# Development of a flexible injection moulding process for integrated products

# Development of a Flexible Injection Moulding Process for Integrated Products

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# 1 Introduction

In the production of products consisting of more components the industry is searching for methods to replace the assembling process by production methods in which the assembly of the different components is integrated in the main production process. The main reason therefor is to reduce the production costs.
An important production process is the injection moulding process for thermoplastics. The two most common injection moulding processes at this moment, in which two or more components are used, are the two-shot injection moulding and the multi-layer injection moulding process. In the first case the components are injected one after another in different shots and in the second case the components are injected in one shot. Examples for these processes are the rear light of a car for the two-shot process (figure 1a) and a product with the core from regrind and the outside from virgin material (figure 1b).

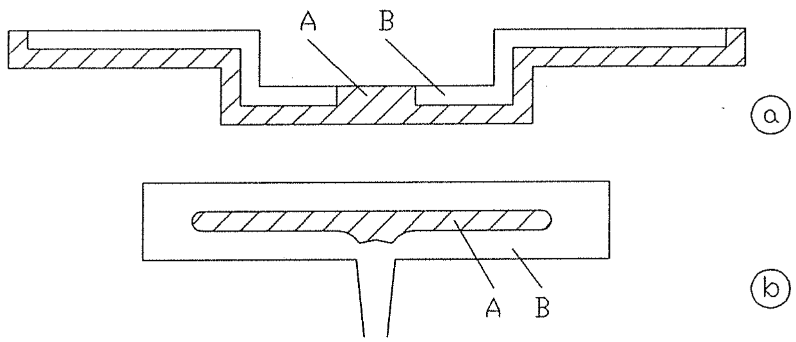


Figure 1: two-component injection moulding, a) two-shot, b) single-shot.

Both processes do have their restrictions. For making integrated injection moulding products it should be possible to define the components on every place in the product. Not, as in the two mentioned processes, that the next component can be injected on the surface or that only layers can be injected in the product.
This research is about the development of a new flexible injection moulding process, in which the components are injected in one shot to get any arbitrary combination of components in the final configuration. An example of such a product is a ball-and-hinge. The two parts are of the same material and the describing surface is of another, non-adhesive material (figure 2).
To make these complex products it's not only necessary that the process is reproducible, but also that the filling process and the final configuration can be predicted by numerical simulation. Prediction of the position is done by labelling a particle in the simulation with time and position and follow the particle during the filling process. This is the so-called 'Particle Tracking'. With this method it's possible to follow every injected particle and see where it ends. By defining these particles on the dividing surface between two components in a simulation, one can exactly follow the development of the layer structure as a function of time. So this Particle Tracking method can be used to predict what a certain combination will give as a final result. On the other hand this method can also be used for the injection moulding of integrated products. For a given end configuration it's possible to calculate the way back and see what combination of components is needed to get that configuration.

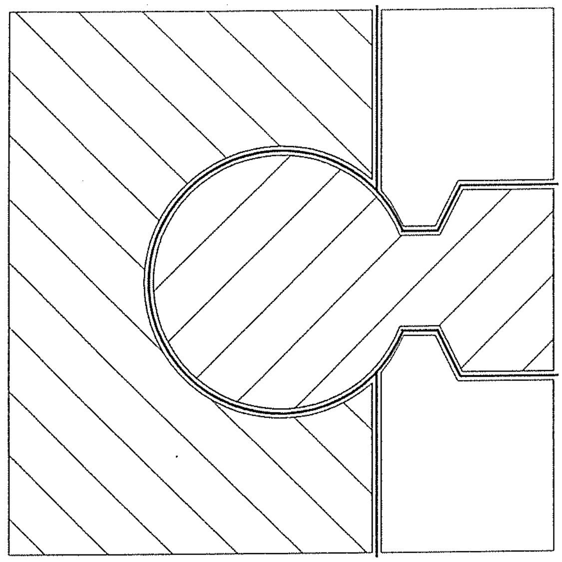

Figure 2: example of an integrated injection moulding product: a ball-and-hinge joint. Hatched areas are of the same material. Dividing surfaces are of a non-adhesive material.

Calculated then are the time and position at a certain point in the injection channel.

