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Water Assisted Injection Molding for Single and Multi-branched Tubular Components

D. Oliveira[a]*, A. Mateus[a], P. Carreira[a], F. Simões[a], C.Malça[a,b]

[a]Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Rua de Portugal, 2430-028 Marinha Grande, Portugal
[b]Department of Mechanical Engineering, Polytechnic Institute of Coimbra, Rua Pedro Nunes, 3030-199 Coimbra, Portugal

Abstract

To produce hollow polymeric parts with complex geometries the Fluid Assisted Injection (FAI) technology is currently used. In this technology water and gas can be employed with or without the aid of a projectile. The process consists in the injection of water at high pressures, after the closing of the mold and polymer injection, and up to the filling of the whole molding zone. The injection of water at high pressures will force the polymer from the core to be expelled to a reservoir. This material expulsion is possible, not only thanks to the high water pressures, but also because the polymer is still in a viscous state, thus facilitating the evacuation. Even though the FAI technology is by direct injection of water/gas or with aid of a projectile, there is a common limitation, which is the inability to produce hollowed parts with forking channels. However, even if creating these branches is possible, there is the impossibility of them being geometrically complex and/or extensive. In these cases, the branches are created with inserts inside the mold, meaning that they will always be limited by a molding insert, and not controlled by the water jet. For cases where it is desired to add complex and/or extensive ramifications, subsequent steps of production and assembling must be added, influencing the overall production time. This work aims, therefore, at studying a new approach for the production of hollow parts with extensive branched channels and complex geometries within a single injection cycle, and thus eliminating subsequent processes that are currently required. The first approach is the application of several water injectors, guided towards the respective branches where hollow sections are intended to be produced. This innovation will have an impact on the serial production of high complexity tubular type parts, reducing the production time with the elimination of subsequent processes. Furthermore, a saving of raw materials is achieved by eliminating the necessity of a creation of additional molds. In this work, a detailed experimental study of the water assisted injection process was done to serve as a knowledge base to the concept of the new process named Multi-Path.H2O.

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* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx

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1. Introduction

Towards an increasingly competitive global market, businesses spend a part of their efforts on the fast and effective development of new products to give answers to the market constant demand and stay competitive. In the developing process of injected parts, the injection mold shows to be a complex system with high cost and great importance for the attainment of quality components in short deadlines. There are currently several technologies to assist the conventional injection in the production of hollow components (tubular). Each of these processes has advantages regarding the production of numerous parts but, on the other hand, also has less favorable features for more complex geometries and with regard to the quality of the interior walls. Focusing on the method of direct fluid injection allows for the creation of hollow sections with varying profiles, which is great for parts of greater complexity with large volumetric variations for an optimal internal polymer removal. In spite of this, FAI technology - performed by the method of direct injection of water or gas, which for both cases can be aided with a projectile -, presents a great versatility in producing hollow parts, but shows a common limitation, which is the inability to produce tubular parts with complex geometries and extensive branches in one injection cycle.
The FAI technology is only used to produce simple hollow tubes, with one or several channels, but only with a low level of complexity. This project aims, therefore at exploring this technology more through the innovation and creation of a new method/technique of production, where the production will be possible of hollow components with forked branches and geometries with a higher level of complexity in a single injection cycle, eliminating the time consuming of subsequent processes. For that, the direct water injection technology is used to universalize the sections of hollow plastic parts with extensive ramifications, complex sections and with a thickness uniformity. The consequences of this procedure is to get a process that contributes to an ecologically sustainable manufacture, less time-consuming and less costly production for parts with these features. The focus of this study consists of a strong study and understanding of water-assisted injection molding (WAIM) process, to aid in the design of a new process/system to help this technology to allow the production of hollow and bifurcated multiple channels parts within a single injection cycle.

