Mould Manufacturing Cycle of The Plastic Materials Products

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When the plastic materials products are obtained by injection into the mould, the fluid plastic mass takes the shape of the cavity and then, in a technological time, the obtained product cools until a temperature which makes possible its unloading without any deformation. Each product or more products may be realized during a period which means the time of one manufacturing cycle. An optimum manufacturing process is a continuous process without waiting times. The paper presents a methodology for the calculation and adjustment of some injection parameters which influence the time of one manufacturing cycle for the plastic materials products realizing.

Keywords: plastic materials manufacturing, thermal processes of the polymers injection

The forming process by injection consists of the plasticization of one macromolecular compound, its pressured insert into the mould, its solidification with the taking of the mould cavity shape, at a certain temperature, the opening of the mould for the injected product unloading; then, the cycle begins again [1-3].

The total cycle time, [4-6], consists of the time necessary for the thermo-chemical forming process of the product and the time necessary for the mould feeding. The thermo-chemical process consists of the following stages: the injection, the cooling and the polymeric blend solidification into the mould cavity. Depending on volume of the cavity, the quantity of the injected material is different, this aspect being a classification criterion of the different types of the injection machines. The injection time of the polymeric melting into the cavity of the mould has a relatively small value; the stages which need time are the stages of the cooling of the polymeric melting. The total using time is an important component of the total cycle time. It has the following components: the mould cavity shutting and locking, the plasticization aggregate approaching by the mould, post-injection component, the retraction of the plasticization aggregate, the material plasticization for the next injection, the unlocking and the opening of the mould and the unloading of the formed product component.

An optimum manufacturing process of the injection products is a continuous process without any waiting time. This condition may be realized by the adjustment of the cycle time required for one or more products manufacturing.

Experimental part

The different polymers used for the injection of some products and the needed quality demands have generated different injection techniques and a variety of aggregates [7,8]. A great variety of injection aggregates are used for the manufacturing of the soles, heals or some other semi-finished parts of the footwear made from different kinds of polymeric blends or of the polymeric finished footwear, [9,10]. The researches made for the optimization of the manufacturing cycle time of some polymeric materials products injection have been made using equipment for the footwear soles injection.

From the constructive point of view, these are compact, easily fitting and handling equipment, but the processes which take place inside them are very complex. [11,12]. From the process adjusted by the worker point of view, the injection is a process with “n” intervention possibilities which realize the adjustment of “j” process quantities and “k”proprieties of the injected product. Using these controlled conditions, it will be coordinated the production, it will be supervised the process and it will be optimized the leading of the process. This is the reason because these aggregates are equipped with process computers which allow the programming, controlling, analyzing and adjusting of the technological parameters, so that to obtain an economical and technical optimum. Figure 1 represents the scheme of the rotating aggregate used for the polymeric materials injection, and which has “n” working places; these aggregates are frequently used in footwear industry.

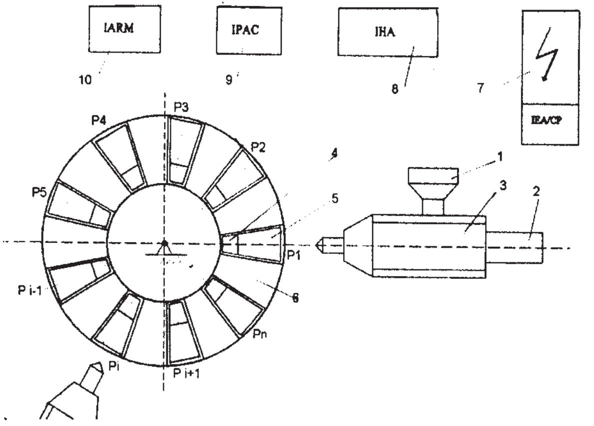

Fig.1. The scheme of the thermoplastics injection aggregate used for the footwear manufacturing
1- feeding-dosing modular unit; 2- hydro drive modular unit; 3- plasticization-injection modular unit; 4- die holder modular unit; 5- mould; 6- rotative transfer modular unit with “n” working places; 7- electric equipment board, including the process computer; 8- pressure engine; 9- pressure air equipment; 10-cooling medium equipment

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The total time of one cycle for the obtaining of one or more products simultaneously [3,4,13], is given by the relation (1):

$$\tau_c = \tau_p + \tau_d \text{, [seconds]} \qquad (1)$$

where:

τ_c- cycle time, s;

τ_p- time of the thermo-chemical process, s;

τ_d– servicing time of the mould, s.

