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Finite Element Method application for structure determining of powder injection moulding samples

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ABSTRACT

Purpose: To improve the understanding of the rheology of a metal-loaded polymer, a computer program which simulates the powder injection molding (PIM) process has been developed and its output has been compared to actual laboratory experiments.

Design/methodology/approach: The polymer-powder feedstock was injection moulded using Arburg injection moulding machine. Feedstock of M2 HSS reinforced with carbides and mixed with stearic acid, paraffin wax and polypropylene as a binder was made by twin-screw extruder. Feedstock viscosity examination was made by capillary rheometer HAAKE RheoCap. Computer simulation results were compared with experimental results.

Findings: Computer aided numerical analysis gives the possibility to select the optimal parameters of injection moulding without necessitate of preparation different feedstocks and manufacturing injected samples in different conditions of injection. Moreover application of ANSYS allows to apply initial process of injection moulding simulations without the necessity of purchasing expensive programs applied to material modeling injection.

Research limitations/implications: It was confirmed that using of finite element method in powder injection moulding process can be a way for reducing the investigation costs Results reached in this way are satisfying and in slight degree differ from results reached by experimental method. However for achieving better calculation accuracy in further researches it should be developed given model which was presented in this paper.

Originality/value: Nowadays the computer simulation is very popular and it is based on the finite element method, which allows to better understand the interdependence between parameters of process and choosing optimal solution. The possibility of application faster and faster calculation machines and coming into being many software make possible the creation of more precise models and more adequate ones to reality.

Keywords: Computational Materials Science; Finite Element Method; Powder injection moulding

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METHODS OF ANALYSIS AND MODELLING

1. Introduction

The need to use the new engineering materials and contemporary fabrication technologies arises from the continuous development of civilisation and demand for the new, better products. Product price, apart from the high properties of the manufactured elements, is also of the significant importance to the customer. Manufacturing cost may often be reduced by employing the mass- or big-lot production. Forming of the polymer-powder mixes may be an example, required for the widely known injection or extrusion of plastics [1-12]. Powder injection moulding is a branch of the widely known powder metallurgy. Powder metallurgy is not only fabrication of powders from metals and their alloys, and designing their properties, but – first of all – consolidation of the powders into a compact solid, which is, as a rule, the completed product, and only in few cases it may be the material as a green [4]. Moreover, despite its name, the non-metallic powders and metallic Or non-metallic fibers are used in powder metallurgy, which are merged with metals powders [6]. Development of injection moulding technology is connected with the more and more intensive use of programs for simulation of this process, making it possible to analyse filling of the mould cavity, packing and cooling phases, as well as analysis of the green deformation during cooling both in the mould and after its removal. There are many economic and qualitative considerations for which the injection simulation analysis should be carried out [13-17]. This work presents results of investigation consisting in modelling of the polymer-powder mix during filling, in which the high-speed steel powder was used along with paraffin and polypropylene as the binding agents.

2. Investigation methodology

The M2 (HS6-5-2) high-speed steel powder with high wettability was used for injection moulding due to its spherical shape. This powder is sprayed with the inert gas and has the average grain size of about 20 µm. Output data from the control panel generated by Arburg injection moulding machine (Fig. 1) are used in this work during forming process of the polymer-powder slurry with the following composition:

- HS6-5-2 high-speed steel powder – 70% volume fraction,
- polypropylene and paraffin – 30% volume fraction.

The slurry filling temperature was 170°C.

Moreover, data obtained during the rheological tests of the polymer-powder slurry was used. These tests were made on the ThermoHaake capillary rheometer. The data obtained during the tests represent the viscosity curve versus shear rate and test temperature, i.e., 170, 180, and 190°C, results of these investigations are presented in Table 1.

Simulations of the polymer-powder mix flow during filling, in which the high-speed steel powder, and paraffin and polypropylene as the binding agents were used, were carried out in the Ansys - Flotran program; this software was developed for filling process simulation of the thermoplastic plastics and rubber using FEM (Finite Elements Method), which makes it possible to eliminate flaws caused by, among others: short filling, air cavities, burns, contraction cavities, uneven distribution of material, traces of streams merging, overfill of the mould cavity, underfill, contraction/warping, skewing, non-uniform cooling [18-19].