1.1. Fluid assisted injection molding

The polymer injection process is the most used process to produce a high number of plastic parts in reduced times. One of the industries that most uses this production process is the automotive industry [3]. Currently, the injection technology assisted by a fluid, which can be performed by direct injection method of water or gas or both cases with the aid of a projectile, is used to manufacture polymer parts with hollow section and complex geometries. The process consists of injecting fluid at high pressure, after the mold closing and injection of polymer of the total filling of molding zone. The injection of fluid will force the expulsion of the polymer from the core into a reservoir [2]. This expulsion of material is not only possible thanks to high pressures of the fluid, but is also due to the fact that the polymer is still in a viscous state which facilitates its outflow. Liu and Wu [1] report the advantages and variants of the injection fluid assisted process in the production of polymeric components with hollow section recording faster injection cycles and greater savings of raw materials. The technology of injection assisted by fluid is an asset for the injection of plastic component industries, bringing greater productivity, speed and sustainability given the ability to produce lighter parts, hollow and complex geometry with functional and structural performance similar to bulk components [4]. These features are absolutely crucial for the automotive and aeronautic industries.

The injection molding assisted by gas, patented in the 70s [5, 6] was the first approach of the process of injection assisted by fluid, which received much attention by the industries of the time [3, 7, 8]. However, the use of gas, usually nitrogen, is decreasing due to limitations such as low thermal conductivity, low heat capacity, the compressibility of the gas and the need to use a high purity gas compromising the process sustainability since nitrogen is a nonrenewable resource.

WAIM reduces the cooling time and the consumption of raw materials of cast plastic parts [10] which, in turn, leads to new application fields for thermoplastic materials [11]. The water incompressibility allows for better control of the process by placing more stringent requirements for a water injection unit, since it is necessary to provide a volumetric flow continuously. The good thermal conductivity of water compared to gas occurs during the phases of compression and cooling, since the optimum performance of the water enables the molten to be cooled therein, reducing thereby the cooling time [11]. Fleack [12] reports that using gas assisted injection molding, the part cooling is about 50% slower than in the WAIM since water has a coefficient of thermal conductivity higher than gas, which is a necessary condition for reducing the production time cycle.

1.2. WAIM molding approaches

WAIM systems are composed of various components, where the most important one is the injector head. This injector, which is connected by pipes to the main system, is the main engineering element that allows the injection process to occur. The use of this component needs to be handled with some care, to promote production cycles with success and avoid possible errors. Another technique that may be used jointly by fluid assisted injection process is the process of assisted injection with a projectile. This section demonstrates several advantages to the WAIM process, but also presents some disadvantages. WAIM with a projectile process was tested during this study to have a better understanding of this process and for later comparison analyses. This injection process consists of the creation of section castings by a projectile, as can be seen in Fig.1. However, in order to boost the projectile, a fluid assisted injection system is also necessary. This bullet is typically manufactured with the same polymer that is injected into the mold for the part/device manufacturing avoiding contamination during recycling. In this sense, the mold cavity is partially filled, and then the projectile is placed in the cavity to serve as the fluid torpedo that will be used to set the internal hollow profile geometry. The main function of this projectile is to push the plastic from the center of the cavity against the walls of the mold by opening an empty tunnel-shaped before solidification. This process has a significant advantage, which is the ability to be used in all thermoplastic materials.

The use of a projectile brought certain advantages when compared with the direct injection of fluid processes, where maximum diameter values between 20 to 25 mm can be reached. Above these dimensional values the projectile application is required. Furthermore, the projectile use has another feature that must be highlighted, which is the ability to guarantee a higher internal wall quality. In comparison with the use of a projectile, the direct fluid injection doesn't allow for the removal of the material from zone which does not have a circular geometry, meaning that if the injected part shows a none geometrical section, it is impossible to have a total material removal as shown in Fig.1. Although the projectile use has great advantages over the direct injection of fluids, this technique presents a disadvantage that is: while the direct injection approach the hollowed section can vary from dimensions, the projectile injection approach is always dependent on the size and geometry of the projectile.

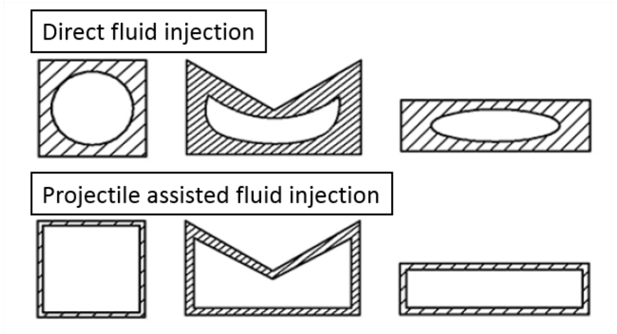

Fig. 1. Injection in sections none circular [13]

2. Mold development and tube manufacturing

The purpose of the mold designed for this study was a geometrically simple tube injection to study and compare the effects of direct injection versus projectile assisted. This tube shows a constant diameter through its variable curved length. The design process of this mold was partaken with the help of professionals in the mold industry, result in the following modulation in Fig. 2.

