form the optimized design objects produced by this process and mold design adequate to achieve desired shapes. Figure 1 shows schematically and briefly evolution plastics processing by injection in the last 80 years, [2].

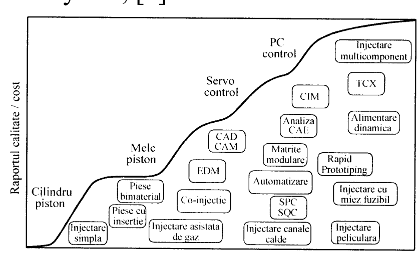


Fig.1. Evolution of polymer processing by injection, [2]

Besides plastics and powder can be injected. Powder injection is a derivate of polymer injection moulding and uses the same technology, along with batch sintering processes used in powder metallurgy. Powder injection moulding is capable of transforming complex designs into high precision, high final properties and net-shaped products, so the filling process is alco complex, [33].

2. THE PRINCIPLE OF INJECTION AND MICRO-INJECTION

2.1 Injection

Plastics injection process is one of the most important processes used in the plastics. Today more than one third of thermoplastics are processed by injection and more than half of polymer processing equipment are injection machines, which are ideal for making parts with complex shapes, and also with high accuracy.

Injection molding is the most popular method for producing plastic products because of its high productivity and the manufacturability for making various complex shapes, [31]. Plastic injection molding is a widely used, complex but highly efficient technique for producing a large variety of plastic products, particularly those with high production requirement, tight tolerance and complex shapes. The quality of injection molded parts is a function of plastic material, part geometry, mold structure and process conditions, [40]. Development and improvement of plastics processing equipment is considered by most people as being as important as the invention of plastics in itself. The main obstacles encountered throughout history in the plastics industry have been the development of processing technologies and developing injection machines. Although the invention of plastic, cellulose, known as celluloid was made Parkesine, Xylon, or Ivoride invention was attributed to three individuals: the Swiss professor, Christian Schonbein, English inventor Alexander Parkes, and American entrepreneur, John Wesley Hyatt, [12]. Hyatt developing the first enterprise in the plastics industry. Plastic injection process is an important part in the plastics industry is big business and the world, consuming about 32% of the total plastics, [8]. Second on the extrusion process, which consumes about 31% of the plastics [8]? United States alone there are about 80,000 injection machines and extruders about 18,000 used to process all types of plastics, [8]. Injection process is a cyclical process, during which succession occurs following operations: dosing of plastic material; heating and melting the plastic inside the cylinder; closing the mold; placing plastic material inside the mold cavity under pressure; melt solidification and cooling; mold opening; elimination product injected. Among these stages above presented, cooling stage is the most important phase because it significantly affects the productivity and the quality of the molded part. Normally, 70%-80% of the molding cycle is taken up by cooling stage, [31]. Simplified injection process of one part inside the mold, is described in Figure 2, [10] and in Figure 3 shows a complete injection cycle, [11]. Granulate raw material is introduced into the chute where it falls in the injection cylinder. Enough plastic injection cylinder is carried by the worm, the movement of rotation to the cylinder head, which is the injection nozzle. Rotation of the screw is made by gearing system. During transport the granules reach the state of the melt due to friction and the heating cylinder heaters. Melted plastic is forced under pressure into the mold by the screw, due to pressure from the drive, [10].

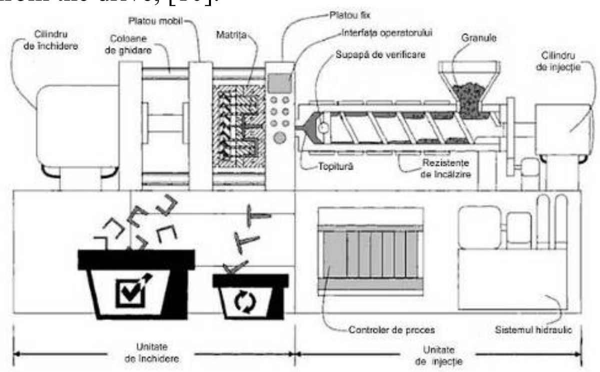


Fig. 2. Schematic diagram of injection, [10]

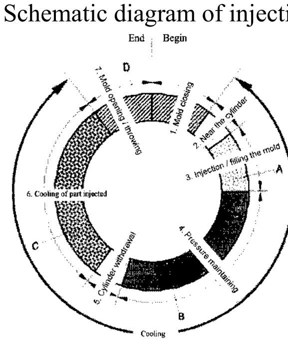


Fig. 3. Injection phases, [11]

Injection, plastic covers operations that are not perfectly defined, thus the polymer thermal lamination start before opening the mold and release the product. Schematic diagram of injection is shown in Figure 4, [12].

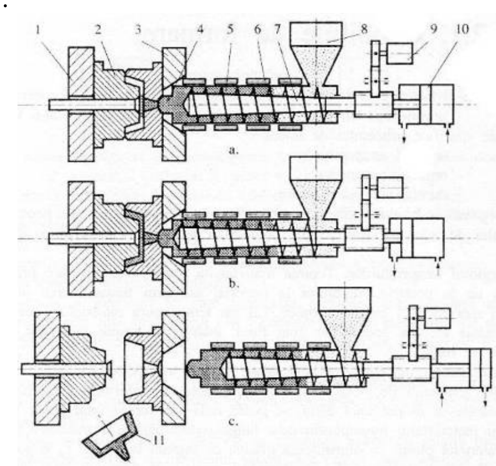


Fig.4. Schematic diagram of injection: a - injection molding material; B - solidification and cooling of the melt, c - throwing open the mold and the part from the mold: 1 - mobile shelf, 2 - matrix, 3 - fixed shelf, 4 - nozzle, 5 - cylinder, 6 - body heating, 7 - snail, 8 - feed hopper, 9 - drive system rotating, 10 - operating system in translational motion, 11 - piece injected

Chart movement worm and mold during the injection process is shown in figure 5, [12]. Entire injection process can be included in the following process steps: lamination, die filling, compacting, cooling and mold release.

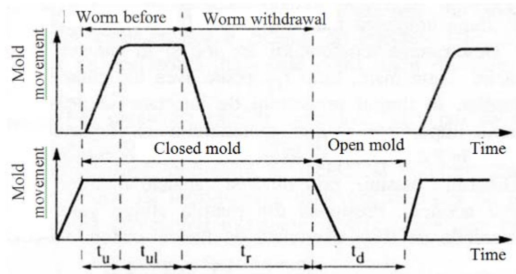


Fig. 5. Worm and mold displacement diagram during the injection process:
t_u - mold filling time; t_{ul} - further pressure time, t_r - cooling time; t_d – demulation time

Figure 6 schematically shows the crossing process of material from solid phase in visco-elastic, visco-plastic and finally melt phases, as the browsing of the four main heating zones of the injection cylinder.

Approximately 60% of the amount of necessary heat to achieve the melting temperature of the plastic is sent to the areas (2), (3) and (4) of plasticizer. In the homogenization area (1), is only required amount of heat that will keep the material temperature during the soaking interval, as close to its melting temperature, [9, 35, 41].

The flow capacity of the material varies radially in the cylinder section, because the melting temperature is higher in the right wall of the heated cylinder.