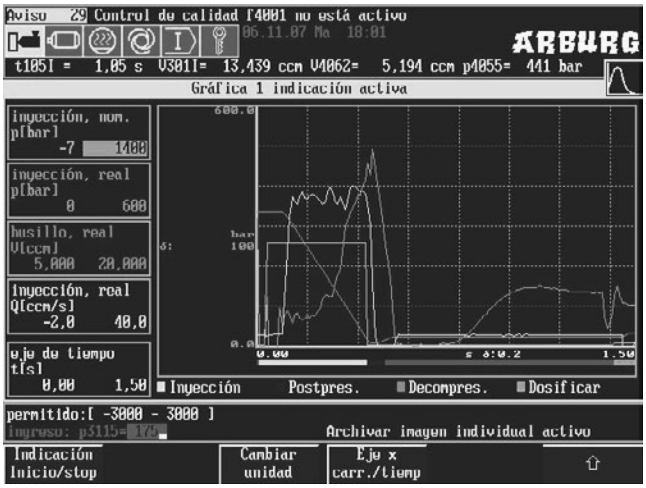

Fig. 1. Arburg injection moulding machine control panel display presenting the injection forming conditions

Table 1.
Rheological data of the mould charge - – PP+M2 powder

Filling temperature, °C	Pressure, Pa	Shear rate, γ,[1/s]	Viscosity, η, Pas
170	4898	10	489.80
	5878	20	293.90
	10780	50	215.50
	18470	100	184.70
	27010	200	135.10
	43380	500	86.77
	59620	1000	59.62
	79770	2000	39.89
	114900	5000	22.98
	152300	10000	15.23
180	7977	10	797.70
	6998	20	349.90
	9797	50	195.90
	17910	100	179.10
	26590	200	133.00
	41710	500	83.41
	55140	1000	55.14
	72070	2000	36.04
	99370	5000	19.87
	124600	10000	12.46
190	7558	10	755.80
	7419	20	370.0
	7838	50	156.80
	10640	100	106.40
	19880	200	99.38
	38210	500	76.42
	52770	1000	52.77
	68590	2000	34.29
	93220	5000	18.64
	115500	10000	11.55

For simulation requirements mould, process, and material data were used as presented in Tables 2 and 3, and the following assumptions were made:

- mould filling time: 0.4 sec,
- mould filling up to 99% (compaction phase follows),
- filling temperature 180°C,
- temperature on the forming surface: 30°C,
- temperature of green removal from the mould cavity: 70°C.

Table 2.
Mould specification

Total Cavity	
Surface	2009.66 mm
Volume	3311.68 mm^3
Centroid	43.722, 5.951, 62.085 mm
Mass	3 g
Part1	
Surface	2009.66 mm
Volume	2277.04 mm^3
Centroid	31.645, 6.00, 54.509 mm
Mass	
Cold Runner	
Volume	1034.63mm^3
Centroid	70.302, 5.842, 78.759 mm
Mass	0.938 g

Table 3.
Polymer-powder slurry injection process parameters

Recommended Process Parameters	
Melting Point	240 ^oC
Wall Temperature	30 ^oC
Ejection Temperature	70 ^oC
Process Parameters	
Filling Time	0.4 s
Pressure-Controlled Filling	99%
Melt Temperature	180 ^oC
Wall Temperature	30 ^oC
Ejection Temperature	70 ^oC
Heat Transfer Coefficient Mould (Filling)	Wall Thickness Dependent
Heat Transfer Coefficient Mould (Packing)	1000 W/(m,K)
Heat Transfer Coefficient Mould (After Packing)	1000 W/(m,K)

Geometrical model was digitized in element FLUID141, which is presented in Figure 2.

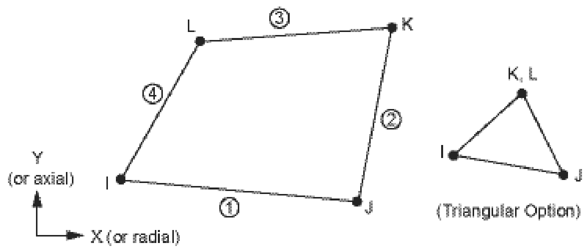

Fig. 2. Geometrical model of element FLUID141

In Figs. 3 and 4 the dimensioned geometry of a plate with constriction and feed channel is presented, whereas in Figs. 5, 6 there is the real model of the injection moulding machine cavity developed in Ansys program. Thickness of the particular elements of the formed green is an important issue in designing the injection moulds, because of the cooling rate of the filled cavity. Thickness of the formed plate in the discussed case is 3 mm; therefore, the biggest thickness is characteristic of the feed channel.

