Development of smart projectiles for multi-dimensional water-assisted injection moulding.

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ABSTRACT: Water-assisted injection moulding (WAIM) is one of the most significant injection moulding techniques to produce high quality polymeric parts with complex geometries and sustainability. The WAIM process with projectile extends the possibilities because it allows the calibration of the thickness wall of plastic parts, but also confers surface finish, reducing the interior roughness and therefore the flow turbulence. For a better understanding of projectile shape change WAIM process, a bench of laboratory tests was developed, as well as the projectiles that make possible the variation of the geometry inside the tube. In this work was been established a low viscosity laboratory system to evaluate and improve the projectiles. We have used transparent tubing for the "mould" (to simulate the walls of pipes) to allow real time observation of the different types of projectiles tested. The smart projectile developed going to be used to improve the production of tubing with different diameters along its length with calibration of thickness. The ability to observe the behaviour of the projectiles has proved to be invaluable in the successful development for the WAIM procedure.

1 INSTRUCTIONS

Currently to manufacture of plastic parts with complex shapes, geometries and hollow core, the best technology to be used is water assisted injection moulding (WAIM) [1] [2] [3]. In recent years this technology has been increasing in demand for the manufacture of plastic parts thanks to its ability to produce lighter parts with faster cycles and greater savings in raw material [2]. This technology aims to aid conventional injection processes to create parts with hollow cross sections by submitting a high-pressure water jet subsequently to the polymer injection, thus removing material from the part's nucleus.

WAIM can be executed by two methods, which can be the direct water injection or water injection with an auxiliary projectile. Each method brings their own advantages and limitations. In the direct water injection, it is possible to create parts with hollow cross sections with no limitations of the profile's geometry and size, thus creating inside walls inconstant and with irregularities (Figure 1 A)). In water injection with an auxiliary projectile, it is only possible to create hollow parts with constant profile geometry, thus creating perfect calibrated inside walls (Figure 1 B)) [4].

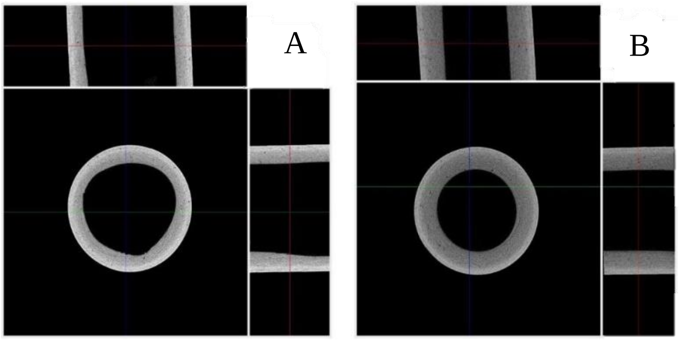

Figure 1. A) Cross section of a sample part produced by direct injection of water; B) Cross section of a sample part produced by injected with the aid of a projectile [4].

The work present in the article arises in the scope of the *waterSHAPE* project, the goal is to combine the advantages of the two processes, aiming to achieve a superior quality in the production of hollow plastic parts with variable sections and calibrated walls. The primordial approach consists in the creation of a projectile with a diameter changeable in time. In this work/paper only, the mechanical actuators are studied, but in this project the mechanical, electromechanical and shape memory alloys actuators were developed and studied.

The main objective of this work was the development of mechanical actuators to change the shape by applying forces and maintain a constant geometry with geometric barriers.

To support the development of the projectiles and without involving too high a cost, such as putting the mould in the injection machine and testing each of the geometries under study in real devices, a test bench was developed that allows us to simulate and visualize the flow, as well as the actuation of the projectiles in real time, also allowing to verify the effect of pressures and back pressures.

2 TEST EQUIPMENT ASSEMBLING AND MATERIALS

The test bench was developed in order to have the inner diameters as similar as possible to those previously established for the test tube to be moulded in the laboratory mould, the test tube varies the outside diameter from 20 to 30 mm, being that we intend to obtain a wall thickness constant of 3 mm, due to this fact the projectiles were developed to have a range of action between 14 and 24 mm. In this phase of study, we didn’t consider any shrinkage.

