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# CONTRIBUTION ABOUT TECHNOLOGICAL REGIME OF FOOTWEAR SOLES INJECTION FORMING INTO THE MOULD

**Cornelia LUCA**
"Gheorghe Asachi" Technical University of Iasi, ROMANIA, e-mail:cionescu@tex.tuiasi.ro

***Abstract*****—**The thermal mechanism of the footwear soles forming processes is different depending on their character during the heating and cooling processes. The cooling processes are in the case of thermoplastic plastic masses, when the mould cavity is injection-feed. The paper presents some theoretic and experimental aspects about the footwear soles injection technological regime.

***Keywords*****—**footwear, sole, mould, injection system

## I. INTRODUCTION

THE thermal mechanism of the footwear soles forming processes is different depending on their character during the heating and cooling processes.

The cooling processes are in the case of thermoplastic plastic masses, when the mould cavity is injection-feed. The fluid plastic mass takes the shape of the cavity and then in certain calculation technologic time the product which was made is cooled until a temperature which makes possible the unloading without any deformation.

For the thermoplastic plastic masses blends the mould cavity has 40-50 ($^oC$) during the injection process, and the polymeric melting has 180-220 ($^oC$) depending on the formula. The polymer cooling takes place by convection heat transference to the environment or by conduction to a cooled area belonging to the injection aggregate refrigerating equipment.

When the soles are made as prefabricated parts which will be assembled by gluing or sewing on the footwear vamps, one mould has two cavities to realize one pair. In the confection "IJ" system case (injected footwear- the soles are made by injection process straight on vamps), the equipments has two moulds for each working posts, one for the left leg and the other for the right one. The number of the working posts of the soles forming equipments depends on the equipments' efficiency. The equipment's efficiency mostly depends on the polymer melting cooling time into the mould cavity after the injection. Beginning with the most simple equipments which have two working posts, the number of the working posts may increase till 6, 12, 16, 20 even 40.

The paper presents some theoretic and experimental aspects about the footwear soles injection technological regime.

## II. EXPOSITION

### *II.1.Dynamics of the cooling process*

The footwear outsoles made by the injection of the polymer blends, often use polymerized vinyl chloride and thermoplastic rubber having special formulas. For these blends the feeding mould temperature is about 40-50 $^oC$, the polymer melting having about 180-220 ($^oC$).

The outsoles injection equipments have two or more working posts. The two working posts equipments have two moulds, left-right, and one for the polymer injection, cooling and solidification process and another one, for the unloading of the obtaining products. The equipments having more working posts are carousel type and they have working posts multiple of 6, 12, 16, 20, even until 40, depending on the productivity of the equipment. The time necessary for one pair of outsoles obtaining, $\tau_c$, is calculated [1], [2] refer to (1). The time of the process, $\tau_p$, has two components: the time necessary for the polymer injection into the mould cavity and the time necessary for the polymer blend cooling and solidification until a temperature which allows the unloading of the product without any deformation. The feeding time is out of the proper thermo chemic process time:

$$\tau_c = \tau_p + \tau_d \tag{1}$$

where: $\tau_c$ - time for one cycle of one outsole obtaining; $\tau_p$ - time for the polymer blend thermo chemical injection, cooling and solidification process; $\tau_d$ - time for the mould feeding. For a continuous manufacturing process, the removing of the waiting times is made respecting the conditions [1], [2] pointed refer to (2):

$$\tau_c = n \cdot \tau_d \tag{2}$$

where: n - number moulds.

An optimum productivity equipment realizes about 200 outsoles pairs/ mould/8 hours. The time for one cycle of one outsoles pair manufacturing is about 150 (s). The injection time is about 10-15 (s). So, for the two working posts equipment, the condition pointed refer to (2) may be realized in controlled cooling conditions of the mould using an refrigerating installation of the equipment [3], [4], [5].