The time of the thermo-chemical process is given by the relation (2):

$$\tau_p = \tau_i + \tau_r \text{, [seconds]} \qquad (2)$$

where:

τ_i - injection time, s;

τ - polymer cooling time, s.

During a continuous manufacturing process, the elimination of the waiting times is realized in the condition given by the relation (3).

$$\tau_c = n \cdot \tau_d \text{, [seconds]} \qquad (3)$$

where: *n* - number of serviced moulds.

This condition exists only if the process is programmed thus the servicing time will take place outside of the time of the thermo-chemical process [14].

The thermo-chemical process time consists of the injection time and of the polymeric blend cooling time. The injection time has a small value but the time consumer is the cooling time of the polymeric blend.

In the case of rotating aggregates which have many working places provided with a large number of moulds, the cooling time enlarges with the increasing of the working places number. This aspect allows that the cooling of the mould performs in the environment atmosphere, during the spin of the rotating aggregates. From practical reasons, the rotating equipment have an odd number of moulds.

The cooling of the polymer takes place into a closed mould, until a temperature which allows the unloading of the injected product without its deformation. In this case, the quantity of heat given by the mass unit [2,3,13,15,16] may be calculated using the relation (4):

$$q = mc\Delta t \text{, [kcal/Kg]} \qquad (4)$$

where:

q-heat given, during the cooling process, by 1 Kg of polymeric melting, Kcal/Kg;

m - mass, Kg;

c-specific heat, kcal/Kg^{0}C;

Δt-temperature difference, from the injection temperature, t_i, to the unloading medium temperature of the product, t_m.

Because the cooling of the polymer takes place beginning with the mould wall contacted by the air or by a cooled surface, we have to admit that the temperature of the middle of the product formed into the mould cavity is equal to the injection temperature. In this case, it can be said about a medium temperature of the product, t_m, considered equal to the average of the two temperatures, as relation (5) shows:

$$t_m = \frac{t_i + t_p}{2} \text{,[(seconds]} \qquad (5)$$

where:

t_i-injection temperature, ^{0}C;

t_p-peripheral temperature of the unloading product, ^{0}C.

The waste heat of the polymer must be taken by the mould and given, through its walls, to the environment. Considering a polymer layer which has a δ thickness, and a layer which has an infinitesimal small thickness, *dx*, placed at *x* distance from the border of the wall through which the heat is transferred to the outside area, figure 2, the heat given from this layer to the exterior is calculated using the relation (6):

$$dQ_c = dmq = \rho dvq = \rho Sdxq \text{, [Kcal]} \qquad (6)$$

where:

dQ_c-given heat, Kcal;

ρ-polymer density, Kg/m^3;

m-polymer mass, Kg;

v- polymer volume, m^3;

S-area of the volume unit which has *dx* thickness, m^2;

q- waste heat per unit of mass, Kcal/Kg.

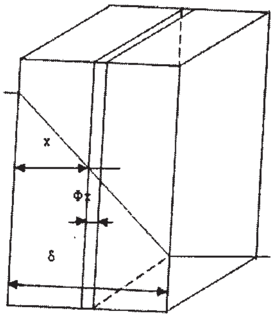

Fig. 2. Dynamics of the cooling into a polymer layer which has δ thickness

This heat must be transfered by the polymer to the mould, after the cavity filling up. Considering the transfer parameters of the heat through the polymer, from the injection temperature to the temperature of the polymer contacted by the mould, the next relation takes place, (7):

$$dQ_t = \frac{\lambda}{x} S(t_i - t_p) d\tau \text{, [Kcal]} \qquad (7)$$

where:

dQ_t-transfer heat, kcal;

λ- transfer coefficient of the polymer, kcal/hm^{0}C;

x- wall thickness, m;

S–area of the transfer surface, m^2;

t_i-temperature of the injected polymer, ^{0}C;

t_p-peripheral temperature of the product, ^{0}C;

τ –time needed for the heat transference.

Because the heat given by the polymer by cooling from the injection temperature to the medium temperature is equal to the heat transfered by the polymer to the mould, relations (6) and (7) will be equalized and the next relation (8) will be obtained:

$$d\tau = \frac{\rho q}{\lambda S(t_i - t_p)} \cdot xdx \text{, [seconds]} \qquad (8)$$

Admitting that the heat transference takes place uniformly both ways, on a direction which is perpendicular on the layer which has *dx* thickness, and integrating in an integral domain from the border to the middle of the polymer, it will be obtained the value of the cooling time given by the relation (9):

$$\tau = \frac{\rho q}{\lambda(t_i - t_p)} \frac{\delta^2}{8} \text{, [seconds]} \qquad (9)$$

The dependence between the cooling time and the quadratic thickness of the polymer layer, explains especially the polymer cooling into the feed orifice and the sealing of the mould.