For the real-time observation of the projectile behaviour, we chose to construct the tests bench with transparent materials, opting to use two tubes of Polycarbonate [5], one with 16 mm of internal diameter and the other one with 26 mm, both with 2 mm of thickness. Both, for the connection between the tubes and the end zones, we chose to print components developed by us in the OBJET30 PRIME, using resin RGD720. We could not find pipes with 14 mm and 24 mm of internal diameter, due to this fact we chose to use the previously described. For a better understanding, in Figure 2 the test bench is shown.

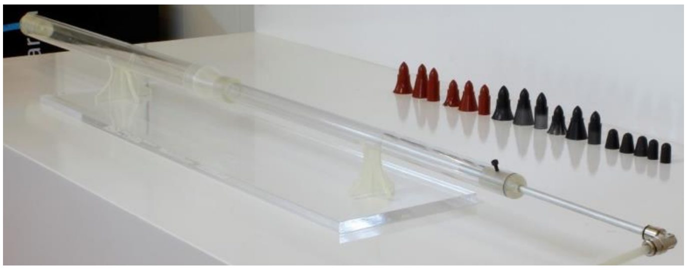

Figure 2. Test bench.

The test bench only simulates the activation of the projectiles helping the development of the geometry, not allowing to establish any prediction if it works in the cases of study in laboratory mould, to be carried out later in the project. In order to study the geometries of the projectiles, we have chosen to use the glycerol 1,2,3-propanetriol on the test bench, this will be the substance to be extracted in full with the aid of the projectiles. As a trigger for the projectile instead of water, air was used. It is also necessary to consider that the pressures involved in this test are not comparable with those developed in real cases when in operation we have the WAIM tocology.

The geometries of the studied projectiles were modelled using SolidWorks software and prototyped in silicon Köraform RTV-2C A42 [6], we chose to use only silicone projectiles on the test bench because it is a sufficiently flexible material to be used with relatively low pressures. The silicone was cast in moulds (Figure 3), modelled with the support of SolidWorks software and prototyped in OBJET30 PRIME, using resin RGD720 and RGD450.

The remaining material used in the test will not make a note, however its need is not less important.

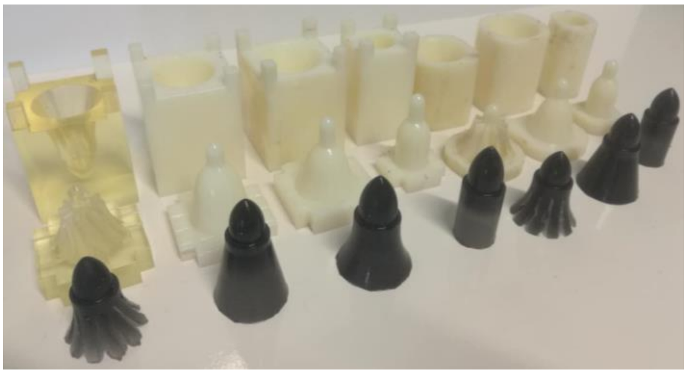

Figure 3. Moulds and projectiles for the test.

3 PROJECTILES, PRINCIPLE OF OPERATION

During the development of this project, the projectiles have been optimized several times, but in this article only the final versions used in a larger bench test will be approached. These tests supported the decision of which advanced to the test phase in laboratory mould. Several principles of projectile performance were thought, developed and materialized, however only three advanced to this stage of testing, in seven different projectiles designed with minor differences within each type.

The first type of projectile, shown in Figure 4 and Figure 5, is a projectile in which the principle of operation is dependent on the flexibility of the building material as well as the operating conditions (pressures and back pressures of the system). The Figure 6 helps to explain the principle of operation. The zone of the initial tube presents geometric constraints, only allows the projectile to move longitudinally, restricting any other action. When the projectile passes to the tube with larger diameter the geometric constraints are changed, and the projectile is free, counting on the flexibility of the material and the pressures involved in the process, the projectile inflates, covering the entire diameter and withdrawing the material in the liquid state.