The goal of this research is to develop a flexible injection moulding system for making integrated products. This means that besides a main component a second component is injected, and that both components may end in any arbitrary combination in the final configuration. So a method should be found to have a controlled injection for every particle.

The main problem in this research can be described as follows. Because of the very accurate injection of two components on micro-scale, it's not possible to inject directly from the feeding part in the mould, due to the short injection time. A temporary solution must be found in which more time can be used to combine the two components. This can be a preform, which can be injected in one time in the mould.

# 2 Existing injection moulding processes

In the injection moulding process there are different techniques in which processes are used to get multi-component products and are a first step to integrated manufacturing. Well-known processes are two-shot moulding, multi-layer injection moulding, insert moulding, in-mould labelling and gas-injection moulding. These different techniques will be shortly discussed now.

**Two-shot injection moulding**

In this injection moulding process one product is made in two processing steps. In the first step the first material is injected in the mould cavity. Then the geometry of the cavity is changed and the new cavity is filled with the second material. Often this technique is used for one material with different colours or with two materials which are adhesive. Two-shot injection moulding is also possible for two materials which are non-adhesive. Then a geometry-closed joint must be used to keep the two materials together (for example a ball-and-hinge joint).

**Insert-moulding**

In the insert-moulding process a metal piece is placed in the cavity before the injection. During injection this piece is embedded in the polymer melt. Examples for this process are electrical plugs and nuts in plastic parts. A variation of this process is the *outsert-moulding*, for example for leadframes.

**In-mould labelling**

With in-mould labelling labels, which are normally placed on plastic parts after the part is injection moulded, are now placed in the cavity and during the injection the polymer melt sticks to the label. The process step of labelling is now included in the production.

**Multi-layer injection moulding**

In the multi-layer injection moulding process two or more components are injected simultaneous in concentric layers or sequential into the mould cavity. With this process products can be made with layers of different material or purpose.
The choice for the core material is for functional purpose, while the outside material is often chosen for visual purpose. For the core material one can think of regrind or a material with different properties, like EMI-shielding. For the outside material standard materials are used.
In the *two-component* injection moulding core and outside material must be adhesive. So there is strong restriction to combinations of materials. In *three-component* injection moulding this is no longer necessary because a third material is injected which forms the adhesive layer between core and outside material.
The two-component process is also used for thick-walled products. Here the outside is made from a normal polymer and the core is filled with a foam, which has the advantage of a decrease in shrinkage and product weight.

Another new process is *gas-injection*. In medium and thick-walled products the core is filled with a gas. This gives a decrease in used material, product weight and shrinkage.
Research now is focused on the use of the multi-layer technique for thin-walled products. Problems in process control are the thickness of the core layer, the place of the core layer over the thickness and avoiding breakthrough of the core material. One of the possibilities is the use of a barrier layer for a low permeability for gases.

**Feeding the materials in two- and three-component injection moulding**

Combining the components is done by a hydraulic valve system that is placed behind the extruders, which take care for feeding the different components. Switching for the different components must happen during the very short injection time. Fast or difficult combinations are in this case no more possible because of the inertia of the valve system.
The solution is to make use of the cooling time of the process to combine the components and then inject the components during the injection time. This can be done by using a temporary stock where the combination is stored. For the two-component process this is realized by injecting one component in the feeding channel

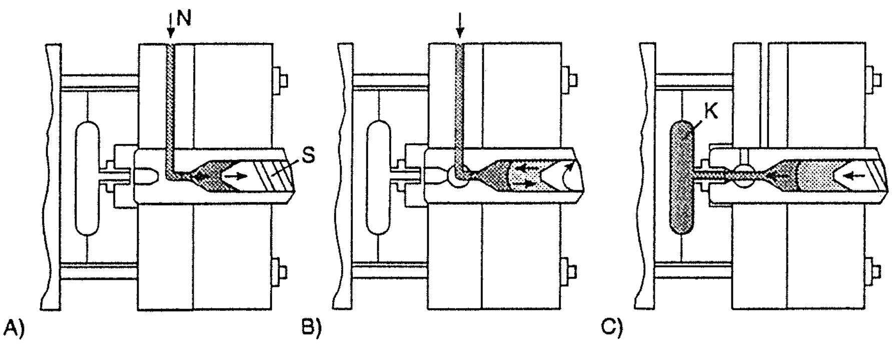


Figure 3: two-component injection moulding principle for multi-layer products.

of the other component and then inject this in the mould (figure 3) [27]. Another solution which can be used is the use of a accumulator. With the hydraulic valve system the components are combined and injected in the accumulator during the cooling time. In the injection time the contents of the accumulator is injected in the mould cavity. This last solution is not seen for more component injection moulding, because of the difficulties of material mixing. The accumulator already exists for a single material injection moulding machine, because in this specific case the extruder can't heat and feed enough material in the restricted injection time [26].