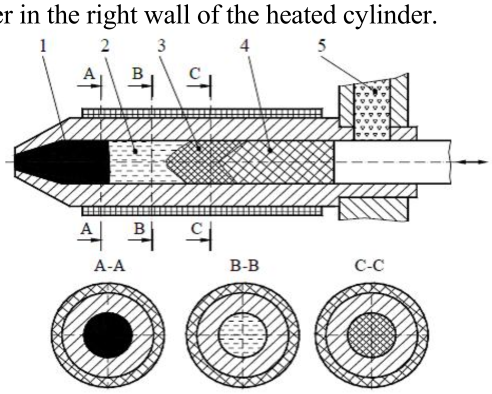


Fig. 6. The plastification phases inside of machine cylinder, [2, 13, 14]:
1 - molten material homogenized 2 – non-homogenized molten material, 3 - partially melted material, 4 - compacted solid material, 5 - granules

The injection can be achieved using modular elements also. Introducing modular design concepts into product design appears a key mean of faciliting product development, since it increases design flexibility and shortens delivery time, [22, 58]. Modularity is to subdivide a complex product into modules that can be independently created and then are easily used interchangeably, [22, 59]. The modularity could be implemented in modularity in design, modularity in use and modularity in production, [60]. The comparison between the modularity design mold development process and the conventional process is presented in the figure 7. Standard structural elements are fast to produce since they are pre-manufactured into general shapes and require minimal manufacturing to yield a finished product. The modular design can be applied in developing beverage-container injection molds, [22].

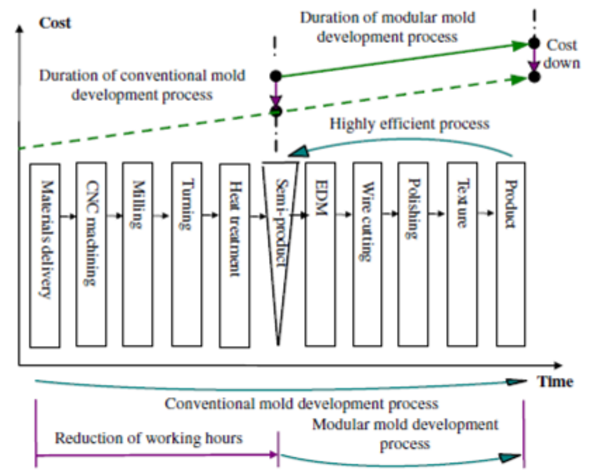


Fig. 7 Comparison of conventional and modular mold development processes, [22]

The important aspect in injection process is the robust motion control for injection moulding machines especially of a clamp-cylinder for energy-saving. As a fundamental step prior to tracking controller design, a feedback control system is suggested by implementing a position control loop in parallel with a system pressure control loop, [32].

2.2 Micro-injection

Miniaturization of products in different fields led to the development of micro-fabrication technologies. Thus the micro-injection is the most developed and widespread micro-technologies because of its mass production capability and relatively low component cost. In this context the micro-injection process of plastic material is one of the key technologies for micro manufacturing of different parts, [17].

Micro-injection moulding, a key technology in high volume micro-manufacturing of polymer-based components, requires accurate control of quality parameters to ensure the replication fidelity and consistency of produced components, [19].

Micro injection molding is a major process for cost-effective mass production of micro plastic parts, [21]. As a hot fabrication technology for micro scale parts, micro injection molding is receiving increasing market attention, [28].

Micro injection molding started in the last eighties last century developed from the traditional injection molding process. It has shorter processing time, which makes it become one of hottest research points of micro fabrication, [62]. Micro injection molding has the following advantages, [28]: processing time is short, suitable for large scale production; net shape molding, further process step is not required; can produced complicated 3D shape parts; easily realized by various industry companies, special equipments needless, like UV light source.

Micro injection molding process represents a key and attractive high cost-efficient technology for realizing large series production of micro dimensional parts and multi micro component binding/assembling [34]. The micro injection molding is always related to some unfavorable defects such as voids, warpage, sink, flow mark, air trap and weld line.

Micro injection molding is a new advanced technology which can realize the manufacture of fine and precision parts with micro-nano structures in one step with high efficiency at low cost, [36].

3. INFLUENCE FACTORS OF PLASTIC PARTS PRODUCTION

Landmarks achieved by injection must meet the purpose for which they are constructed. Quality, dimensional stability of parts depends on the factors that influence the injection process.

The injection can be presented as a system of machine and mold, type information system. The system is characterized by the input quantities, output quantities, parameters and disturbance size. Through systematic analysis of dependencies between input quantities and output quantities can optimize the process. Thus in figure 8 is presented the mold-injected machine.

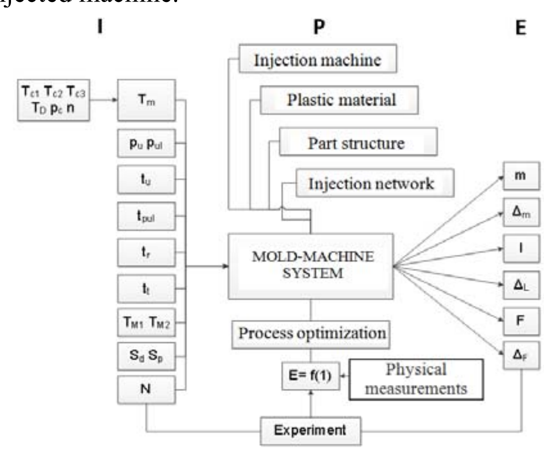


Fig. 8. The mold - injection machine system, [10], [12]

The meaning of terms is as follows: I - input parameters (Tc1...Tc3 - injection cylinder temperatures, TD - nozzle temperature; pc - backpressure dosing, n - worm rotation, Tm - material temperature; pu - filling pressure; pul - further pressure; tu - filling time; tpui – further pressure time; tr -cooling time; tt - total time, TM1, TM2 - mold temperatures, Sp - pillow material, N - mold clamping force); P - parameters, E - output size (m - mass of injected parts, Δm - mass dispersion piece, 1 - size, Δl - dimensional dispersion, F - form deviation, ΔF - dispersion deviation form).

In terms of contraction and deformation of molded parts influence factors are presented in Figure 9, [15].

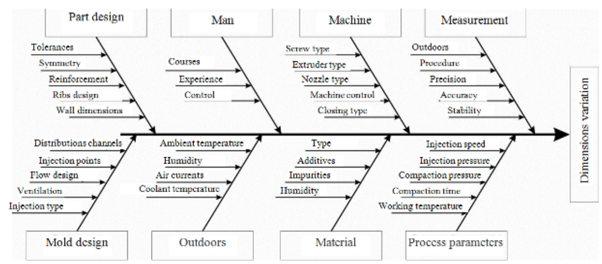


Fig. 9. Factors influencing the size and precision parts, [15]

The processing conditions and factors have always a strong influence on the properties of polymers, particularly its mechanical and long-term behavior. A better control of the process variables would allow for a better control of the final properties of the injection molded thermoplastics. From engineering point of view, the particular process variables that would maximize the product's performance are crucial and from a research point of view the resulting molecular or physical structures that can influence the viscoelastic properties are of fundamental interest and so this area has always been a field of interest to many polymer engineers and scientists, [29].

So, there are many factors which have an important influence upon the injection process. A sub-set of them called process factors are of significant importance and therefore have been studied by many researches such as, [17, 18, 19, 21, 27, 33, 46, 47, 48, 49]. In general, the process factors studied are melt and mould temperature, injection speed/rate, injection and holding pressures and cooling time, [17]. The main conclusions from these studies are that high melt and mould temperatures and high injection speed have a positive effect on the melt flow in very small cavities. Also the injection speed, melt temperature or holding pressure was the most influential factors. The studies were carried out under different experimental conditions for example different polymers and test structures were used. Also it should be point out that although high settings of the considered process factors could improve the melt on injection moulded components. For example, a high mould temperature may results in temperature-induced defects on micro features as reported by Madou [50] and also could increase the cycle time and the processing cost due to the need of additional heating and cooling devices, [51].

Quality parameters (responses) are usually associated with evaluating the replication fidelity of the processes by completely filling the mould cavity, [19]. Typical responses include filling quality of micro-sized channels, features dimension, part mass, flow length, filling volume fraction, weld-line formation, demoulding forces and minimizing Injection time, pressure and temperature distribution using a three-dimensional simulation package, [17, 19, 52, 53, 54].