In the equipment carousel type case, having a big moulds number, more than 6-40, the cooling time amplifies in the same time with the increasing of the working posts number. This aspect allows an environment cooling of the mould, in the same time with the carousel rotation or permissive conditions for the cooling, more permissive than in two working posts equipments case.

The cooling of the polymer into the mould until 70-80 ($^oC$), (in this field, the handle deformation is hardly probable) takes place into the mould.

In this case, the heat quantity transfer by a mass unit may be calculated [1], [2] refer to (3):

$$\mathbf{Q = mc\Delta c} \tag{3}$$

where: Q - heat given by 1 Kg of polymer melting; m- mass; c - specific heat; Δt - temperature difference between the injection temperature, $t_i$ = 180-200 ($^oC$), and the medium unloading temperature of the product, $t_m$=70-80 ($^oC$) [6], [7].

Considering that the polymer cooling takes place from the mould wall in contact with the cool area, the temperature into the middle of the product made into the mould cavity is about equal to the injection temperature. In this case, it is possible to admit a medium temperature of the product, $t_m$, which may be considered equal to the arithmetic media of the two temperatures, refer to (4):

$$\mathbf{t_m = \frac{t_i + t_p}{2}} \tag{4}$$

where: $t_i$ - injection temperature; $t_p$ - peripheral temperature of the product.

The polymer warm lost must be taken by the mould and given to the environment, through the walls. Considering an polymer layer, having a δ thickness and an infinitesimal layer having a dx infinitesimal thickness, placed at x distance from the edge of the wall, which transfer warm to the environment, as pointed in Fig.1 [2], the heat transference from this layer to the environment is pointed refer to (5).

$$\mathbf{dQ_c = dmq = \rho dvq = \rho A dx q} \tag{5}$$

where: $dQ_c$ - transference warm; ρ- polymer density; m - polymer mass; v - polymer volume; A - area of the volume unit having dx thickness; q - warm transference by a mass unit.

This warm must be transference by the mould polymer after the filling up the cavity. Considering the parameters transference through polymer [8], [9], from the injection temperature to the contacting mould polymer temperature, it is valid [1], [2] refer to (6):

$$\mathbf{dQ_t = \frac{\lambda}{x} A(t_i - t_p) d\tau} \tag{6}$$

where : $dQ_t$ - transference warm; λ - polymer coefficient of transference; x - wall thickness; A - area of the heat transference surface; $t_i$ - polymer temperature at the injection moment; $t_p$ - peripheral temperature of the product; τ - time of the warm transference.

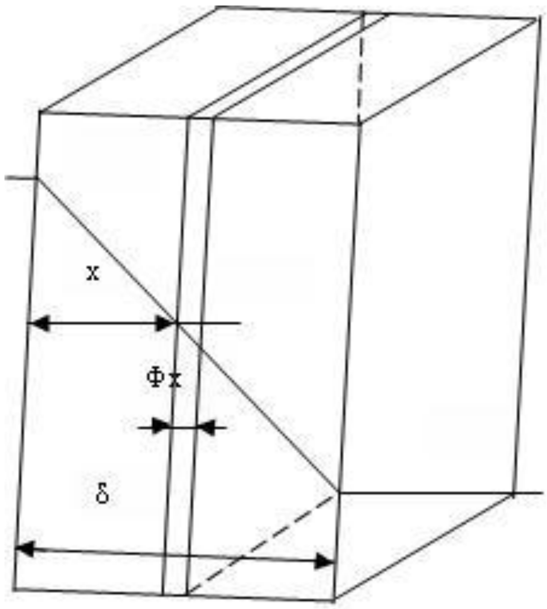


Fig. 1. Cooling dynamics of one polymer layer having δ thickness

Knowing that, the polymer warm transference by cooling, from the injection temperature to the medium temperature is equal to the polymer warm transference to the mould, making equal between (5) and (6), it will be obtained refer to (7):