The projectiles shown in Figure 4 and Figure 5 have several differences, the projectile BT_F01 is smaller, thinner, but thicker than the projectile BT_F02, the differences will allow the study different aspects, of the geometry such as: the length difference will allow you to check for guiding differences with length; the difference of diameters allows to verify if the projectile with the smallest diameter inflates soon at the beginning of the pipe, improving the performance; the difference in thickness, allows us to verify the difference in performance with the variation of geometry. The huge variation of parameters in such a small sampling is because these projectiles are still to define a guideline for future developments.

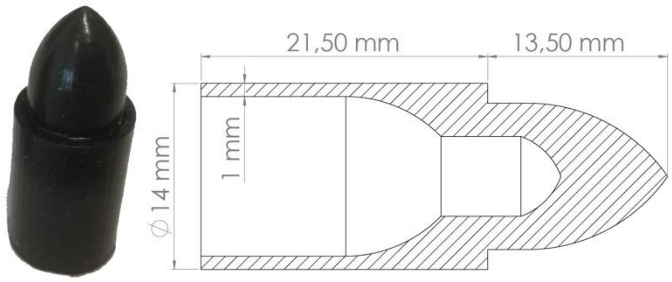

Figure 4. Projectile BT_F01.

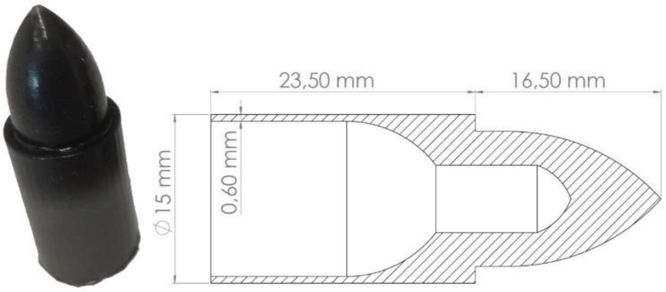

Figure 5. Projectile BT_F02.

Figure 6. Test bench with the actuation of the projectile type BT_F.

The second type of projectile, shown in Figure 7, Figure 8 and Figure 9, as in the first also the operating principle is dependent on the flexibility of the building material, but not so much on the operating conditions (pressures and back pressures of the system). Figure 10 helps to explain the principle of operation, the initial zone of the tube presents geometric constraints, the projectile is required to change shape to pass. Only when the projectile passes to the tube with larger diameter geometric constraints are altered and the projectile is free to return to the initial shape, covering the entire diameter and withdrawing the material in the liquid state. This geometry supports a correct operation, but such as the first only when the projectile's building material is flexible is such a geometry can be used.

The projectile of Figure 7 and Figure 8 are similar only with differences in the length and thickness of the skirt, the projectile present in Figure 9 is quite different from the previous ones.

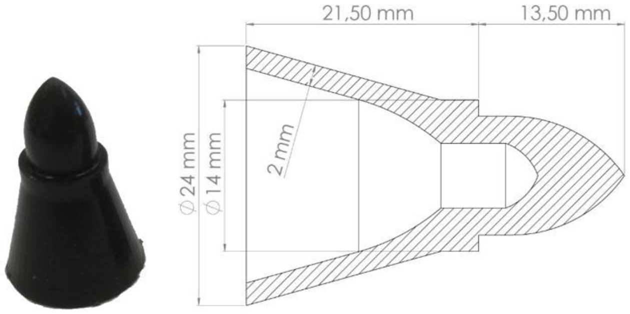

Figure 7. Projectile BT_A01.