**Integrated products**

If it's possible to get every arbitrary combination of two components in a final configuration, then completely integrated products can be produced. Products which are made through two-shot injection moulding or assemblage can then be made in one production cycle (figures 2 and 4). For integrated products it's not enough that components can be combined as in normal two or three component injection moulding. Combining components becomes very complex. The first problem is that

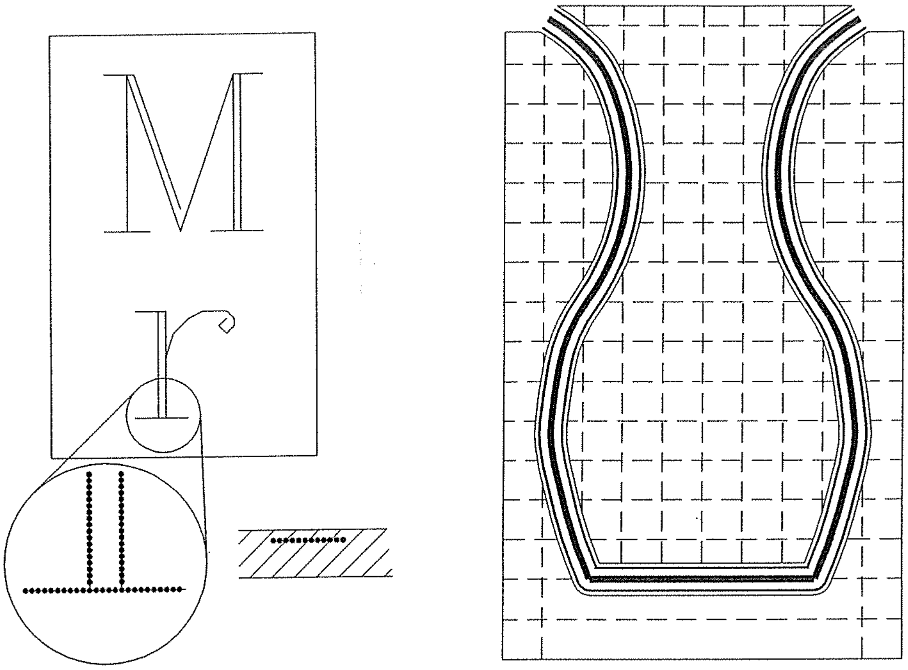

Figure 4: two examples for integrated products. a) objects of text direct beneath the surface, b) pot where the mould is formed by the second material.

the given injection time is too short, just as with de complex combinations in the hydraulic valve system. The solution is to combine the components during the cooling time, which is much longer than the injection time, store the combined components in some accumulator and next inject the contents of the accumulator in the mould cavity, like in transfer moulding. Because every particle has to be controlled and not only a layer, the valve system can't be used. With a numerical simulation the final configuration can be calculated to the accumulator geometry. A process must then be developed to get the components in the right position in the accumulator.

# 3 Numerical simulations

Predicting the multi-layer injection moulding process via numerical simulations is done with the so-called Particle Tracking method (figure 5) [23]. This is done by defining particles on the dividing surface of the components and label these particles with time and position at entry. By following these particles during the simulation the development of the layer can be followed into the final configuration can be calculated. Labelling is done on a defined cross section in the injection channel. One