Usama M Attia and Jeffrey R. Alcok, [19] took into consideration five parameters, such as: polymer-melt temperature, mould temperature, holding pressure, injection velocity and cooling time and the data collected was the component mass. Also a two-level and half factorial design of resolution were selected. The mass of each moulded part was measured using a sensitive scale with a readability of 0,01mg. The purpose of the experiment was to detect potential influential process parameters that affect the variability in part mass rather than the mass of the part itself. Standard deviation of the process replicates would be a measure the extent that is has a normal distribution. Hence the natural logarithm of standard deviation was used as the experimental response. The main conclusion is that in one component no factor was identified as a source of variability, whilst for the other component, melt temperature was identified as a statistically significant factor affecting the replicability of the process. The increasing the melt temperature beyond the limits of the experimental design decreased standard deviation by more 40% (figure 10).

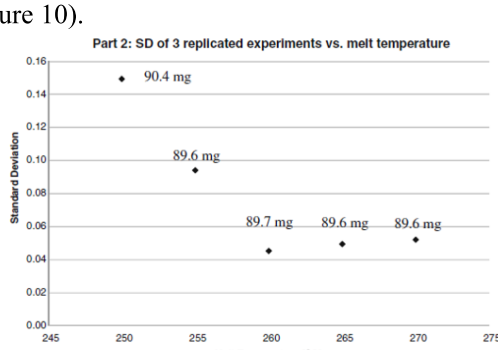


Fig.10. Standard deviation vs melt temperature at recommended setup (mould T of 84°C, injection V of 200mm/s, holding P of 300 bars and cooling t of 3s). Average mass noted for each data point

To minimizing the maximum injection pressure at the injection port and maximum pressure difference among the gates on a product with constraints on shear stress and weld line is necessary to locate the gate positions [24]. From this point it is possible to explore the design of injection mold using a micro genetic algorithm which is based on the Darwin's theory of the survival of the fittest and adopts the concept of natural evolution [24]. This algorithm is advantageous when the design problem is represented by a mixture of integer/discrete and continuous design variables. The main difference between a conventional genetic algorithm and micro genetic algorithm resides on the population size. The micro genetic algorithm process is presented on the figure 11. This micro genetic algorithm enables to locate an optimal solution because of the small size of populations, tournament and elitism operations in selection and the full participation in crossover.

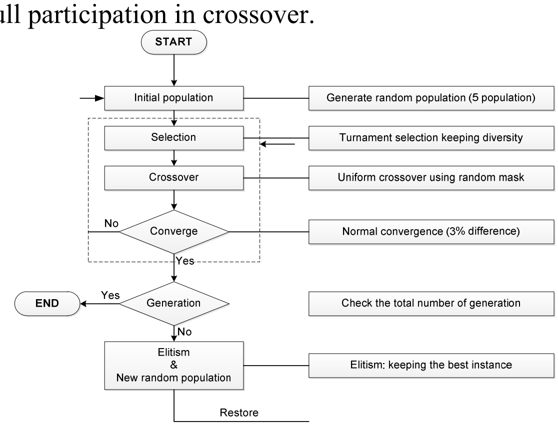


Fig.11. Micro genetic algorithm, [24]

A gate position is one of the most important aspects of product quality of injection molding. Ming Zhai and Ying Xie [38] studied the gate location optimization of plastic injection molding using sequential linear programming. Thus the numerical simulation of injection mold filling process is combined with the design optimization method to find the optimum gate location to achieve balanced flow. The coordination of gate are chosen as design variables and a constraint is employed to limit the clamp force lower than the reference value. Optimization of gate location in the mold design is addressed based on the results of mold filling simulations with finite difference approximation being used to evaluate the sensitivity and the sequential linear programming algorithm implemented as the optimization algorithm. The optimization technique is primarily classifying into two search methods: the direct search method and the gradient-based method [38]. For verification of the purposes a square plate is chosen as the first example since the optimal gate location is known to be at the center of the plate and the second example considers a toy table. The optimization algorithm is as efficient as that adopting injection pressure is an objective function.

Others researchers Li Ji-quan et al, [40] considered that the objective of gate optimization is to minimize the war page of injection molded parts. The optimization is combined with the numerical simulation technology to find the optimal gate position. A gate is characterized by its size and location and the runner system by the size and layout. The gate size and runner layout are usually determined as constants. Different gate locations introduce inhomogeneity in orientation, density, pressure and temperature distribution, accordingly introducing different value and distribution of warpage. Thus the gate location is a valuable design variable to minimize the injection molded part warpage.

Other important aspect concerning the technologically parameters is the effect of gate type and dimension on micro injection molded weld line studied by Lei Xie and Gerhard Ziegmann, [34]. The weld line in unfavorable since it will influence the surface quality and mechanical properties of micro parts. Based on the results for polypropylene, it is apparent that the relation between gate dimension and weld line strength is not linear. In the table 2 are presented the gate dimension used and in figure 12 we can see that the gate no.3 always responds to strongest weld line strength, followed by gate no. 2, gate no. 1 and gate no. 4. They do not show obvious influence on the weld line strength. The gate dimension has effects on the weld line strength and this effect is coupled with processing conditions, [34].

Table 2. Gate dimensions used in the experimental mold

Gate No.	1	2	3	4
Width (mm)	1,5	1,0	1,0	0,5
Depth (mm)	0,1	0,1	0,05	0,1
Length (mm)	0,5	0,5	0,5	0,5

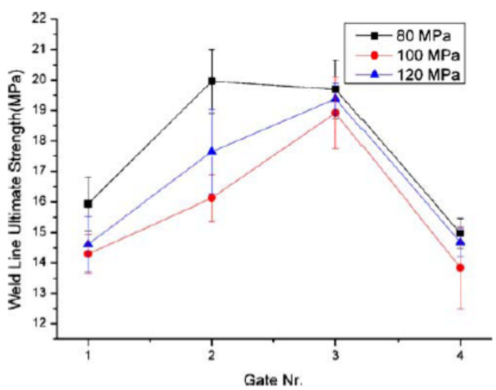


Fig. 12. Weld line strength response to different gate size in 80, 100 and 120 Mpa injection molding pressure for polypropylene, melt temperature 220°C, mold temperature 135°C and injection speed 70cm^3/s

In injection molding of plastics, an important aspect having a bearing on the quality of articles is the appearance of weld lines that are formed when there are inserts, barriers, molding signs, reinforcements and so on, in the cavity of the injection mold, [41]. The melt temperature affects weld strength most. In general, the tensile strength of welds increases with rise of temperature.

Improving mechanical properties of micro parts should be an important issue of micro injection molding process, [28]. Lei Xie and Gerhard Ziegmann, [28] studied the relation between weld line strength in micro injection molding parts and processing parameters such as melt temperature, mold temperature, injection pressure, packing pressure, ejection temperature and injection speed. A visual mold with variotherm unit is designed and constructed in which the micro tensile specimen with weld line are prepared. The low mechanical properties in weld lines are considered to be caused by several factors such as poor intermolecular entanglement across the weld line, molecular orientation induced by fountain flow and the stress concentration effect for surface V-notch [28, 63]. When the mold temperature is not high enough (lower than 120oC) the micro specimen cavity cannot be fully filled, even if the highest injection pressure (2500 bar) was used. That is because the fast freezing problem for polymer melts flowing in micro scale cavity. When the mold temperature increase even in relatively lower injection pressure, the complete filled specimen still can be produced. Figure 13 shows the V notch size in the specimens' middle surface is larger and deeper than in the edge and the surface height in the middle surface is lower than in edge. That can be explained as the frozen layer and shrinkage in middle part of specimen is bigger than in edge part. The smaller V notch area leads to a stringer micro weld line similar to macro scale case. The influencing mechanism of flow front shape on weld line strength is presented in figure 14, [34, 64].