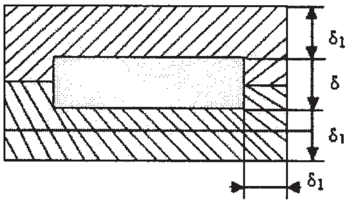

Fig.3. Mould consisting of two plates

Considering the cavity of the mould, figure 3, containing two plates which have δ_1 thickness, (the metal having a conductivity coefficient, λ) and knowing that the heat is transferred to the environment by convection, the heat transference to the environment is given by the general relation (10):

$$Q_m = K_m S' \Delta' t\text{, [Kcal/h]} \qquad (10)$$

where:

Q_p-waste heat of the mould to the environment, Kcal/h;

K_m-transfer coefficient of the mould, Kcal/h;

S'-mould surface of the waste heat, m^2;

$\Delta' t$-temperature difference, ^0C.

The transfer coefficient, K_m, will be obtained using the relation (11):

$$K_m = \frac{1}{\frac{1}{\alpha} + \frac{\delta_1}{\lambda_1}}\text{ , [Kcal/h]} \qquad (11)$$

where:

α-transfer coefficient of the layer of the stationary air which surrounds the mould, Kcal/h $m^{20}C$;

δ_1-thickness of the mould wall, m;

λ_1- transfer coefficient of the mould metal, kcal/hm^{0}C.

The value $\Delta' t$ will be obtained using the relation (12) :

$$\Delta' t = t_p - t_a\text{ , } [^0C] \qquad (12)$$

where:

t_p-temperature of the mould, considered equal to the external temperature of the product, ^0C;

t_a-air temperature, ^0C.

The quantity of heat given by the polymer to the mould must be equal to the quantity of heat given from the mould to the environment by convection (13):

$$mq = Q_p \frac{\tau'}{60} \qquad (13)$$

Considering relation (13), it results the value of the time necessary for the wasting of the heat to the environment, relation (14):

$$\tau' = \frac{60 m \cdot q}{Q_p}\text{, [seconds]} \qquad (14)$$

It will be compared the cooling time, τ, obtained using the relation (8), with the cooling time, τ' obtained using the relation (14).

If $\tau < \tau'$ the cooling of the polymer by transfer of the heat from the polymer to the mould walls and from the mould walls to the environment takes place. In this situation, the mould walls will cool, contacted by air, in the same time with their heating from the injected polymer.

If $\tau > \tau'$ the polymer can not be cooled by waste heat through the mould walls to the environment. In this case, it must be increased the time τ' using a supplementary cooling of the mould walls.

Results and discussions

The efficiency, in pairs per 8 h, of one aggregate used for the footwear soles injection, for each working place, is given by the relation (15):

$$P = \frac{T - \tau_{PI}}{\tau_c}\text{, [pairs/480 minutes]} \qquad (15)$$

where:

P-number of pairs/480 min;

T-time of one shift, 480 min;

τ_{PI}-set-up and ending time needed for the preparing and finishing of the work, in min;

τ_c-one cycle time, in min.

Imposing the medium efficiency of the aggregate, 200 pairs/8 h/mould, for a set-up and ending time equal to 30 min, relation (15) indicates that the time of one cycle per one mould is τ_c =2.25 min. This time contains the injection-cooling time and the mould servicing time, too. Practical, it was demonstrated that the time necessary for the servicing of one mould, used for the obtaining of one pair of soles , is 0.5 min.

On the other side, from the total thermo-chemical time used for the injection-cooling, the certain injection time is short, 10-15 s (0.16-0.25 min) depending on the quantity of the injected polymeric blend. The main time is the cooling one.

The value of the cooling time is an important parameter when the injection aggregate type will be chosen.

In table 1 are presented the experimental results and the calculation methodology of the cooling time of one polymerized vinyl chloride polymeric melting, [17-19].

Considering the table 1, it results:

- when the heat transfered from the polymer to the mould walls takes place in one single direction, $\tau > \tau'$ (τ=5.02 min,τ'=3.04 min), the polymer can not be cooled by the waste heat to the environment but only through the mould walls; it is necessary a supplementary mould cooling;

-when the heat is transfered from the polymer to the mould walls both directionally, $\tau < \tau'$ (τ=2.58 min, τ'=3.04 min), the mould walls are cooled contacted by the air, in the same time with their heating from the injected polymer; it is not necessary a supplementary mould cooling.