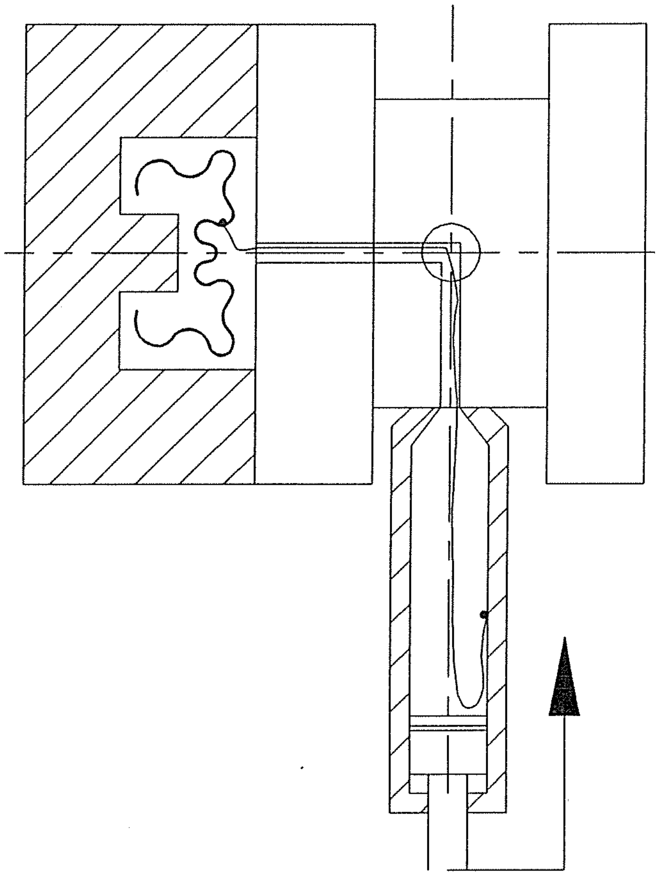

Figure 5: Particle Tracking method. Particle is labelled with time and position.

coordinate (the position of the cross section in the channel) is constant. The other two coordinates together with time of passing the cross section are for every particle unique. The goal of the simulation is not to calculate a final configuration from a defined injection combination, but exactly the other way. This means that from a defined final configuration the combination of components has to be calculated that will give this result. Therefor particles are defined on the dividing surface of the components in the final configuration with defined time $t_{end}$. All the particles do have the same time but every particle has its specific coordinates. The position of the components in the accumulator can now be calculated for every particle, by using the Particle Tracking and calculate the particles to time $t_o$, which is defined when the complete volume is in the accumulator.
In the numerical simulations points are defined, which do not have any volume. If the

points describe a surface there is no problem when translating it to reality, because a surface also has no volume. if points have to be translated to real particles, the problem is how to define a volume to the points. This is the case when the whole accumulator is thought as build from small drops with a certain volume.

# 4 Design of the accumulator

The accumulator which has to be designed will in the first case be used for the three components injection moulding machine. Because of the inertia of the already existing valve system it's not possible to make difficult combinations. With the use of an accumulator it's possible to use the cooling time for combining the components and to fill the accumulator. During the injection time the contents the accumulator can be injected in the mould cavity. The assumption is that filling the accumulator is the inverse process of emptying the accumulator. This may be expected because of the piston driven flow experiments which have been carried out. But when the accumulator is filled slowly and is emptied fast differences in the flow could occur. Finally the division of the components has to be calculated with the Particle Tracking method.
Through another process the preform with the two materials has to be made, placed in the accumulator and next injected in the mould cavity.