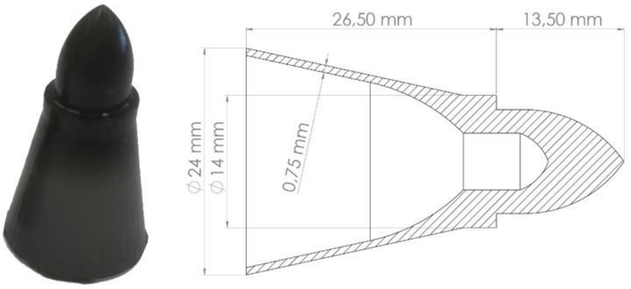

Figure 8. Projectile BT_A02.

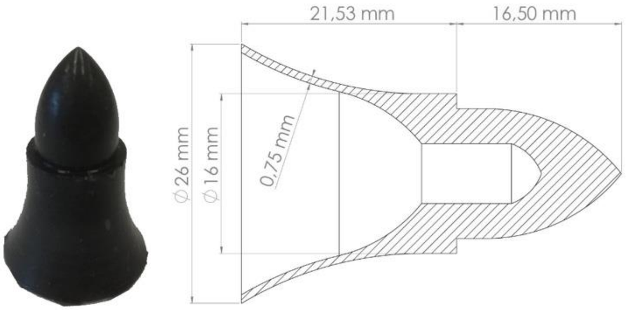

Figure 9. Projectile BT_A03.

Figure 10. Test bench with the actuation of the projectile type BT_A.

The third type of projectile, shown in Figure 11 A and B, is different from the previous ones, it does not depend exclusively on the flexibility of the constituent material, and can even be used with more rigid polymers.

This projectile was developed with flaps. Each flap being separated from the next when necessary that the projectile changes form to a more compact, subjected the same to geometric constraints the flaps overlap one on the others, as exemplified in Figure 12 A. Even with a more rigid polymer they can overlap with relative ease.

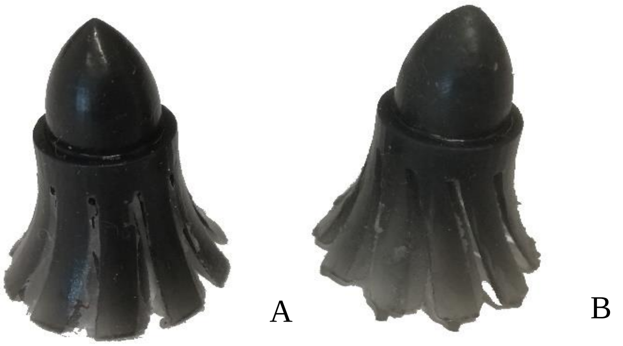

Figure 11. Projectile type BT_B: A) Projectile BT_B01; B) Projectile BT_B02

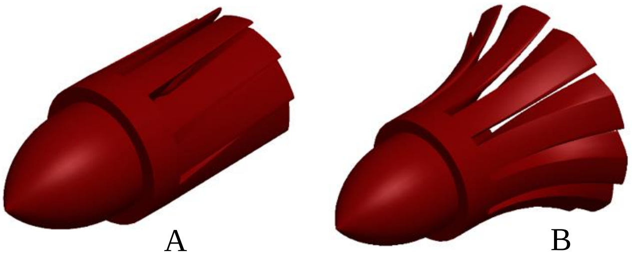

Figure 12. Projectile BT_B01: A) closed; B) open normal resting position.

Figure 13 helps to explain the principle of operation, the zone of the initial tube presents geometric constraints, the projectile is inserted in the compact form as exemplified in Figure 12 A, only when the projectile passes to the tube with larger diameter geometric constraints are changed and the projectile is free to return to the initial shape, covering the entire diameter and withdrawing the material in the liquid state.

Figure 13. Test bench with the actuation of the projectile type BT_B.

The differences between the projectile BT_B01 and BT_B02 are only in the angle of the flaps. An angle has been added to the flaps, for the projectile rotate around its axis during the path, ideally improving the finish and decreasing drag resistance.

4 TEST METHODS

We planned a series of tests with the purpose of verifying different parameters of the projectile geometry, as well as the behaviour at different pressures and back pressures. These tests made it possible to verify the behaviour to be expected of the projectile during the tests in the laboratory mould.