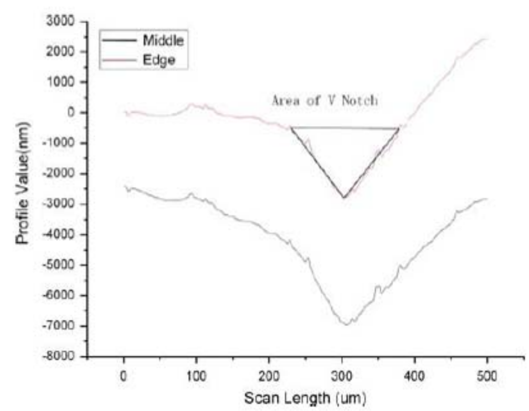


Fig.13. Weld line V notch profile scan test for Micro Weld Line Sample in T_{melt}=210^{O}C, T_{tool}=140 ^{O}C, Inj.pressure=1000 bar, post pressure=800 bar, T_{demold}=60 ^{O}C, Injection speed=80cm^3/s, separately in middle and edge of sample, [28]

Warpage is an important factor affecting product quality. The causes of warpage are attributed to the uneven shrinkage of parts the warpage could be reduced by changing the geometry parts, or modifying the structure of molds, or adjusting the process conditions [44]. It is an important aspect to predict and optimize the warpage deformations before manufacturing takes place. Like factors were taken into consideration the packing pressure, melt temperature, mold temperature and injection time. The Kriging model, [65] combining modified rectangular grid approach is applied to build the approximate relantionship of warpage and the process parameters, and the optimization iterations are based on the approximate relantionship for reducing the high computational cost, [44]. In this paper as far as a cellular phone cover is concerned the injection time is the important factor of warpage in the chosen range.

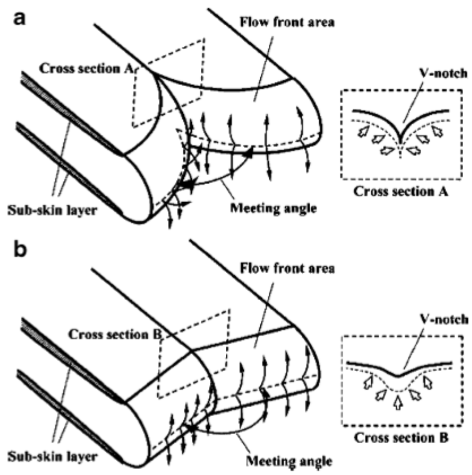


Fig.14. The principle that the flow front shape influences the V notch size which is the main factor deciding weld line strength, [34, 64]

4. ANALYSIS OF THE INJECTION / MICRO-INJECTION

To increase quality injection molds and to optimize the process parameters during injection and micro-injection, different software packages CAD and CAE such as: UG, ProE and SolidWorks for CAD and MolFlow, Simpoe for CAE, they the latter being specialized injection process analysis.

Using these modeling and simulation tools significantly reduce design time parts and molds, and injection process analysis which draws on a shorter time regarding the emergence of a new product on the market. Another major advantage of using these instruments is to analyze the results obtained from simulation and make some corrections to eliminate defects occurring in the simulated injection. Figure 15 shows the stages of work and interaction between them in the process of injection molding plastics.

Injection and micro-injection simulation process using software packages mentioned can generate some major advantages such as: reducing research time and manufacturing time, resulting in a shorter time to bring a new product to market, improve design quality by reducing the number of design errors, and a major advantage would be to cut costs.

A complete simulation model can be seen in figure 16, the model is simulated both the injection and mold working, [30].

Software packages used to simulate the injection process, especially when filling the mold allow varying input parameters in the process, such as: mold temperature, melt temperature, injection time, injection pressure, nozzle type etc., thus can be made an optimization of input parameters in such a way that it generates an optimal point of injection through successive iterations. After software development and comparing the results obtained from simulations with results obtained from mathematical calculations can see a very good accuracy and their closer to the physical model, which leads to increased confidence in the results of steps the software simulation, [37].

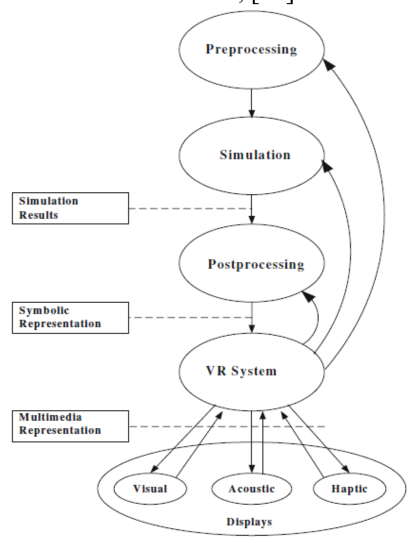


Fig. 15. Virtual reality environment for plastic injection molding

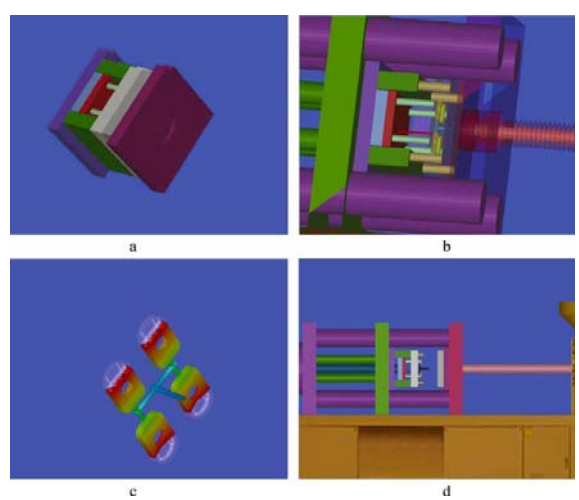


Fig. 16. The example of injection: a- binocular image of the assembled mold; b- the process of filling; c- flow simulation; d -the process of product ejection, [30]

Another factor so important in the plastics injection process can be optimized through simulation is the point of injection, a factor that may have only features: geometric feature that includes the requirements of design, product sharing in the mold and positioning, feature engineering that refers to filling cavities is influenced by the part geometry, size and position of point size and shape filling and filling channels. Regarding this factor to watch two very important aspects, namely: balancing curgetii cavities and location of weld lines.

A balanced fill process leads to an even distribution of pressure and temperature of injection and even a reduction in areas where welding lines appear inside the part. Welding lines represents the area that meet during the injection process with two or more injection points, quantities of melt injected by different injection points. As the welding lines are less present on the surface of a landmark so it is more resistant and durable, thus trying to eliminate, where possible, to this factor, figures 17,18,19,20 and there which can not be eliminated by optimizing the balancing process is trying to inject a displacement of these lines of welding in areas where their influence does not affect the quality and functioning of the landmark, figures 21 and 22a, b, [23].