$$\mathbf{d\tau = \frac{\rho q}{\lambda A(t_i - t_p)} x dx} \tag{7}$$

Admitting that the warm transference is uniform on both directions, normally on the layer with dx thickness and making an integration from the border to the middle of the polymer, the cooling time is pointed [1], [2] refer to (8):

$$\mathbf{\tau = \frac{\rho q}{\lambda(t_i - t_p)} \frac{\delta^2}{8}} \tag{8}$$

The dependence between the cooling time and the square polymer layer thickness, gives an explanation about the certain cooling of the polymer into the feeding canal and the sealing of the mould. In these conditions, the feeding canal has a diameter between 0,003 (m) and 0,006 (m).

*II.2.Particularities in dynamics of the injection cooling moulds in footwear outsoles manufacturing*

Considering the construction of the mould cavity [10], [11], as it is pointed in Fig. 2, [2] composed by two plates having $\delta_1$ thicknesses, the metal coefficient of heat transfer by conductivity, λ, and the transference of the warm to the environment making by convection, the warm transference to the environment is pointed [1], refer to (9):

$$\mathbf{Q_p = KA'\Delta' t} \quad (9)$$

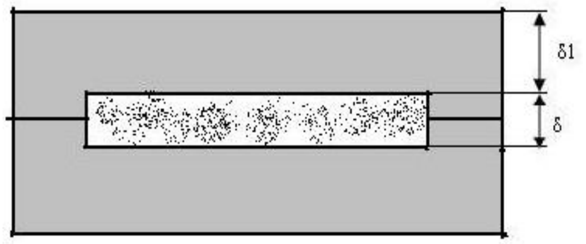


Fig. 2. Mould composed by two plates

Where, the coefficient of heat transference, K, is pointed [1], refer to (10) and $\Delta' t$ is pointed refer to (11):

$$\mathbf{K = \frac{1}{\frac{1}{\alpha} + \frac{\delta_1}{\lambda_1}}} \quad (10)$$

$$\mathbf{\Delta' t = t_p - t_a} \quad (11)$$

where: $Q_p$ - lost warm quantity of the mould to the environment; K - coefficient of heat transference; $A'$ - heat transference mould area; α - coefficient of heat transference of the stationary air layer surrounding the mould; $\delta_1$ - thickness of the mould wall; $\lambda_1$ - coefficient of heat transference of the metal of the mould; $t_p$ - mould temperature adopted equal to the exterior temperature of the product; $t_a$ - air temperature.

Considering the condition pointed refer to (12), (equality between the warm quantity given by the polymer to the mould and the warm quantity given by the mould to the environment, by convection):

$$\mathbf{mq = Q_p \frac{\tau'}{60}} \quad (12)$$

It results refer to (13) for the time of the lost warm to the environment:

$$\mathbf{\tau' = \frac{60m \cdot q}{Q_p}} \quad (13)$$

The time τ pointed refer to (8) will be compare with the time $\tau'$.

If $\tau > \tau'$, the mould cooling because of the heat transference to the environment takes place and the mould cools in contact with air in the same time with its warming from the injected polymer.

If $\tau_1 < \tau_i$, the mould can not cool loosing warm to the environment during the polymer decreases the temperature until, $t_m$, and loosing the warm quantity, Q. So, this period of time must increase or it is necessary an additional cooling, if the mould using a cooling fluid.

## III. EXPERIMENTAL RESULTS AND DISCUSSIONS

*III.1.Creation of some technologic regime used in the soles injection equipments*

The different types of soles injection equipments have, depending on the number of the working posts, different productivities and different technologic regimes.

Referring to the entire using time there are three stages, the servicing, the injection and the cooling. The injected diagram [2] pointed in Fig. 3 shows that the so-called injection time has a small value but for the ending of one cycle it must take place a complete filling of the cavity as a result of the polymer contraction by cooling, of the continuous cooling and of the polymer solidification into the canal [10], [11].