All the tests were filmed by two cameras, a high-speed camera that shot at 300 fps and the second normal, shot at 60 fps, all videos can be viewed on the project website (http://cdrsp.ipleiria.pt/watershape/)

The tests were all carried out in the same manner, initially the pipe is filled with glycerol 1,2,3-propanetriol, and a projectile is fitted into the aluminium tube and then the assembly is fitted into the smaller tube of the test bench, placed in its proper place, adjusts the air pressure, finally opens the air. After all the glycerol is poured and with the projectile on the other end, the test bench is opened again the projectile is removed and the process is repeated.

For each projectile nine stages were performed, the air pressure was varied from two to four and finally to six bar, as well as the counter pressure, we will only characterize the back pressure with the values of the tube diameter. Because the back pressure varies with multiple factors such as the projectile's friction with the pipe walls, different frictions for the pipes due to the different contact, the initial pressure of air, the air that escapes forward of the projectile, the variation of the tube diameters, as well as the way the projectiles are placed. All these are too many factors to consider due to this fact we assume as being the only factor to consider for back pressure the diameter of the tube through which the entirety of the glycerine will pass. The counter pressure was performed by three sections of diameter six, eight and ten mm. By changing these parameters, we can verify the influence of the pressure as well as the back pressure in the activation of the projectiles.

5 RESULTS, ANALYSIS AND DISCUSSION

It is necessary to make some considerations to analyse the results, during the tests only the activation of the projectiles was relevant, reason why the time described in the tables is only an approximation to the elapsed, the times were only extrapolated from those observed in the videos. All times marked with the symbol of infinity, the projectile could not finish the course of the test bench. All stages present in the table were only traversed twice for each projectile, in most cases without changes. When the results changed, we only use the results of the best performance.

Table 1. Behaviour of the Projectile BT_F01 during the bench tests.

Projectile BT_F01	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	≈ 14s
	6 bar	6 mm	∞
	2 bar	8 mm	∞
	4 bar	8 mm	∞
	6 bar	8 mm	∞
	2 bar	10 mm	≈ 2s
	4 bar	10 mm	≈ 1s
	6 bar	10 mm	≈ 1s

The tests represented in Table 1, allowed us to compare values and take some elations, such as:

In all the tests performed with the fluid outlet section of 6 mm, the behaviour was similar, but only in the with the pressure of 4 bar, the projectile was able to finish the course in the others the projectile lost the guide in the tube with larger diameter, more or less on 70% of the course, with the projectile tip followed by a downward trajectory, which caused the air to pass over it. Observing the videos of the test is not noticeable any opening of the projectile skirt, this in the tube with larger diameter just passed over the glycerine, not successfully cleaning the tube.

In the tests with the fluid outlet section of 8 mm, the results obtained were worse than those previously described, with these parameters the projectile barely left the beginning of the tube with smaller diameter, only with the pressure of 6 bar the projectile was able to cover 60% of the route, in which the tip of the projectile followed a descending trajectory, which caused the air to pass over it, as in the first, no opening of the projectile skirt is visible.

For the fluid outlet section of 10 mm, no matter what the set air pressure, the projectile was able to finish the course, even pretending to open the skirt a little, not enough to completely sweep all the glycerine.

Table 2. Behaviour of the Projectile BT_F02 during the bench tests.

Projectile BT_F02	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	≈ 9 s
	2 bar	8 mm	∞
	4 bar	8 mm	≈ 8 s
	6 bar	8 mm	≈ 5 s
	2 bar	10 mm	≈ 2 s
	4 bar	10 mm	≈ 1,5 s
	6 bar	10 mm	≈ 1 s

The tests represented in Table 2, allowed us to compare values and take some elations, such as: In tests conducted with the backpressure 6 mm, the behaviour is uneven, with 2 bar of pressure the projectile did not pass the zone of increase of section, with 4 bar reached to 70% and with 6 bar, finished all the way, however still not appearing open the skirt.