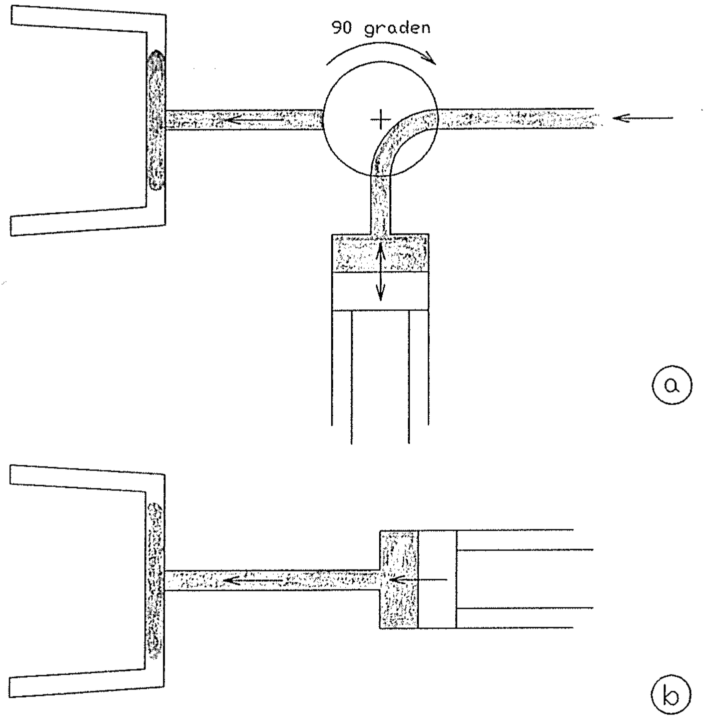


Figure 6: Possible designs for an injection method with accumulator for a (a) multi-layer product where combing is done in the injection moulding machine and for an (b) integrated product where the preform is produced outside the injection moulding machine.

The first step is to find the right geometry for the accumulator. The preform, which is defined by the geometry of the accumulator, consists of two components in arbitrary positions. The geometry for the accumulator is derived from the transfer moulding process. In this process the accumulator has a cylindrical shape. The flow with a cylindrical geometry is already done with a piston driven flow apparatus.
Because of the shear flow the length to diameter ratio should be about unity. But the preform is pressed in the runner system and therefor the ratio of the diameter of the preform to the diameter of the runner should be less than about 4, to avoid strong elongation and vortices when entering the runner system. Because of these two

boundary conditions it's best that the length and diameter are of the same order. The length to diameter ratio will be in between 2 and 6.
In the first situation the solution for the accumulator can look as in figure 6a. For the second situation the solution of figure 6b is a good possibility. Situation two is realized after situation one. So the solution for situation one will also be used for situation 2, with the right channel not in use and the valve fixed. Boundary conditions for the design of the accumulator are:

- The channel length should be as short as possible;
- The channel diameter should not be too small, which causes higher shear rates in the flow;
- The channel diameter should be equal over the total length, so that no disturbances will occur in the flow;
- The system has to be cleaned easily, so it should be easily taken apart;
- The channels and the accumulator should have an homogeneous heating;
- If possible, use must be made of standard parts, which has less own manufacturing and is easy to order and replace in case of failure.

The problems that occur are:

- The plastic material in the vertical channel, if the accumulator is emptied, will not be replaced by new material. Because of this the material will degrade when heated to long.
- The contraction from the accumulator to the channel is made from a removable part, so the entrance corner can be changed easily. At the same time the piston has to be changed to fit with the new entrance corner.

With these boundary conditions a design is made for the complete accumulator that can be placed between the mould and the fixed back plate. A sketch of this design is shown in figure 7.

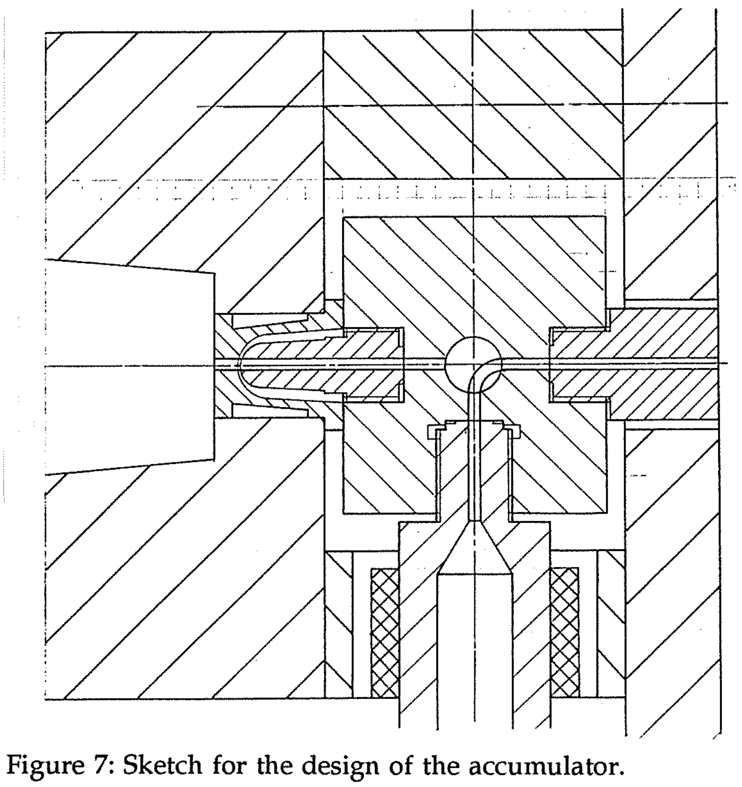

Figure 7: Sketch for the design of the accumulator.