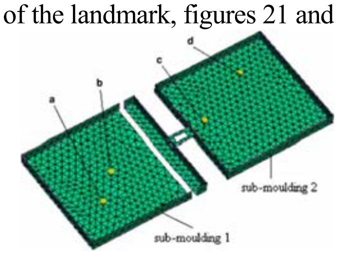


Fig. 17. The gate locations of the sub-mouldings

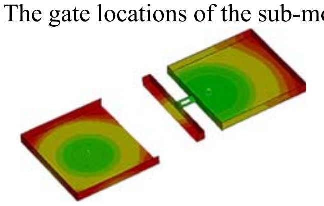


Fig. 18. Filling pattern of the sub-mouldings of the two chamber moulding

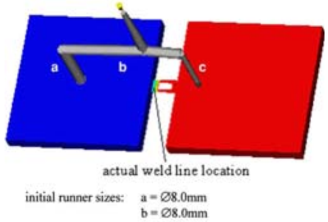


Fig. 19. Actual weld line with the initial runner system

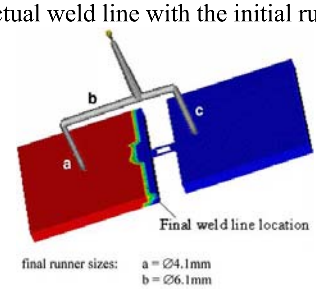


Fig. 20. The final runner design for the two chamber moulding

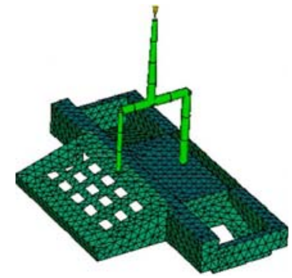


Fig. 21. The runner system

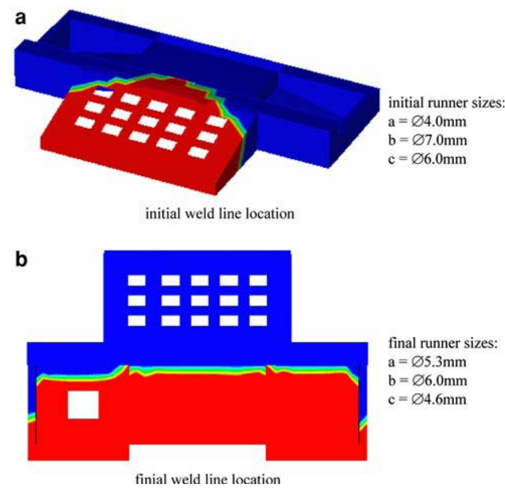


Fig. 22. The final runner design for the two-chamber moulding

Lei Xie si Gerhard Ziegmann, [28] realizeaza simularea in MoldFlow a timpului de injectare, figura 23. In a and b positions the micro tensile cavity cannot be completed filled and in c position the sample can be successfully filled. The injection parameters took into account was as follow: melt temperature 210^{o}C, mold temperature 80^{o}C, flow rate 60cm3/s, injection pressure 150MPa.

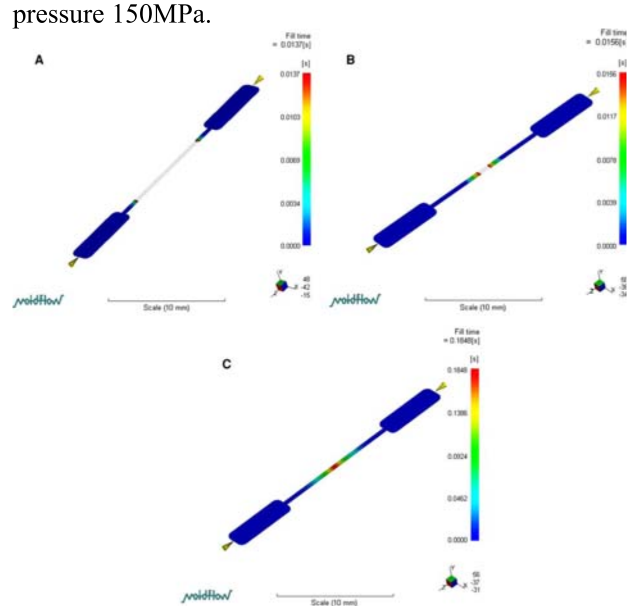


Fig. 23. Filling simulation results in different processing conditions, [28]

The same authors inside the paper [34] presents the effect of gate dimension on micro injection molded weld line strength with polypropylene (PP) and high-density polyethylene (HDPE), figura 24.

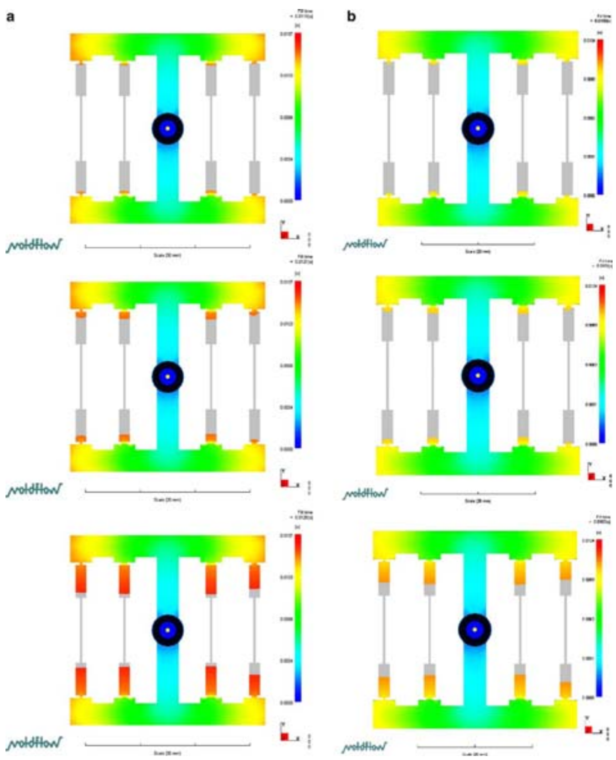
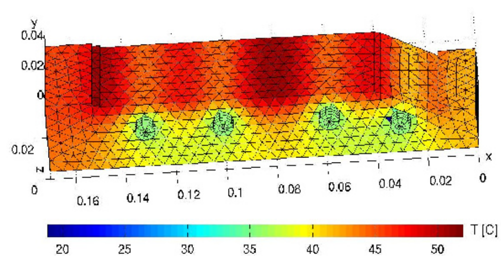
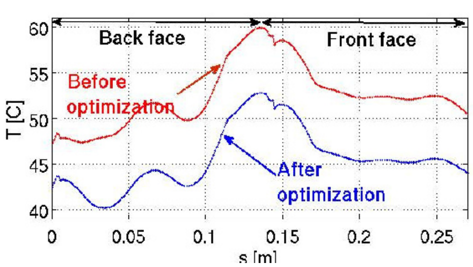


Fig. 24. a- Filling process of the entire part for PP. b- Filling process of the entire part for HDPE

Pirc, N., et al in [66] presents optimization of cooling channels position, figure 25a and figure 25b shows the temperature profile on the surface of the cavity before and after optimization.



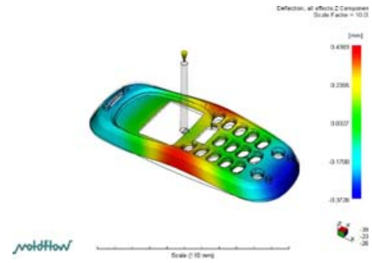
a



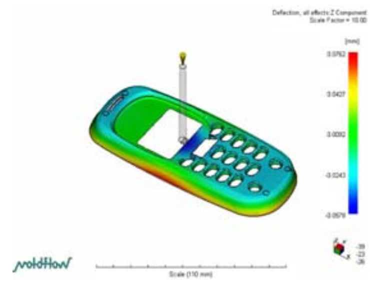
b

Fig.25. a-optimization of cooling channel position; b-cavity surface temperature profile before and after optimization

Landmarks warpage is studied by the authors Yuehua Gao & Xicheng Wang in [44] for mobile landmark case, figure 26.



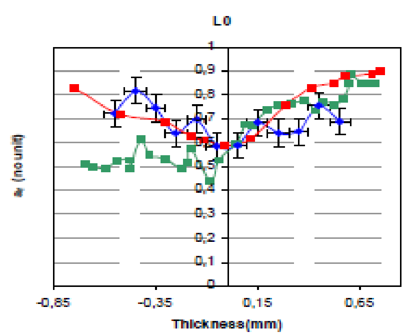
a



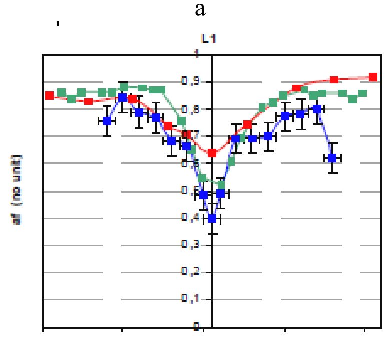
b

Fig. 26. Warpage of mobile cover: a- before optimization, b-after optimization

Comparative research between injection simulation and injectable part confirm again that simulation results are quite real and close to those obtained by experiment. This can be seen by simulating the injection process where we can see reinforced materials including fiber orientation in the part. A comparison between measured values and those obtained by simulation can be seen in figure 27a, b, c, d, [25].