Practically, there are situations when the managed cooling time must be smaller than the time of the heat transfer from the polymer to the mould walls and from the mould walls to the environment. When this situation must be solved, there are two possible variants: the using of certain aggregates which have a working places number which may provide the cooling time polymer-mould-environment or the using of certain aggregates equipped with cooling installations for a supplementary cooling of the polymer.

Using relations (1), (2) and (3), which consider: the servicing time of the mould, τ_d= 0.56 min and the injection time,τ_i=0,25 min, there were calculated the technological cooling times, τ_r, for the situations when the injection equipment have 2, 4, 6, 8, 10, 12, 14, 16 moulds.

Calculations gave the following results:

n=2, τ_r=0.31 min; n=4, τ_r=1.43 min; n=6, τ_r=2.55 min; n=8, τ_r=3,67 min; n=10, τ_r=4,79 min; n=12, τ_r=5.91 min; n=14, τ_r=7.84; n=16, τ_r=8.15 min.

It results that the injection aggregates which have a mould number n<8, do not provide the polymer cooling time without a supplementary mould cooling. In all the other

Table 1
COOLING TIME CALCULATION. EXPERIMENTAL RESULTS

No. crt.	Mould parameters, symbols, units of measurement	Calculation relations	Values
1.	Injection temperature, t_i, [^{0}C]	-	200
2.	External temperature of the product at the unloading moment, t_p, [^{0}C]	-	80
3.	Temperature of the mould contacted by the polymer, t'_p, [^{0}C]	-	70
4.	Air temperature, t_a, [^{0}C]	-	20
5.	Polymer quantity for one pair of soles, m, [Kg]	-	0,2
6.	Specific heat of the polymer, c, [Kcal/Kg^{0}C]	-	0,33
7.	Transfer coefficient of the polymer, λ, [kcal/hm^{0}C]	-	0,14
8.	Sole thickness, δ, [m]	-	0,01
9.	Sole surface, S, [m^2]	-	0,014
10.	Mould thickness, δ_1, [m]	-	0,05
11.	Transfer coefficient of the mould metal, λ_1, [[kcal/hm^{0}C]	-	40
12.	Transfer coefficient of the air stationary layer, α, [kcal/hm^2 ^{0}C]	-	20
13.	Transfer surface between the mould and the air, S$'$, [m^2]	It was considered only the lateral area of the mould	0,08
14.	Polymer medium temperature, t_m, [^{0}C]	$t_m = \frac{t_i + t_p}{2}$	140
15.	Difference between the injection temperature and the medium temperature, Δt, [^{0}C]	$\Delta t = t_i - t_m$	60
16.	Heat wasted during the polymer cooling, Q, [Kcal]	$q = mc\Delta t$	396
17.	Heat quantity transfer by the polymer, K, by cooling from t_i to t_p	$Q_1 = KS\Delta t$ $K = \frac{1}{\frac{1}{\alpha} + \frac{\lambda}{\delta}}$	
	Q_1, [Kcal/h]		47,04
	Q_1, [kcal/minute]		0,784
18.	Temperature difference between the injection temperature and the external temperature of the product, Δ$'$t, [^{0}C]	$\Delta' t = t_i - t_p$	120
19.	Total time of the heat transfer from the polymer to the mould walls, τ, in one single direction, τ,[minutes];	$\tau = \frac{q}{Q_1}$	5,05
	Total time of the heat transfer from the polymer to the mould walls, τ, in both directions, τ,[minutes].	τ	2,58
20.	Heat transfer from the mould to the environment, Q_2, [Kcal/h]	$Q_2 = K'S'\Delta' t$	78,04
21.	Global coefficient of transfer metal-stationary layer, K_m, [kcal/hm^2 ^{0}C]	$K' = \frac{1}{\frac{1}{\alpha} + \frac{\delta_1}{\lambda_1}}$	19,51
22.	Temperature difference between the mould and the air, Δ$''$t, [^{0}C]	$\Delta'' t = t'_p - t_a$	50
23.	Time for the transfer of the heat given by the polymer from the mould walls to the environment, τ$'$, [minutes]	$\tau' = \frac{q}{Q_2}$	3,04

cases, when n ≥ 8, the cooling takes place only because of the heat transfer polymer-mould-environment.

In conclusion, in the analyzed case, it will be used rotating equipment which have the number of working places n ≥8, or equipments which have n<8 but they have controlled cooling installations.

In the case of rotating aggregates which have a large number of working places, the cooling time increases in the same time with the increasing of the mould number. So, the cooling of the injected polymer may take place in the working atmosphere, without any cooling equipment.