# 5 Making the preform

## 5.1 Considerations for making the preform

If the geometry of the accumulator is chosen then also the geometry of the preform is defined. The next problem is how to build the preform with the two components as calculated with the particle tracking. A first condition is that, to get an accurate product, the positioning of the components has to be even more accurate when taking into account that at injection the material undergoes a strong shear flow. So, even a small initial difference will occur in great differences in the final product. The first idea was to use the same setup as in the three-component machine. Instead of the hydraulic valve system there should be some ingenious system to add a second component to a main component in a channel flow. This has the disadvantage that again the particle tracking has to be calculated from the preform to the point in the feeding channel where the second component is added to the first component. Another disadvantage is that the second component is injected in the 3-dimensional flow of the main component. This means that the flow is disturbed when injecting the other component and that the way of injection is dependent of the position (near the wall or in the centre of the flow) and of the time of injection. So to get a more reproducible process it's better to put the components in the preform directly as calculated and not fill the preform through another entrance flow. Problems when working with the polymer melt are the high viscosity, the high temperatures and the high pressures which are needed to press the melt through small runners and cavities. To simplify the process, the preform can be made in another machine and be placed in the injection moulding machine to be transferred in the mould. The time needed to make a preform is now equal to the number of preforms you can make simultaneous times the cycle time of the injection moulding process. Instead of just the injection time there is now more time to make the preform.
Making the preform of the two components can be separated in two limit methods : 1) building the preform directly from a plastic melt, 2) building the preform from solid plastic. Because with the 'particle tracking' particles are followed, the preform can be thought as build from small particles. The smaller the particles are in the preform the better the calculated situation is approached. So the preform is digitized. At this point making a preform can be compared with the Rapid Prototyping process. Rapid Prototyping (RP) is the collective name for a number of processes that make 3-dimensional forms from a selected type of plastics and other materials (see next section). In an easy way it's possible to make in a relative short time a real prototype from a CAD-design. The RP-processes are however too slow to be used in mass production and the products do not have the strength of injection moulded products. The characteristics of the two processes are compared with each other in table 1.

In the preform the components should be divided as fine as possible in three dimensions. Looking to the RP-processes we see that by using layer-technic one dimension, the layer thickness, is easy to control. The other two dimensions depend on the process.
Looking to the preform this also can be divided in layers in different ways. The preform can be sliced in layers perpendicular to the cylinder axis, in layers parallel

Table I: Comparison between the RP-process and our own process.

| Rapid Prototyping process | our process |
|---|---|
| selected type of materials | any plastic type |
| relative slow process | fast process |
| any 3-D form | only 1 defined preform |
| large products | small form |
| one material at a time | two components |
| product build by layer technic | end product injection moulded |

to the cylinder axis, or it can be rolled out to one long film with a width equal to the cylinder length (figure 8). An advantage of the last solution is that one gets a continuous film. A disadvantage is that the film has to be rolled around a solid core. The film can be produced in a continuous process. With the other two layer methods the form is build in a similar way as with the RP-process and it would be more easy to make the final product directly. The difference with the RP-processes is that the product is made of two components. There's no process yet for making a film consisting of two components as is desired in our process. All the processes that exist are processes where one component is added to another, the carrier. Compare printing ink on a paper. In our film it's essential that the second component replaces the other one so that the thickness is no more equal on every place, which is a problem when rolling the film on a core because air entrapment can occur more easily. Also if one component is added to another component, there's not a continuous phase any more in radial direction for one of the components.