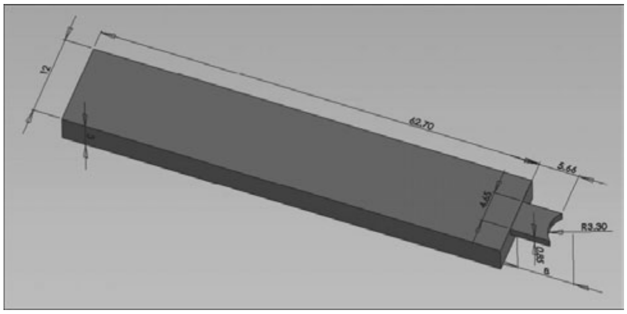

Fig. 3. Drawing of the formed green with constriction

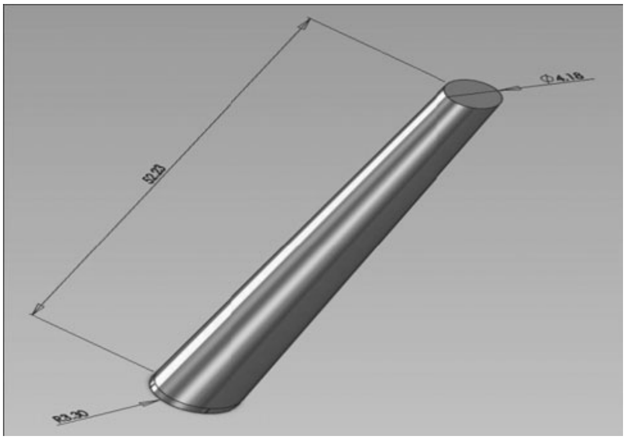

Fig. 4. Feed channel

Fig. 5. Real model of the injection machine cavity

Fig. 6. Model with the finite elements mesh superimposed

3. Investigation results

Modelling was carried out in the work of the injection moulding process of the polymer-powder slurry composed of the M2 (HS6-5-2) high-speed steel powder, paraffin, and polypropylene. Employment of the finite elements method for powders injection moulding modelling is not that commonly used as for simulation of the plastics injection moulding process. This is connected with many problems arising from the injection moulding machine charge properties. Properties of a thermoplastic, e.g., polypropylene, used as a binding agent change after adding the metal or ceramic powder.

The volume fraction of the powder, its grain size and shape are very important. Modelling of the powder-polymer slurry flow calls for its previous rheological tests carried out for the slurry with the same chemical composition. Results of modelling carried out for the polymer-powder slurry, i.e., HS6-5-2 high-speed steel with polypropylene as the binding agent, of its injection moulding forming are comparable to the real filling conditions presented in Figure 1.

One should pay special attention to the mould filling time. The filling time is about 0.7 sec both for the real mould filling and in the modelled process. Therefore, we can conclude that the model and filling conditions were selected properly.

Detailed analysis of the maximum filling pressure revealed that this pressure is about three times lower in the modelled process than the real pressure (Fig. 1). This was caused undoubtedly by the nominal pressure that was selected by the injection moulding machine operator during filling. One should expect that lowering the real filling pressure would not affect development of flaws in the injection moulded green, e.g., like air cavities. However, lowering the filling pressure will reduce the screw and injection moulding machine cavity wear. This is especially important if the injection moulding machine charge is rich in the hard ceramic or metallic powder.

The calculation mesh is shown in Figure 6, on which all numerical calculations are carried out. The mesh is generated by the Ansys - Flotran program automatically, however offers the possibility to change the mesh parameters (its refinement) or manual editing, depending on requirements. Figure 7 presents injection machine filled with air.