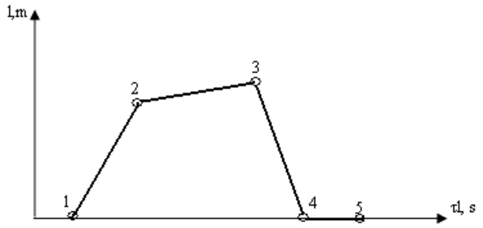


Fig. 3. Diagram of injection
1-2 injection; 2-3 cooling polymer; 3-4 further cooling the polymer; 4-5-opening mould

The paper [12], [13], [14], presents the injection technologic regime both in the two working posts equipment case (two moulds) and in the portative equipment with a big number of moulds, 6-40, case, too.

Considering the productivity of one equipment equal to 200 pairs/8 hours/mould, for a preparing and finishing working time equal to 1800 (s), refer to (4) shows that one cycle time per one mould is $\tau_{ci}$ =135 (s).

Considering the entire injection-cooling time, the so-called injection time has a small value, about 10-15(s). depending on the injected polymer blend quantity. The main time is the cooling time. This means that, when one cycle injection-cooling time is ($\tau_{ci}$), the cooling time, $\tau_r$, depends on the moulds number n=2, $\tau_r$ = 65,4-60 (s); n=4, $\tau_r$ = 91,8-98,4 (s); n=4, $\tau_r$=97,2-102 (s) etc.

Practically, it was demonstrated that the time necessary for one mould servicing used for one pair of soles is about 33,6 (s). Applying the condition pointed refer to (5), it results the servicing time: n=2, $\tau_d$=67,5 (s); n=4, $\tau_d$ =33,72 (s); n=6, $\tau_d$=22,5 (s) etc. So, one worker may service simultaneously about 4 moulds corresponding to four pairs.

The Table I shows the situation of one worker who needs a servicing time about 33,6 (s), for 4 moulds simultaneously used.

Because of a polymer medium cooling time, about 182,4 (s), the cooling by heat transference to the environment is not possible, but only in the case of portative equipments with a big moulds number. In the contrarily case, it is necessary a controlled cooling using refrigerating equipments.

Knowing that one mould productivity is 200 pairs/ 8 hours and the servicing time is about 33,6 (s), it results that one worker may service medium 4 moulds realizing medium 800 pairs/8 hours.

When the moulds are placed on the injection aggregate unselected, the polymer blend cooling time after the injection is calculated refer to (14):

$$\tau_r = (n-1)\tau_d - \tau_i \qquad (14)$$

In the portative aggregate case, having on working 6-40 moulds, the cooling time increases in the same time with the moulds number increase. When the moulds number rises over 16, the injected polymer cooling may take place in the work environment without any refrigerating equipment.

In the equipment having 16 moulds case, when the servicing time is $\tau_d$=33,9 (s), refer to (5), it results that the injection-cooling time is about $\tau_{ci}$= 540 (s). Because the so-called injection time is $\tau_i$ = 9,6-15 (s), it results that the cooling time is $\tau_r$= 497,4-500,4 (s), and so, the polymer cooling may take place in the environment air.

*III.2. Particularities of the cooling moulds dynamics in the footwear soles injection*

In technological field, the polymer cooling time into the mould must be decreased cooling the mould with water or with another refrigerant liquid. The Table II shows the calculation of the time necessary for the heat transference from the polymer in a certain situation [4].

Analyzing the results [13], [14] from Table II, the conclusions are when the polymer warm is lost in only one direction, the necessary time is $\tau_1$=303 (s). In this case, $\tau_1$> $\tau_i$, so, the conclusion is that the time lost by the polymer to the environment causes the polymer cooling in an available time. In this case, the adopted cooling will be equal to $\tau_1$, the transference warm of the polymer being faster through the mould. When the cooling takes place bidirectional, the technological time will be chosen equal with $\tau_2$. Knowing that the warm transference speed through the metallic mould will be, in all cases, bigger than the transference speed through the polymer it will not be the situation $\tau_1$< $\tau_i$. This situation is only in a plastic mass mould case, where the coefficient of heat transference is smaller than that belongs the formed polymer one.