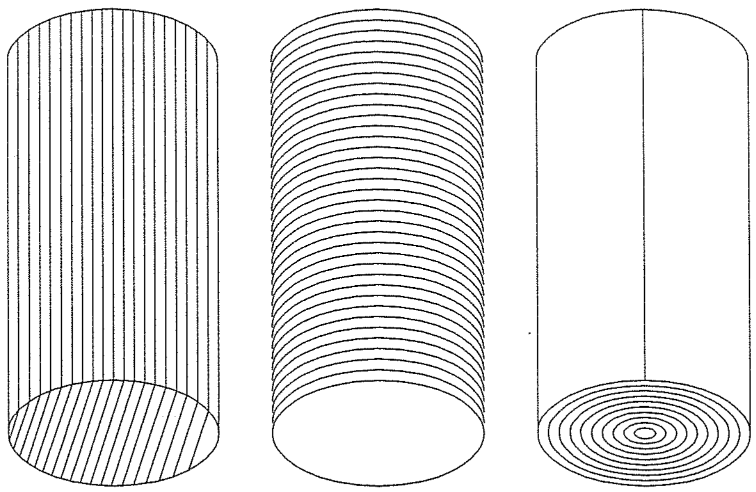

Figure 8: The three possibilities for slicing the cylindrical preform in layers.

Besides layers the cylinder can be thought as build from a thread which is rolled around a core. The division of the two components now only has to be controlled in one dimension. This is the length of each component on the thread. The problem is that this is not possible for non-adhesive materials, because the thread will break every time the components are switched.

## 5.2 New technologies

### Rapid Prototyping

Rapid Prototyping (RP) is a technique for making real prototypes directly from the computer. Real prototypes are still necessary for fit-and-function testing, or as a show model. Compared to the conventional methods of making prototypes, RP is a very fast process. But it still can't be used in mass production because production times are slow compared to other mass production techniques.
A characteristic of this process is that the model is built up in a series of layers. All the RP processes use this layer-by-layer technique, but use it in different ways. The data for each layer comes from the CAD system where the computer model is sliced to get the information for the layers.
The technique of Rapid Prototyping is growing very fast and more new methods are developed. With the first methods only a limited number of material could be used, but now this range is extended very fast. For more information about the specific Rapid Prototyping techniques see the articles [1..11].

### Printing techniques

In the printing process different techniques are used. The different printing processes are matrix, thermo, inkjet and laser printing. All these processes use a different technique but they do have in common that the object that is printed is digitized. This means that every object is build from small pixels. This in contrary to an ordinary typewriter where every letter is one complete character.
The different processes have their own technique to put the ink on the carrier. The matrixprinter puts the ink on through a mechanical device that presses a carbon on the paper. The thermoprinter works with a solid ink or wax that is pressed to the carrier and for printing the wax is locally heated and the melt sticks to the carrier. The inkjetprinter shoots small liquid inkdrops on the carrier and the laserprinter uses powder that can be handled because of electrostatic principles and which is heated to keep it on the carrier. For detailed information see the articles [12..22].

### Other techniques

- Applications with piezoelectric materials [29..32].
- Production of fabrics.
- Development of a braille-apparatus [28].
- Powder coating [25].
- Printing on plastic films [24].
- Silk screen printing.

## 5.3 experimental

The problem is now reduced how to make a film from two (non-adhesive) materials with a high resolution in the patterns and next to role the film around a core without air entrapment. To see how a film with two material would look like,