The presented calculation methodology may be applied for other kind of products or for other polymeric blends, too.

Conclusions

The time of the manufacturing cycle of the products made from plastic materials depends, especially, on the time of the thermo-chemical processes and on the servicing time of the moulds. The phases which need long periods of time are those of the cooling polymer into the mould cavity and of the mould servicing.

A continuous manufacturing process will be obtained when the time of one manufacturing cycle is equal to the servicing mould number multiplied with the servicing time of one mould. This condition means that the time of the mould servicing is not a component of the time needed for the thermo-chemical process of the product obtaining. During the thermo-chemical process, the time for the polymer injected has a small value, the cooling time being almost all the time.

The servicing time of the moulds and the injection time can not be essentially modified, so the modifying of one cycle time is possible only modifying the cooling time.

Practically, in many cases, the technological time is smaller than the time of heat transfer from the polymer to the mould walls and then to the environment. This aspect often imposes the necessity of the supplementary cooling of the mould using cooling equipment. The knowing of the cooling time imposes the adopting of the type of the injection aggregate which will lead to the best technical and economical results.

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References

1.MANEA, GH., Prelucrarea prin injecţie a materialelor plastice, Ed. Tehnică, Bucureţti, 1986, p. 180

2.IONESCU MUSCEL, I., SERES, L., Proiectarea matriţelor pentru produse injectate din materiale plastice, Ed. Tehnică, Bucureţti, 1987

3.COCIU, V.; VOLOCARIU, R.S & IONESCU LUCA C., (1994), Matriţe şi dispozitive de formare, Rotaprint, Universitatea Tehnică “Gheorghe Asachi” Iasi

4.IONESCU LUCA, C. (1995) Matriţe şi procese de formare în matriţe din industria de încălţăminte, Editura Cronica Iaşi, ISBN 973-9206-09-3

5.RUSU, M., RUSU D.L., Tehnologii de prelucrare a polimerilor, vol. I, Ed. Dosoftei Iaşi, 1995

6.MENGES, G., MAHRER, P., Haw to Injection Molds, Hauser Publishers Munich, Vienna, New York, 1986

7.NORMAN C. LEE, Understanding Blow Molding, Ed. Hanser Gardner Publication, ISBN 1-56990-301-8,2000; http://www.hansergardner.ro

8.SEREŢ, I., Materiale termoplastice pentru injectare, tehnologie, încercări, Ed. Imprimeriei de Vest, Oradea, 2002

9.IONESCU LUCA, C., Buletinul Intitutului Politehnic din Iasi, Tomul LII (LVI), Fasc.5, Secţia Construcţii de maşini, 2006, pp.385-389, ISSN:1011-2855

10.DRAGOMIR, A., IONESCU LUCA, C., “ X International Conference on the Theory of Machines and Mechanism, Proceedings, sept. 2-4, 2008, Tehnical University of Liberec, Czech Republic, p.189-193, ISBN 978-80-7372-370-5

11.DRAGOMIR,A., Buletinul Intitutului Politehnic din Iasi, Tomul LII (LVI), Fasc.5 A, Secţia Construcţii de maşini, 2006, pp.389-393, ISSN:1011-2855

12.IONESCU LUCA, C., DRAGOMIR, A., Buletinul Intitutului Politehnic din Iasi, Tomul LII (LVI), Fasc.5 A, Secţia Construcţii de maşini, 2006, pg.381-385, ISSN:1011-2855

13.CHIRILĂ, E., IONESCU LUCA, C, Proceedings of The 13th Internaţional Conference, ModTech2009, 21-23 May, Iaşi, 2009, Romania, ISSN:2006-3919,p.131

14. IONESCU LUCA, C., CHIRILĂ, E., Anals of the Oradea University, fascicle of Management and Technological Engineering, vol.VII (XVIII), ISSN 1583-0691, 2009, pp. 1179

15. STEFĂNESCU, D., MARINESCU, M., DANESCU, AL., Transferul de căldură în tehnică, Ed. Tehnică, Bucureţti,1982

16. EHRENSTEIN, G.W., Polymeric materials: Structure, Properties, Aplications, Ed. Hanser Gardner Publication, ISBN 1-56990-310-7, 2001

17.IONESCU LUCA, C., CHIRILĂ, E., Anals of the Oradea University, fascicle of Management and Technological Engineering, vol.VII (XVIII), ISSN 1583-0691, 2009, pp. 1173

18. *** Project no. 134124-LLP 2007-RO-LMP, Project no. 2007-3111/001-001 LE3-MULPRO, (http://www.virtual-shoedesign.com/)

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