When the outsoles are made into the moulds, there are frequently the situations where the cooling time, $\tau_r$ , is smaller than the time $\tau_1$ or $\tau_2$. In these cases, the cooling can not be realized [15]. To solve the situation, there are possible two variants: the using of the equipments with many moulds placed in an carousel way and the using of the equipments with refrigerating installation.

In the first variant, it will be adopted the solution of the production organization on a horizontal carousel, so, for the same equipment with one or two workers, the cooling time will be bigger. In this situation, considering the working time 33,6 (s), including the product opening, closing and unloading time and the time necessary for the rotation of the carousel with $360^0$/n, the time of one cycle is pointed refer to (3) and (5).

From the practical point of view, the carousels have an even number moulds. For this kind of carousel which has groups with "*n*" moulds, the cooling time will be bigger than 182,4 (s). Appling (3) and (5), for a certain case of an carousel having n=6 moulds, the working time is τd=30 (s). and the injection time is $\tau_i$=10-15 (s), so, the time of one cycle is $\tau_c$= 240 (s). In this cycle, the cooling time is $\tau_r$ =182,4 (s).

In the second variant, the decreasing of the cooling time can be realized using a refrigerant liquid (water, octafluorocyclobutane, ammonia, etc.).

In the case of water cooling, the cooling time, as a result of the ratiocination from Table II, for a temperature of the cooling water equal to 30 ($^o$C), is 14,4 (s). This time doesn't satisfied the equipments having a small number 2, 4, 6, of working posts. For these equipments, the cooling of the moulds is made using refrigerating installations based on octafluorocyclobutane, ammonia, etc.

TABLE I. TECHNOLOGICAL SCHEME OF THE INJECTION CYCLE WHEN SERVICING A FOUR INJECTION MOULDS

| Time (s) | Number of moulds | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| $\tau_d$ | 33.6 | - | - | - |
| $\tau_{i+}$ $\tau_r$ | 101,4 | 33,6 | 67,8 | 101,4 |
| $\tau_d$ | - | 33,6 | 33,6 | 33,6 |
| $\tau_{i+}$ $\tau_r$ | - | 67,8 | 33,6 | - |
| Total cycle | 135 | 135 | 135 | 135 |