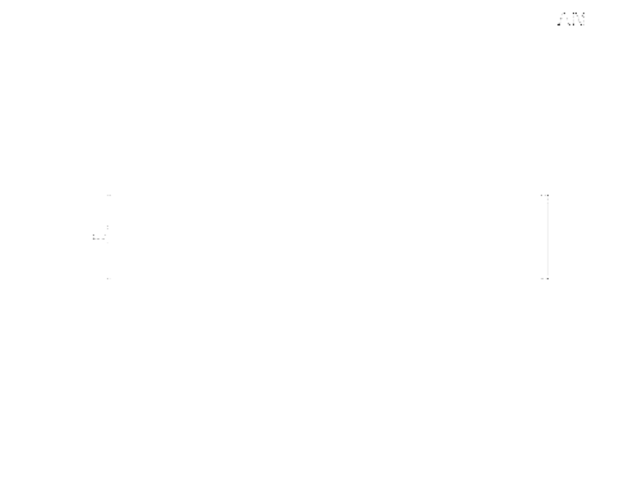

Fig. 7. Injection machine filled with air

One can observe significant pressure jumps versus filling time (0.7 sec) in the filling simulation results. One can see three mould cavity filling stages on the curve (Fig. 6): filling of gating system, filling of constriction, filling of green (plate).

Figures 8-13 presents filling pressure during mould cavity filling. One can observe the most significant pressure jump with the feed channel completely filled, when the material commences passing through the constriction (Fig. 8). The gray zone is the zone that is still not filled with the material. The pressure keeps on growing in the next filling process phases but sudden jumps do not occur any more, and the pressure increase may be qualified as linear.

Simulation presented in Figures 14-19 in which filling the particular zones of the mould cavity is shown in time is essential in case of the analysis of a system of two elements whose volumes vary – the correct design of the feed channels guarantees the simultaneous filling of both elements in the mould cavity. One can observe in Figure 14 that the material flow rate grows significantly in the constriction zone, which leads often to the binding agent temperature growth, its degradation, and to development of gas cavities in the green volume. Is the undesirable effect and one should consider possibility of increasing the constriction transverse area.

Figures 20-25 presents total speed of polymer-powder mixture. The most meaningful speed can be observed at a total filled filler channel.

Fig. 8. Distribution of pressure in the matrix at 0.5006 second of injection, Pa

Fig. 9. Distribution of pressure in the matrix at 0.5306 second of injection, Pa

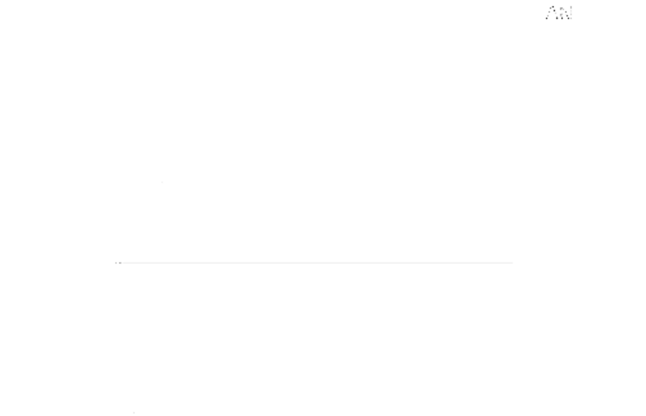

Fig. 10. Distribution of pressure in the matrix at 0.5839 second of injection, Pa

Fig. 11. Distribution of pressure in the matrix at 0.6068 second of injection, Pa

Fig. 12. Distribution of pressure in the matrix at 0.6430 second of injection, Pa

Fig. 13. Distribution of pressure in the matrix at 0.6776 second of injection, Pa

Fig. 14. Distribution of polymer-powder mixture in the matrix at 0.5006 second of injection m/s

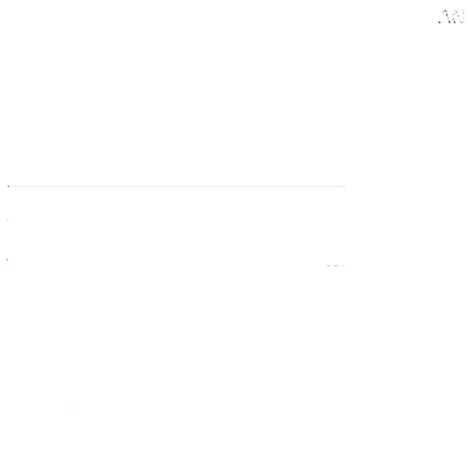

Fig. 15. Distribution of polymer-powder mixture in the matrix at 0.5305 second of injection m/s