With the fluid outlet section of 8 mm, the behaviour of the projectile during the test was more stable, only in the test with 2 bar of air pressure, the projectile not reach the end, in the other two he reached the goal, even pretending to open a little his skirt.

For the fluid outlet section of 10 mm, regardless of the air pressure placed, the projectile was able to finish the course, appearing to open the skirt more than in the test with the fluid outlet section of 8 mm.

It is possible to extract some results from this projectile, for example, for the same back pressure the increase of the pressure helps the operation, but by itself, considering the limitations of the test, does not induce the opening of the projectile skirt.

Comparing the performance of the two designs (BT_F01 and BT_F02) during the tests, it is possible to state that the correct design for the diameter of the projectile in relation to the walls of the tube to be calibrated makes a difference in the drive during startup, in the smaller tube, this was very noticeable in the test with the fluid outlet section of 8 mm with the projectile BT_F01, it was unable to leave the beginning of the course.

Compared the front length of both projectiles are not at first sight perceptible improvements in guidance, more tests will be required, where only the front size of the projectiles is the variable.

It was also possible to see that the thickness of the projectile skirt as well as the flexibility of the material are fundamental for the correct firing of the projectiles.

We can, conclude that this geometry does not work the way we want, regardless of the requests.

Table 3. Behaviour of the Projectile BT_A01 during the bench tests.

Projectile BT_A01	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	∞
	2 bar	8 mm	∞
	4 bar	8 mm	∞
	6 bar	8 mm	≈ 5s
	2 bar	10 mm	∞
	4 bar	10 mm	≈ 1,5s
	6 bar	10 mm	≈ 1s

The tests represented in Table 3, allowed us to compare values and take some elations, such as:

In all the tests performed with the fluid outlet section of 6 mm, the behaviour was similar, the projectile did not perform any work, with 2 bar nor moved, with 4 and 6 bar the air was able to pass to the side of the projectile, not being able to stir.

With the fluid outlet section of 8 mm, the results were similar to the previous ones, except for when the pressure used was 6 bar, in this case the projectile was able to complete the course efficiently, cleaning the whole of the glycerine, but without any guidance and with the front of the projectile leaned toward the top of the tube.

For the fluid outlet section of 10 mm, with the pressure at 2 bar the projectile did not move, but the air was able to pass, for the other pressures introduced the projectile was able to complete the course effectively, but as with the fluid outlet section of 8 mm the front of the projectile tilted to the top of the tube.

Table 4. Behaviour of the Projectile BT_A02 during the bench tests.

Projectile BT_A02	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	∞
	2 bar	8 mm	∞
	4 bar	8 mm	∞
	6 bar	8 mm	∞
	2 bar	10 mm	∞
	4 bar	10 mm	≈ 2s
	6 bar	10 mm	≈ 1s

The tests represented in Table 4, allowed us to compare values and take some elations, such as:

This projectile had an equal behaviour for the different pressures introduced during the tests with the fluid outlet section of 6 mm and 8 mm, with the exception of the fluid flow velocity, in these tests the projectile only reached 50% of the route, being that in the zone of increase of section could not open the skirt and was stopped.

With the fluid outlet section of 10 mm only when it suffers from a pressure drop such as the air leak by the side of the projectile is that it can open the skirt and finish the course, in which case the projectile is able to complete the course with effective cleaning of the entire glycerine, only when the introduced pressure was 2 bar that this did not happen and the projectile was unable to finish the course correctly. Also notable was the absence of guiding having the front of the projectile tilted to the bottom of the tube.

Table 5. Behaviour of the Projectile BT_A03 during the bench tests.

Projectile BT_A03	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	∞
	2 bar	8 mm	∞
	4 bar	8 mm	∞
	6 bar	8 mm	∞
	2 bar	10 mm	∞
	4 bar	10 mm	∞
	6 bar	10 mm	≈ 1s

The tests represented in Table 5, allowed us to compare values and take some elations, such as:

As in the projectile BT_A02 during the tests with the fluid outlet sections of 6 mm and 8 mm, the projectile only reached 50% of the course, and in the area of section increase could not successfully open the skirt and was stopped.