TABLE II. CALCULATION OF THE TIME NECESSARY FOR THE HEAT TRANSFERENCE FROM THE POLYMER TO THE ENVIRONMENT

| No. | Mould parameters, Symbol, Measures | Calculation relations | Values |
|---|---|---|---|
| 1. | Injection temperature, $t_i$, (°C) | - | 200 |
| 2. | External temperature of the product at unloading time, $t_p$, (°C) | - | 80 |
| 3. | Temperature of the mould contacting the polymer, $t_p'$, (°C) | - | 70 |
| 4. | Air temperature, $t_a$, (°C) | - | 20 |
| 5. | Polymer quantity necessary for one outsole, m, (Kg) | - | 0,2 |
| 6. | Specific heat of the polymer, c, (Kcal/Kg°C) | - | 0,33 |
| 7. | Coefficient of heat transference of the polymer, λ, (kcal/hm°C) | - | 0,14 |
| 8. | Outsole thickness, δ, (m) | - | 0,01 |
| 9. | Outsole area, A, (m) | - | 0,014 |
| 10. | Mould thickness, $\delta_m$, (m) | - | 0,05 |
| 11. | Coefficient of heat transference of the metal, $\lambda_m$, (kcal/hm°C) | - | 40 |
| 12. | Coefficient of heat transfer nice of the stationary air layer, α, (kcal/hm$^2$ °C) | - | 20 |
| 13. | K- coefficient of heat transference, K, (Kcal/hm$^2$ °C) | - | 28 |
| 14 | Warm transference by a mass unit, q, (Kcal/Kg) | - | 237,24 |
| 15. | Transference area between the mould and the environment, A', (m$^2$) | - | 0,08 |
| 16. | Medium temperature of the polymer, $t_m$, (°C) | $\frac{t_i + t_p}{2}$ | 140 |
| 17. | Difference between the injection temperature and the medium temperature, Δt, (°C) | $\Delta t = t_i - t_m$ | 60 |
| 18. | Warm lost when the polymer is cooled, Q, (Kcal) | $Q = mc\Delta t$ | 396 |
| 19. | Polymer transference warm by cooling from $t_i$ $t_o$, $t_p$, , $Q_1$, (Kcal/h) and $Q_1'$, (kcal/min.) | $Q_1 = KA\Delta' t$<br>$Q_1'$ | 47,04<br>0,784 |
| 20. | Temperature difference between the injection one and the product exterior one, Δ't, (°C) | $\Delta' t = t_i - t_p$ | 120 |
| 21. | Total time for the warm transference through the polymer to one direction, $\tau_1$ (s) | $\tau_1 = \frac{q}{Q_1}$<br>$\tau_2$ | 303<br>154,8 |
| 22. | Transference warm of the mould to the environment, $Q_2$, (Kcal/h) | $Q_2 = K'A'\Delta'' t$ | 78,04 |
| 23. | Global coefficient of transference from metal to stationary layer, K', (kcal/hm$^2$ °C) | $K' = \frac{1}{\frac{1}{\alpha} + \frac{\delta_m}{\lambda_m}}$ | 19,51 |
| 24. | Temperature difference between the mould and the environment, Δ''t, (°C) | $\Delta'' t = t_{p'} - t_a$ | 50 |
| 25. | Time for warm transference from the polymer, $\tau_i$, (s) | $\tau_i = \frac{q}{Q_2}$ | 182,4 |

## IV. CONCLUSION

- The necessary moulds stock for a product volume in rhythmical conditions depends on a lot of criterions such as: the daily product assortment volume, the structure on sizes numbers of these assortments, respectively the sizes tally, the technologic time for one mould using in products manufacturing process in correlation with the equipment efficiency, the providing necessity of some spare moulds, the using and fixing conditions, etc.
- The equipments used in footwear soles manufacturing by injection and cold moulds thermo chemical processes are, from a constructive point of view, soles injection equipments straight on vamps and soles injection equipments, as semi products which will be assembled on vamps. From the efficiency point of view, these equipments may have two working posts (left-right), or more working posts, an even number, such as 6, 12, 24, ….,40 posts. These two different situations have an important influence to the time of one manufacturing cycle, respectively, to the time between two successive identical stages of the process. Entirely, this time has two components: the imposed time of the thermo chemical process and the technological attendance time of the equipment and of the mould.
- When the footwear soles are manufactured by injection using portative aggregates with "n" working posts, the distribution of the moulds on the working posts is very important. This distribution must provide the same kind products series in the contractual pre-established tallies of sizes and in the same time

the equipment working posts must be used in a balanced way.

- Taking into account the time of one cycle for one pair of outsoles obtaining, it has two components: the time necessary for the mould and equipment feeding and the time for the cooling of the polymer. In the outsoles injection equipment case, the feeding stages take place out of the polymer injection, solidification and cooling proper time. So, the main consumer time stage of the manufacturing process is the polymer cooling stage. The injection equipment's efficiency mostly depends on the polymer melting cooling time into the mould cavity after the injection.
- The cooling time of a polymer in a mould cavity, respectively the time the formation of soles shoes, is an essential parameter in the adoption installations injected soles of shoes. An optimal exploitation footwear soles injected equipments requires constant study of various thermal processes in polymer blends which form the soles footwear. Therefore, the manufacturing launch in of new models of manufacturing of footwear soles, and the principal new polymer melts mixtures is absolutely necessary to make a series of the thermal calculations.

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