Fig. 16. Distribution of polymer-powder mixture in the matrix at 0.5839 second of injection m/s

Fig. 17. Distribution of polymer-powder mixture in the matrix at 0.6068 second of injection m/s

Fig. 18. Distribution of polymer-powder mixture in the matrix at 0.6430 second of injection m/s

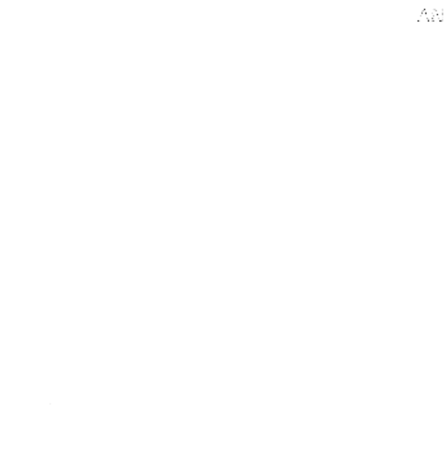

Fig. 19. Distribution of polymer-powder mixture in the matrix at 0.6776 second of injection m/s

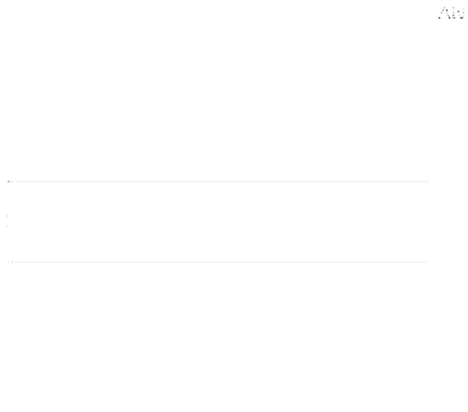

Fig. 20. Total speed of polymer-powder mixture at 0.5006 second of injection, m/s

Fig. 21. Total speed of polymer-powder mixture at 0.5305 second of injection, m/s

Fig. 22. Total speed of polymer-powder mixture at 0.5839 second of injection, m/s

Fig. 23. Total speed of polymer-powder mixture at 0.6068 second of injection, m/s

Fig. 24. Total speed of polymer-powder mixture at 0.6430 second of injection, m/s

Fig. 25. Total speed of polymer-powder mixture at 0.6776 second of injection, m/s

4. Conclusions

It is necessary to perform numerical simulation before proper process of form design which check the degree of mould form shot(injection). For that purpose material's data are indispensable, which should be obtained from laboratory for specific material or from material data base such as CADMOULD, POLYFLOW or MOLDFLOW. These are programmes or the whole software package giving huge possibilities of material and rubber moulding and simulation. Because of high costs concerning these programs which are necessary to analysis of polymer- powder mixture flow and to analysis of mould form shot degree, it was applied professional and easier accessible programme which allows to analyse by the use of the finite element method of the company ANSYS making use of Foltran module.

Beyond any doubt application of powder injection moulding simulation allows to reduce the costs connected with injection moulding machine researches concerning selection of optimal injection's conditions with the purposes of complete mould form shot (injection). However it does not exclude expensive rheology researches, which are necessary and base to obtain detailed information about moulding material viscosity in the case of simulation and experimental researches on injection moulding machine. In order to perform simulation of the injection additional information is necessary about physical properties of polymer-powder slurry in dependence on its temperature.

Rheology researches showed that given the polymer-powder slurry is characterized by low viscosity and its moulding injection should not be a problem. It is confirmed by the experimental results consist in moulding injection and results obtained in simulation of this process.

On the basis of computer simulation results and real conditions of the injection in the injection moulding machine given by Arburg company, it was found that time needed to complete mould form shot by polymer-powder slurry what testifies about good performed numerical analysis of moulding injection powder process.

Additional information

Selected issues related to this paper were presented at the 18th International Scientific Conference on Achievements in Mechanical and Materials Engineering AMME`2010.

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