With the fluid outlet section of 10 mm and only with the pressure of 6 bar, the projectile functioned as expected but weakly, just as in the projectile described above, only when it suffers from a pressure drop such as air leakage from the side of the projectile is able to open the skirt and finish the course, in which case the projectile is able to complete the course effectively by cleaning the entire glycerine. This projectile unlike the others of this version when it was able to complete the tube followed straight.

Based on the tests described for de projectiles BT_A01, BT_A02 and BT_A03, it is possible to affirm that this geometry only works with high pressures and low backpressures, and the geometries of the first two it has no guidance, already with the projectile BT_A03 this does not happen, it works as badly or worse than the previous ones but in the tube of greater section followed a route balanced by the center of the tube, this could be due to two factors or due to follow more just and guided in the tube of smaller size due to having the diameters coincident or is due to the increase in the length of the front of the projectile, whichever of these is the factor will be necessary a study with more samples to establish a definitive relation.

Lack of guidance may be a problem if in operation we have fluids with high viscosities, leading to failure, or uncertainty of operation of the projectiles.

The geometry of the projectiles type BT_A, presents several problems, one of the most visible being the difficulty of placing the projectile in the smaller tube, the projectiles with smaller skirt thickness were easier to put on but the skirt was covered with pleats, which proved to facilitate the passage of air through the side of the projectiles, it was also found that these projectiles of the rare times that worked, only when some air escaped is were able to successfully open the skirt and complete the course, since the projectile BT_A01, has more thickness of skirt, was more difficult to put that the others, but it worked with more frequently, also it was possible to verify that this one due to the friction with the walls, when it was not able to function badly moved, and the air or did not pass or pass through one of the folds formed by the skirt.

We can, conclude that this geometry does not give us any certainty if it will work in the case study mould.

Table 6. Behaviour of the Projectile BT_B01 during the bench tests.

Projectile BT_B01	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	≈ 15 s
	2 bar	8 mm	≈ 20 s
	4 bar	8 mm	≈ 10 s
	6 bar	8 mm	≈ 8 s
	2 bar	10 mm	≈ 3 s
	4 bar	10 mm	≈ 2 s
	6 bar	10 mm	≈ 1 s

The tests represented in Table 6, allowed us to compare values and take some elations, such as:

With the fluid outlet section of 6 mm and with the pressures of 2 and 4 bar the operation was similar, the back pressure was too much to allow the correct operation of the projectile. At 4 bar the projectile was able to travel 75% of the way, with both the projectile tilted, which caused that it lost the guidance by letting the air pass, causing a sudden stop of the projectile. With 6 bar managed to maintain a stable course finishing the course, it was still possible to verify that the opening of the projectile did not allow him to push the whole of the glycerine.

With the Fluid outlet section of 8 mm, regardless of the pressure introduced, the projectile was able to successfully complete the trajectory, but the guiding of the projectile by the glycerine was weak.

Finally, with the Fluid outlet section of 10 mm, only with the pressure of 2bar the guide was smaller, for the others the guiding was quite good, and the glycerine that remained behind was less.

Table 7. Behavior of the Projectile BT_B02 during the bench tests.

Projectile BT_B02	Air pressure	Fluid outlet section	Time
	2 bar	6 mm	∞
	4 bar	6 mm	∞
	6 bar	6 mm	≈ 13 s
	2 bar	8 mm	∞
	4 bar	8 mm	∞
	6 bar	8 mm	≈ 6 s
	2 bar	10 mm	≈ 3 s
	4 bar	10 mm	≈ 2 s
	6 bar	10 mm	≈ 1 s

The tests represented in Table 7, allowed us to compare values and take some elations, such as:

For the fluid outlet section of 6 mm, the behaviour of this projectile was in all equal to BT_B01, the only noticeable difference was expected, the projectile rotated on its axis of revolution, but less than we expected.