a



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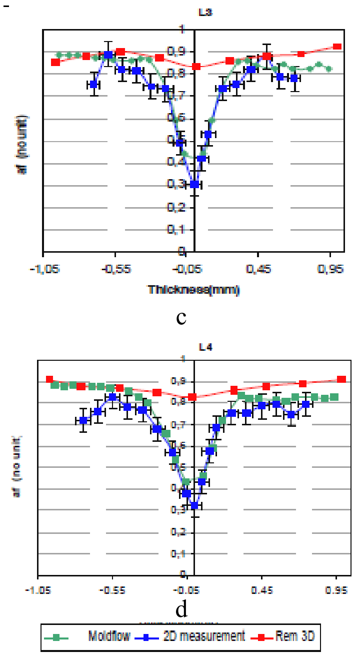

Fig. 27. Comparison of fibre orientation distribution, [25]

5. RESEARCH RESULTS. USING PARTS OBTAINED BY INJECTION / MICRO-INJECTION

The demand on injection molded products such as from conventional plastic goods to micro optical devices is being dramatically increased over the recent years, [61]. By micro-injection can obtain a wide range of polymer products. You can also get products and polymer foam (foam products). The mechanical properties of foam polymers are closely related to the size of the bubbles created inside the material, [20]. That's why a theoretical framework to improve the bubble growth rate and size predictions and experimentally verified it's an important contributions concerning the micro-injection process. The morphology of the generated cells inside the products, cell size, shape and density has the important influence to mechanical properties, [55]. Several studies on the mechanical properties of a product manufactured using an ultrafine foaming methos have focused on batch tests using high pressure containers. Many analysis simulation tools have been developed to predict the size of the bubbles that grow in polymers inside the molds. The bubble model proposed by Yongrak Moon [20] took into consideration any gas growth inside the mold using a theoretical approach that considers the flow properties of the polymer and an estimation technique developed to provide more accurate prediction by comparing the results of existing analysis tools with the actual size of bubbles observed on a metal specimen (figure 28). This figure shows scanning electron microscope (SEM) images at different positions in the same specimen. The difference, at the initially injected polymer, between the saturation pressure of the bubbles and the pressure experienced by the polymer near the bubbles was large because the pressure change contributed to the bubble growth. Toward to the end the bubble growth declined because the saturation pressure difference was small.

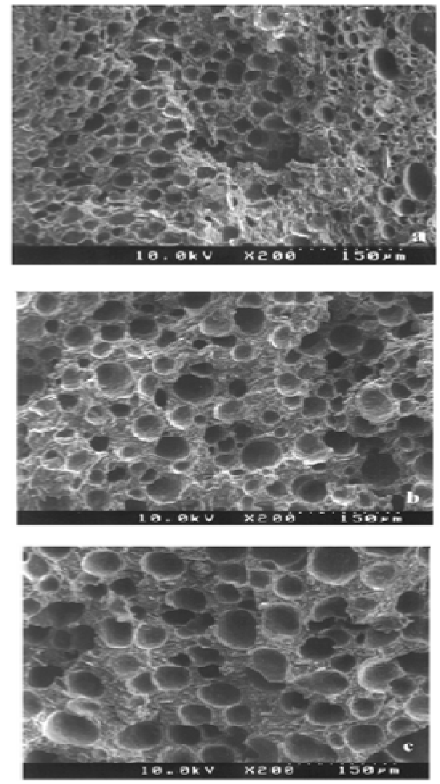
Fig. 28. Bubble size according to the residence time in the injection mold: (a)-section closest to the gate, b-middle section between the gate and the end of the flow, c-section at the end of the flow, [20]

Micro injection molding presents many challenges in the injection molding community. When the dimensions of the parts are small micro scale factors such as mold surface roughness may play an important role in the filling of polymer melt, [56]. There are only few investigations on the effects of mold surface roughness. As the mold surface roughness increases the contact area between melt polymer and mold surface will also increase. The heat transfer rate is proportional with the contact surface are between melt polymer and wall of the mold, [21, 57]. The surface roughness may have significant effects on pressure gradient, friction factor and heat transfer, [57]. The figure 29a shows a microscopic image of a molded part that is molded with injection rate of 2,7mm^3/s, mold temperature of 323K and melt temperature of 453K. The rougher half of the cavity insert results in higher surface roughness of the molded part and smoother half results in lower surface roughness of the molded part. The figure 29b shows the measured roughness profile of the molded part along the A-B direction. The molded part has good replication of mold surface roughness, [21].

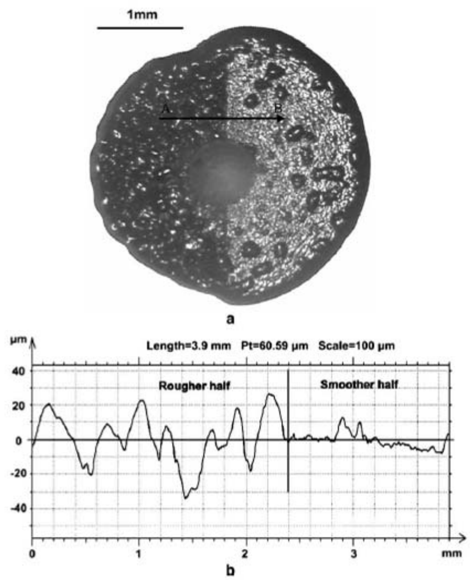

Fig. 29 A molded part: a-microscopic image, b-roughness profile measured in the A-B direction, [21]

It's important to view the fracture behavior of injection molded polypropylene composites filled with surface modified nano-TiO2 particles at different tensile rates. A small amount of surface modified nano-TiO2 particles significantly affected the skin structure of injection molded polypropylene samples and in turn improved the whole fracture energy of the nanocomposites dramatically, [27]. The uniform nanoparticle dispersion in polypropylene matrix was proved by transmission electron microscopy inspection (figure 30a). A scanning electron microscopy micrograph taken from a cryogenically fractured sample (figure 30b) confirms that some small aggregates exist in the matrix which contains several primary nanoparticles and most of them are less than 200nm. The nanoparticle matrix interfacial adhesion seems relatively weak because all the nano-TiO2 particles are observed to sit on the fracture surface. The weak particle matrix adhesion would affect the rheological behaviour.

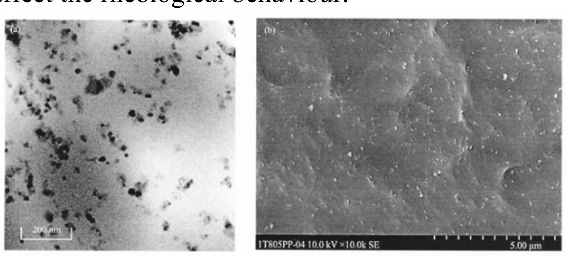
Fig.30. a-Transmission electron microscopy, b-scanning electron microscopy micrographs of 1 vol.% nano-TiO2 particles filled polypropylene composites, [27]

Micro electrical sensor, micro/nano mechanical parts, heat exchanger for micro fuel cells, accelerator and transducer and optical elements are the main parts in this field of micro injection process. The micro molding is regarded as the most suitable production process because it offers high repeatability, production at low cost and versatility in selecting polymers, [28].

Other important aspect consists of creep behavior of different polymers. Banik and Mennig [29] studied the influence of the injection molding process on the creep behavior of semicrystalline PBT (polybutylene terepthalate). Creep behavior was determined by performing creep tests in a creep instrument fitted with strain gauges at room temperature (figure 31).