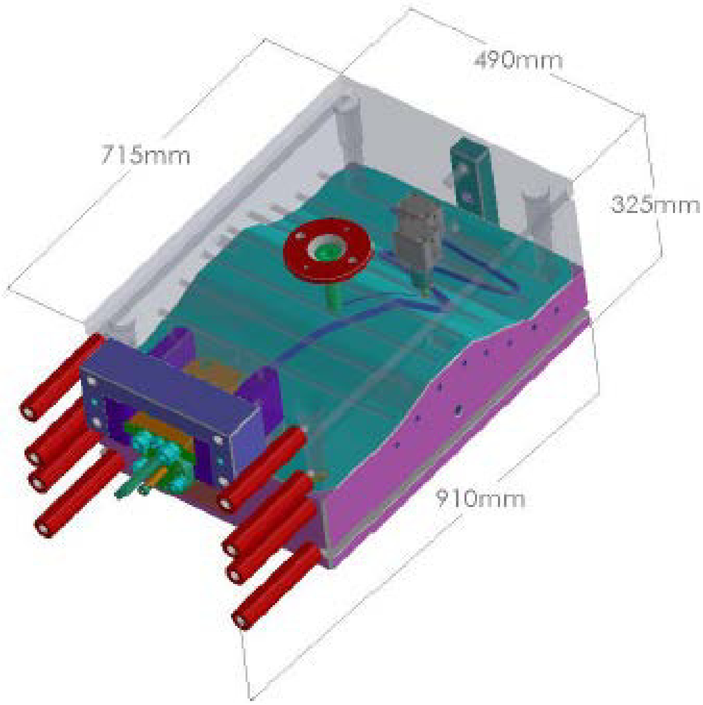

Fig. 2. 3D CAD model of the mold

The mold was designed using the “overflow” approach. This approach consists of the creation of a reservoir cavity in the mold to allocate the molten core material of the tube. Using the Fig. 3. as reference, the injection process has the following sequence: The polymer is injected through (6) until the cavity of the part’s main body is fully filled. The compact injected polymer valve (5) is closed, to prevent reflux of the material back to its injector fuse, and the valve (3) is opened to allow the internal molten core material to pass to the reservoir (4). With these valves opened and closed, the fluid injection takes effect at (1) and pushes the molten core material to the reservoir (4).

After the mold design, the programing computer aided manufacturing (CAM), the mold manufacturing and the mold assembly procedure were performed. The preliminary tests carried out demonstrated, as expected, that the mold development process must went by an interactive process of corrections/adjustments/amendments of the molding zone and of the necessary elements for the its proper functioning. The mold was then mounted on the injection machine (Euroinj D300), which is coupled to a water injection system (PMEfluidtec). The elastomer TPE TC8GPN B100 was selected to perform these injection testes [14]. Fig. 4. shows the mold mounted in the injection unit with the two components still coupled to the fixed part of the mold. In the figure of the left side the injected component without the application of fluid injection can be seen while the figure of the right side shows the component totally injected, the workpiece and the "material pouch" completely filled.

The injections done with this mold were performed without fluid assistance, with direct fluid assistance and with fluid plus projectile assistance. In Fig. 5 it's possible to observer the projectile on top of the fluid injector, in this case, a water injector. To produce components by this approach, it is only need to carefully insert a projectile on the top of the injector. In the particular case of this work, the projectile was manually applied but for a mass production the projectile will be obviously applied by a robot.