With the fluid outlet section of 8 mm, the projectile was only able to successfully perform the course with the pressure of 6 bar for the rest, as soon as the projectile came into contact with a bubble of air in the course, lost the stability let the air pass and stopped.

With the fluid outlet section of 10 mm, the projectile performed its function independently of the pressure involved in dragging the projectile, the guiding was quite good, and the glycerine left behind was less.

The weak cleaning performed by this projectile is due entirely to the design of the projectile, it should not be forgotten that the projectile has a larger diameter of 24 mm and the tube has 26 mm, the poor guiding can also be due to the same factor, it was also still notorious that in the space between the wings it let pass some glycerine.

The problems that the BT_B version presents in the drag of the glycerine is due in part to the dimensioning of the projectile, it should not be forgotten that the projectile has a larger diameter of 24 mm and the tube has 26 mm, the weak guiding can also be due to the same factor, it was also still notorious that in the space between the flaps it left some glycerine pass in both projectiles of this version. But otherwise this version had an exemplary performance in most of the tests. One of the ways to mitigate the problems noticed with these projectiles is the correct sizing, in this test the projectile flaps had to open more than the supposed one leaving more space open, as well as more flaps could be added to the projectile reducing the space between them.

6 CONCLUSIONS

Conversely, as we initially thought, increasing back pressure by decreasing the fluid escape section did not help trigger the projectiles. On the contrary, in real cases of polymer injection, every second counts to reduce the cost of production and increase productivity, even in the few cases in which the projectile was able to finish the course would not be advantageous for the operation, the part cycle would be too long, which is a disadvantage. With the cycle time that would be needed we could also have the polymer crystallized before the projectile can finish the entire route, making the process unfeasible again.

It was possible to verify that the less back pressure exists in the system the better the projectiles work. however, we cannot say that the absence of back pressure, or a constant diameter for finalization of the course will be the best, in the bench test, we did not decrease the back pressure more than that achieved by a 10 mm section, never having come close to the 26 mm section which is the final diameter of the test bench tube. We have also verified that the increasing of the fluid pressure is advantageous, but again our limitations have prevented us from exceeding 6 bar.

We could not establish a relationship between projectile guidance and any geometry and / or configuration, we realized that with a bad guide the projectile easily failed during execution at the maximum diameter, the failure caused by a projectile inclination occurred in several tests.

One of the ways of mitigating this problem discovered was to increase the speed of the process by decreasing the back pressure. We also believe that increasing the length of the front of the projectile may bring advantages in guiding, but it will still be necessary to establish a relationship between diameter and length as well as eliminate the uncertainty that such a problem does not occur due to the space between the diameter of the projectile and the smaller tube.

Regarding the studied projects the BT_F version does not seem to be a good option, since it is too complex to control all the parameters for a correct operation, in this work we cannot establish any relation of parameters that allows the correct operation of the projectile, as well as it must be constructed with flexible materials. Unless the polymer to be moulded has elastic properties that ensure the correct operation of the projectile, it will always be a contaminant to be extracted before proceeding to the recycling process of surplus material.

The BT_A version, although it worked less often than BT_F, was more effective, extracting all the glycerine every time when worked, this version with geometry adjustments and operating parameters may work well, but just as the BT_F version will have to be made of flexible materials to operate, presenting the same limitations as those previously described for the BT_F projectile.

The version that most fiability brought to the process was the version BT_B, worked correctly in most cases, we only noticed some problems that easily resolved with a correct sizing of the projectile for the work to perform, unlike the other versions presented this is not dependent of the flexibility of the material and can perform its function with a wider range of polymeric materials due to geometry, even if the material has a reduced elasticity, the flaps can shrink and perform their function correctly. The advantage of being constituted with a broader range of polymeric materials eliminates the disadvantage of the foregoing, since it can be moulded with the same material that is intended to be used in the injection moulding process, it is no longer a contaminant to be extracted before the surplus material is recycled.

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