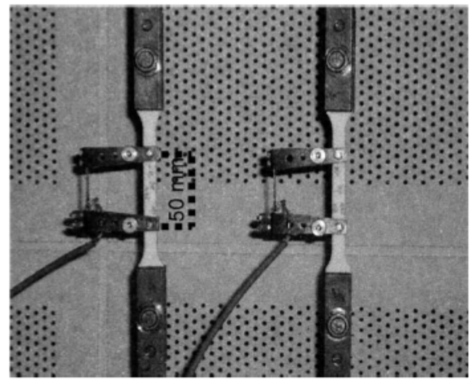

Fig. 31. Creep instrument fitted with clip-on strain gauges at the middle, [29]

The effect of varying the mold temperature on the creep behavior of the injection molded PBT sample is shown in figure 32. The tendency of the material to creep clearly increases with lowering the mold temperature and the difference in creep strain becomes more pronounced at longer creep times [29]. The creep strain increased by about 162% for a mold temperature of 23°C and 133% for a mold temperature 40°C respectively at the end of the creep test and after an aging time of 1 day. Cooling rate increases with decrease the mold temperature and affects the solidified material crystallinity.

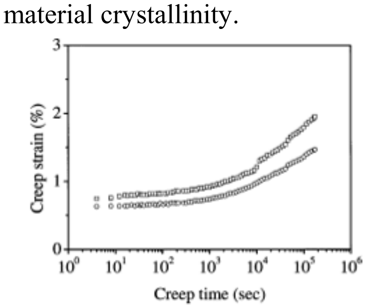

Fig. 32. Creep behavior of PBT processed at different mold temperatures after an aging time of 1 day under a constant stress of 20MPa; □ T_w=23°C, ○ T_w=40°C

Concerning the solidified material the cooling time is the most important aspect because it significantly affects also the productivity and the quality of the molded part. An appropiate cooling channels design can considerably reduce the cooling time. Mold cooling design is still mainly based on practical knowledge and designers' experience. But when the molded part becomes more complex this approach becomes less feasible. In this case Xuan-Phuong Dang and Hong-Seok Park [31] proposed a strategy for optimizing conformal cooling channels on the figure 33.

Conformal cooling channels offer the benefit of uniform cooling that reduce the cooling time and increase the quality of molded part, especially for products with large size and free-form shape.

Another product that can be obtained using the injection process is spur gears. In this case two design methods for the compensation of shrinkage are widely used. One is the module correction method and the other is the pressure angle correction method. Both methods are based on the assumption that shrinkage occurs toward the center of a molded gear, [35].

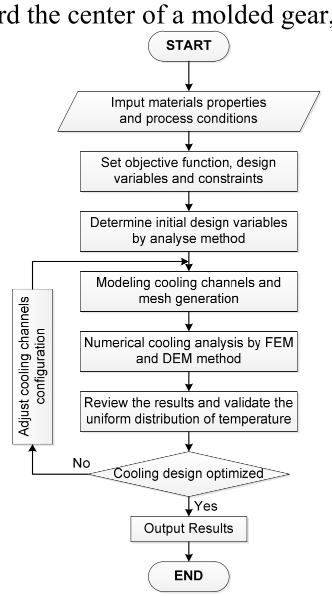

Fig. 33. Strategy for optimizing conformal cooling channels

To study the weld line developing process a visual mold with variotherm system mold was designed and fabricated by Lei Xie and Gerhard Ziegmann, [36]. This system is presented in figure 34.

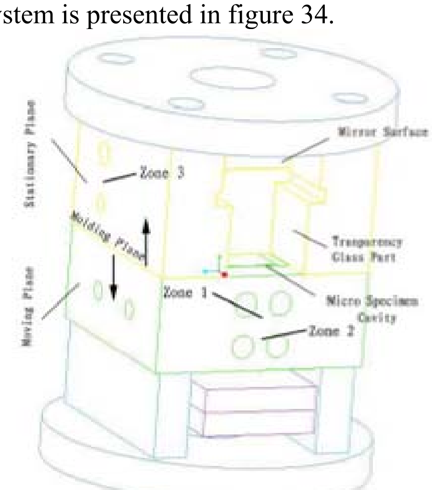

Fig. 34. The visual and variotherm mold design

A visual mechanism and a rapid heating/cooling system were designed to be used in combination. To observe and record the developing process of weld line was used a glass part made of Borosilicate and arranged on the top of the specimen cavity. For reflecting the melt flow process in the cavity of specimen, a 45^{o} mirror surface to the molding plane was machined which can transfer the image to the high speed recording camera outside of mold, [36].

Injection and micro-injection processes have so an important role in industry due to the fact that they were greatly expanded and thermoplastics, they even replacing metallic materials.

Depending on the size of landmarks can break off the two types of processes, the injection and the micro-injection processes that are found in many areas. Predominantly in the automotive, aeronautical, etc., we can find injected parts, also in electronics or medicine areas dominated the micro-injection process. In the figure 35 is presented the main positions of the plastic industry, [67].

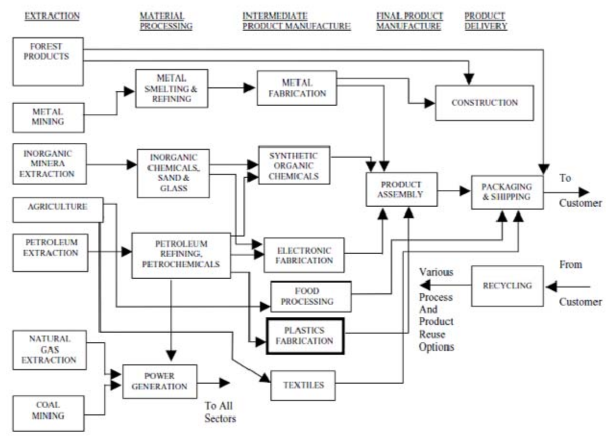

Fig. 35. The position of the plastics industry within the sector sequence diagram. The industry sector itself is indicated by heavy outlining, [67]

As we can see from above figure the parts obtained by injection / micro-injection of plastics have a wide application in many areas (Table 3).

Fig. 36. Rear center armrest with a cup-holder, [42]

Table 3. Use of parts obtained by injection of different plastics, [2,42,68,69,70,71,72,73,74,75]

No.	Material	Application
1	Cellulose acetate (CA)	-Handles of hand tools, various luminaries in the field of cosmetic (brush handles, toothbrushes), transparent packaging.
2	Cellulose acetate propionate (CAP)	-Spectacle frames, handles on hand tools, electrical and telecommunications industry (parts for various equipment), lighting, drawing tools, the cosmetic industry (packaging, handles, toothbrushes, combs, etc..), pharmaceuticals (packaging) etc.
3	General purpose polystyrene (PS)	-Household items, stationery items, household electrical items, insulating parts in electrical industry, electronics, toys, etc.
4	Impact-resistant polystyrene (PAS)	Different parts in appliances (refrigerators, mixers, coffee pots, etc..), components of electronic devices (TV, radio, cassette, etc.), household items, different packaging, toys, toiletries, etc..
5	Acrylonitrile-butadiene-styrene (ABS)	-Household electrical items (vacuum cleaners, coffee makers, mixers, hair dryers, etc.) -Electrical and electronic equipment (radios, stereos, video); -Medical equipment; -Automotive (board equipment, boxes, fittings, interior parts, Figure 36); -Office equipment and computers (computer cases, typewriters, copiers); -Optical and Cameras (housing, film holders, etc.) -Toys, sports and recreation.
6	Polyamide 6 (PA 6)	-Automotive (different components, Figure 37); -Electrical industry (housings, connectors, etc..) -Sports material industry (ski boots, roller skates); -The electronics industry (housing equipment);
7	Polyamide 6.6 (PA 6.6)	-Electrical industry (coil housings, connectors, switches); -Automotive (connectors, safety boxes); -In fine mechanics (gears, wheels, guides); -In the textile industry (zips) etc.
8	Low density polyethylene (LDPE)	-Glassware (bowls, buckets, basins, etc.) -Different packages; -Toys; -Parts for various industries.
9	High Density Polyethylene (HDPE)	-Household items (buckets, bowls, pots, pots etc.) -Toys; -Packaging (crates, containers, etc.) -Covers various (for bottles, cans, threaded plugs, etc..) Miscellaneous items.
10	Polypropylene (PP)	-Medicine (syringes, pipettes etc.-Figure 43); -Textile (coils, wear items.) -Glassware (bowls, buckets, basins, etc.) -Garden items (chairs, tables, planters, pots, etc.) -Packaging (cups, caps, boxes etc.-Figure 44); -Electronics and electrical industry (household electrical accessories, parts for vacuum cleaners, electric accessory boxes, etc.) -Automotive (bumper, dashboards, etc. contact boxes.) -In sports (ski boots, roller skates, etc.).
11	Polymethyl methacrylate (PMMA)	-Aeronautics industry; -The construction industry; -The electronics industry (pick-ups, dials, scales, etc.) -Automotive (dashboard, and signal lamps, dials); -Office, IT (parts office furniture, typewriters, etc.) -Household items (hoods, parts for domestic appliances, etc.) -Medical (equipment housings, different parts); -Bathroom accessories (buttons, taps, shower handles, towel holder); -Photographic and optical equipment (lenses, magnifiers, precision parts, lenses, etc. watches.) -Sport and Recreation (portholes of ships, toys, games, etc.) -Packaging (boxes, cosmetics).
12	Methyl methacrylate-butadiene-styrene (MABS)	-Writing articles (rolling pens, pencils); -Electronic equipment (covers, screens, etc.) -Toiletries (frames brushes and toothbrushes, cosmetic boxes, etc.) -Medical equipment (different parts of high transparency).
13	Polycarbonate (PC)	-Optical industry (glasses, lenses, cameras, etc.) -In the electrical industry (connectors, plugs, switches, electric meters); -Automotive (headlights, tail lights, ceiling etc.-Figure 41); -Household items (dishes for microwave, electrical household appliances, bowls); -In the medical field (dialysis machines, blood filters, syringes, etc.).
14	Rigid polyvinyl chloride (PVC-R)	-Electrical industry (plugs, insulation parts, fuse boxes, etc.) -Chemical industry (various fittings, structural elements, etc..)