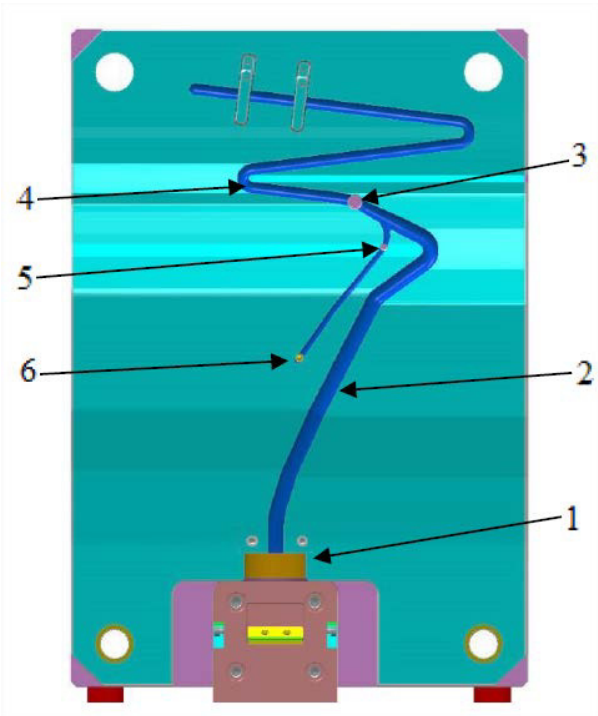

Fig.3. Mold cavity

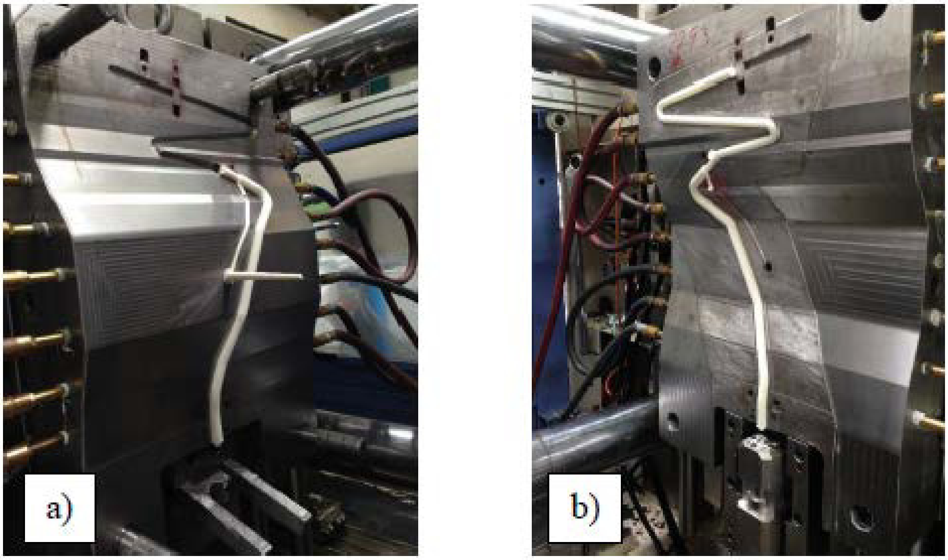

Fig. 4. Mold test

Fig. 5. Projectile application

During the injection phase, several injection cycles were done until it was found the ideal parameters to produce the desired parts. After these optimizations, batches of parts were produced by the different approaches. The biggest problem find was the application of the projectile. The bad projectile application lead to parts with defects, i.e. parts partially hollowed. Solved this problem, the series production continued with no problems.

3. Preliminary tests of the produced tubes

One of the factors that makes the fluid assisted injection molding an effective technology, is the ability to produce light weighted components. With this in mind, parts without the application of fluid injection were injected to understand how much material can be save from each part produced. The structural viability is not, in this particular case, a main factor to the produced component. Fig. 6. Illustrates the weight test performed. It can be observed that the fully solid body weights around 100gr, the tube produced using the injection assisted by projectile process around 64gr, and the sample produced with direct water injection around 52gr. From these results it can be concluded that using the water assisted injection a save up to 48% in part weight can be expected, while with the application of a projectile around 36% can be saved. In this case study the weight optimization between the direct water injection and assisted projectile was around 19%, which means that there was a higher removal of material with direct water injection.