No.	Material	Application
		-Construction (joints, support elements, etc..) -The birotics parts.
15	Flexible polyvinyl chloride (PVC-F)	-Light industry (shoe soles, heels shoes); -Electrical industry (electrical plugs, control buttons, insulation elements); -Office-computers (cases with complicated shape, keyboards); -In the automotive industry (fittings, protective elements, buttons pad-Figure 42).
16	Chlorinated polyvinyl chloride (PVC-C)	Are used like valvescomponents in the chemical industry, at electrical apparatus which working in corrosive environment.
17	Polytetrafluoroethylene (PTFE)	-Equipment working in diverse chemical aggressive environment (gears, filter plates, rotors, etc.) -Construction machinery, bearings, pump seals, wear parts etc.-Figure 45); -Electrical industry (plugs, sockets, etc.) -Aviation.
18	Polyethylene terephthalate (PET)	-In the automotive industry (housing, grills, etc.) -In electrical and electronic (insulating parts, frames, mats etc.-Figure 39); -The manufacture of machinery and equipment (bushings, bearings, couplings, screws, springs, parts for valves, pump housings, etc.), high precision parts etc.; -In the furniture industry (hinged, sliding elements, levers, etc.).
19	Polibutilentereftalat (PBT)	-The electrical industry (lamps support, connectors, switches, sockets, support, etc.) -The construction car (gears, fog lamps, headlights, brackets, beams, rear lamp housing); -The mechanical precision (meters, pumps, microscopes, binoculars); -The appliances (stove knobs, couplings).
20	Polifenilenoxid (PPO) (PPE)	-Automotive (dashboard, ventilation and heating elements for boxes, safety belts, etc.) -Electrical industry (housing coils, capacitors boxes, remote controls); -Office equipment (housing typewriters, computers, copiers, printers); -Electronics (housing television, radio); -Miscellaneous (pump bodies, water meters).
21	Polysulfone (PSU)	-The electrical industry (switches, contactors etc.-Figure 40); -Automotive (various parts); -Manufacturing industry (fittings, car parts, tachometers, etc.) -The medical industry.
22	Polyetherimides (PEI)	-Medical equipment; -Household items used for microwave ovens transparent; -High precision parts and strength in the electronics industry; -In the automotive industry (halogen lamp, floats in the fuel tanks etc.).
23	Liquid crystal polymer (LCP)	-In computers (media circuits, connectors, diodes); -In the electrical industry (rolling coil, connectors, etc.) -In the aviation industry; -The chemical industry (components working in chemical agents); -Telecommunications (telephone, connectors, cards, etc.) -In the automotive industry.
24	Thermoplastic polyurethane (TPU), (TPE-U)	-The manufacturing of sports (ski boots, boots for skates wheels); -The construction of automobiles (protective sleeves, gaskets, rings, rods protection, etc.) -In the electrical industry (couplers, plugs); -In manufacturing household appliances, etc.
25	Acrylonitrile-styrene-acrylate (ASA)	-In the electrical industry: contactors, connectors, plugs, etc.; -In the automotive industry: mask, back and front bumpers; -Elements of traffic sign, reflective sign boards etc. -The phone: carcases of fixed and mobile phones, various components, etc..; -Machinery and garden items: grass cutters, tables, chairs.
26	Polimetilenpentenă (PMP)	-Medical equipment (body syringes, tubes); -In the electrical industry (electrical insulation parts).
27	Poliarilamidă (PAA)	-In medicine (medical aspirators, surgical forceps, etc.) -In the electronics industry (connectors, chassis, boxes, etc.) -In the automotive industry (petrol pump, oil filter boxes); -In the electrical industry (media, induction motors, circuit breakers Security etc.) -The mechanical (gears, axes, shields, etc.).
28	Poliamidimidă (PAI)	-In the aviation industry; -In machine building (wearing parts bearing cages).

Fig. 37. Injected part, [42]

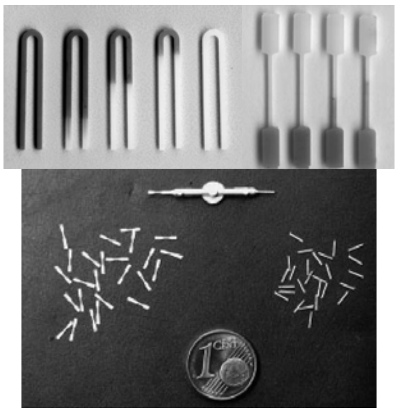

Fig. 38. Microinjected parts, [68]

Fig. 39. Parts used in electronics and obtained by micro-injection, [69]

Fig. 40. Parts used in electronics, [70]

Fig. 41. Parts used in automotive, [71]

Fig.42. Parts used in automotive, [72]

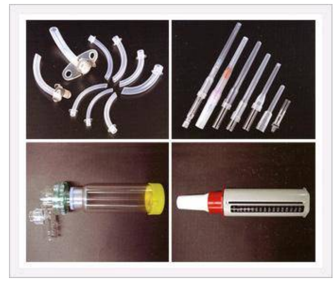

Fig. 43. Parts used in medicine, [73]

Fig.44. Parts used in food industry, [74]

Fig. 45. Parts used in machine manufacturing, [75]

6. CONCLUSIONS

Plastics are widely used in many fields, from electronics to cars to food and toys.The plastic materials are made from polymers and are produced in the temperature at which they become plastic in order to obtain the finished product. The most common technology of plastic parts is injection and micro-injection.The main factors that have influence over the products were grouped into: input factors (process factors), factors related to material structure and machine and output factors. The main process factors are as follow: temperature, injection pressure, injection time, cooling time, melting temperature, mould temperature, filling time etc. Thus from the literature the main results presented refer to: standard deviation vs melt temperature, microgenetic algorithm for locate an optimal solution, weld line strength response to different gate size, weld line V notch profile and principle that the flow front shape influences the V notch; bubble size according to the residence time, microscopic images and roughness; creep strain at different mold temperatures, strategy for optimizing the cooling channels. Other part of the paper refers to analysis and simulation of the injection and micro-injection processes using different software.

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