For a deeper understanding of this study, the internal wall quality of parts manufactured by direct water injection and assisted projectile was compared. For that, after extracting samples from each type of tube, samples were cut and a micro CT scan analysis was done to observe dimensional deviations. Fig. 7. shows the results from the scan obtained of a tube sample directly injected by water (a) and a sample from injected tube assisted by a projectile (b). From these images observation it is possible to evaluate the difference of the internal dimensional quality from each manufacturing approach. The internal wall quality from the injected tube by projectile assistance shows a more uniform and stable dimensional section, while the sample from direct water injection shows a more irregular internal wall along its length. These irregularities are caused by the water, which removes more material from the walls due to its fluid nature. Furthermore, the direct fluid injection lead to a more fragile component generation because several areas with low thickness can be observed.

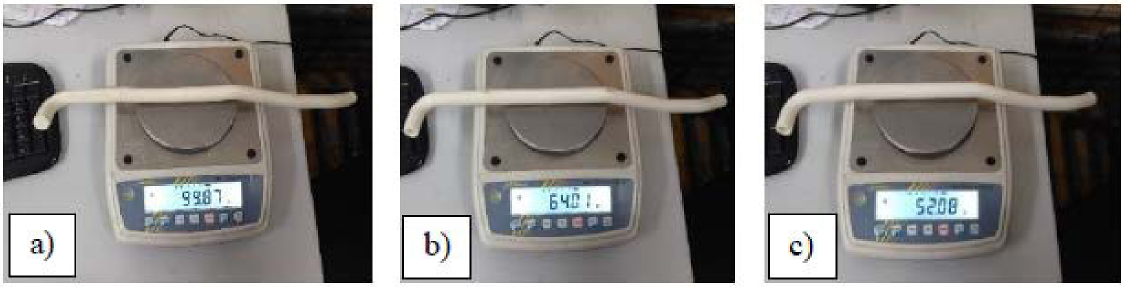

Fig.6. Elements: a) Solid; b) Hollowed with projectile; c) Hollowed with direct water injection

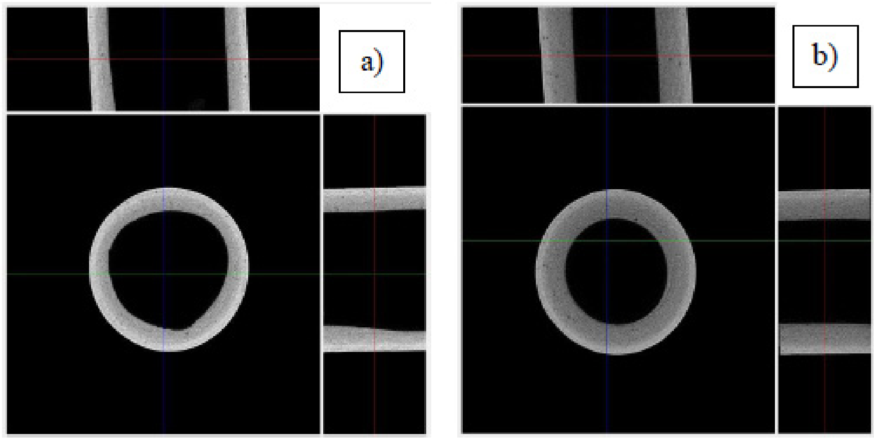

Fig. 7. 12mm tube samples: a) Direct water injection; b) Projectile assisted

4. Conclusions

The results obtained demonstrated that the majority of the occurred errors in the tubular parts manufacturing are related with the fluid injection molding assisted by a projectile. In fact, the use of a projectile can bring a chance of fail during the production process, nevertheless with some optimization on the insertion of the projectile, this technique become a very promising manufacturing process. Currently, the entities that use the projectile approach tend to use automated system to apply the projectile, making sure that it's correctly inserted on top of the fluid injector. In the case study presented here the projectile were placed manually, thus bringing human error to the process.

The produced components internal wall quality was analysed. The obtained results demonstrated that the use of a projectile lead to a better quality and constant dimensions trough the length of the tube. For components which a high dimensional rigor is required, this approach is a good solution, but if the inter wall quality isn't a crucial factor the assisted projectile approach should be ignored. Furthermore, from the weights comparison analysis, it can be conclude that the direct water injection can optimize the weight, which is a determinant economic factor for the automobile industry components production. In addition, the material volume removed without the projectile is higher, which meaning that the projectile is not adjusted to manufacture hollow components with variable sections or by other words it's impossible to apply this approach on the multipath process at least for now.

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