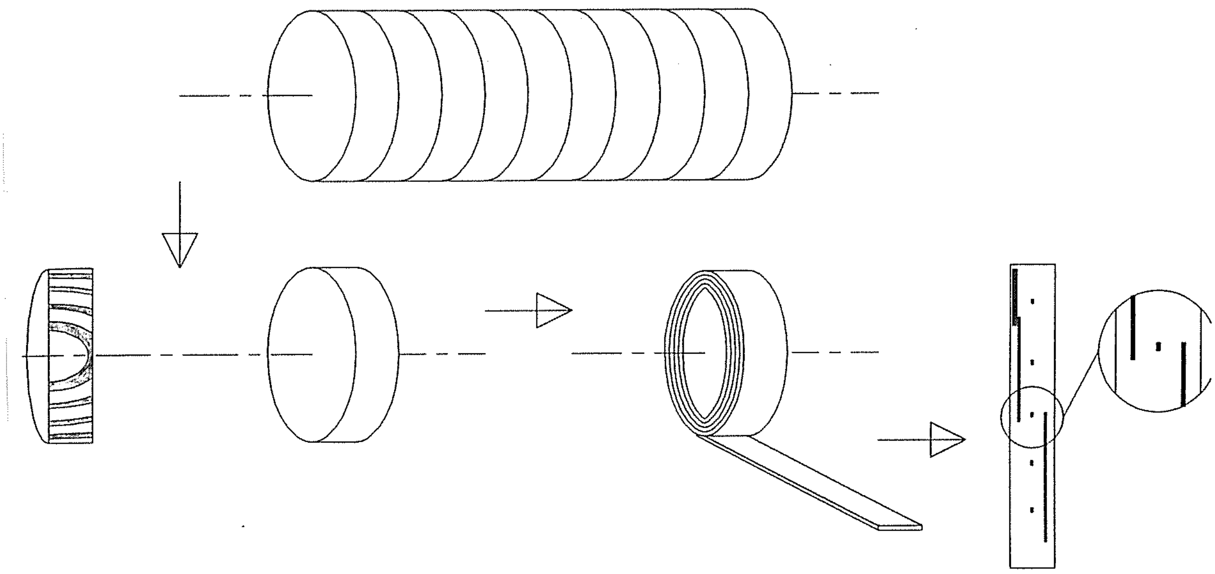

Figure 9: The process of stripping the preform to a series of continuous films.

experiments have been carried out. In a piston driven flow one material in two colours is melted and a small displacement is described (This is done for ABS, PE, PS). Next the plastic cylinder is stripped to a film of about 0.1 mm thickness. Because of problems to control the stripping process the width of one film is 10 mm (figure 9). So more film strokes are stripped from one plastic cylinder (height of the cylinder is about 60 mm). As a next step the film is rolled around a core and stacked in the same way as they were stripped and heated in the piston driven flow apparatus. This was only possible for ABS and PE. The results of this experiment were very good: no air entrapment was encountered after heating the rolled film and the original pattern was also obtained. The recovery of the original pattern was not perfect which is due to the simplicity of the experiment. During the stripping process the film dimensions were changed because of process heat. The core that broke during stripping had not always the same final diameter, but when rolling the film, a solid core was used which had the same diameter for every film. The film was rolled around the core by hand, so there was no equal stress during this process. Even with under these conditions the result was very good. So it's possible to use a film consisting of two materials to make a preform. The only question still is how to make a film of two materials. Looking at the stripped film, consisting of the two components, it can be seen that besides a high accuracy, also a resolution of at least 50 dpi (500 μm) is required to get most of patterns.
No further experiments to make a film, consisting of two components, are carried out. This has different causes. Carrying out simple experiments to make something complex is not always possible. The simplification will result in the fact that boundary conditions to the problem have to made more broad, or that a 'once-only' product can be made, but that for a 'massproduction' product it's still not known if it works within the specifications.
Most of the ideas for making a film come from processes that use new technologies, which are most of the time very complicated and are not easy build in a simple setup. These new technologies have their principles in physics and chemistry. To convert a new technology for a different purpose it is necessary to understand the physics of the process.

# 6 Results

No actual result has come forward in the sense that a complete and usable technique is developed. The investigation and the search for a new technique has lead to a insight in the problems and the way that can be followed to come in the future to a new working production process. The techniques which can be used are now being developed in the fields of rapid prototyping and new applications for the printing techniques. The best example is that it's now possible to use the inkjet process to make prototypes with a plastic from small droplets with a diameter of 75 µm at 110 °C. So an integration of printing and rapid prototyping. Keeping up with the actual developments is of great importance.
Using or converting these techniques to a working process can only be done in cooperation with research in the industry, because the development of a new flexible injection moulding process is not only a theoretical and fundamental problem, but more a practical problem. Most of the techniques which can be used are available, but have to be converted in some sense.
The most important result is that the process is analyzed and is simplified to make it possible that in the future completely integrated products can be made.

# 7 Conclusions and recommendations

- It's found that combining the two materials is not possible by injecting a second component in the flow of the main component in a melt situation because of the process conditions (high temperature, viscosity and pressure) and the visco-elastic behaviour.
- The design of the accumulator is realistic and can be constructed to put it in the 3-component injection machine. Then it can be investigated if filling and emptying the accumulator are inverse processes.
- In a next step a preform can be made by hand outside the injection moulding machine, put in the accumulator and transferred into the mould to see if this system works.
- The idea of rolling the preform from one continuous film is until now the best solution to get an accurate division, specificly in the radial direction, of the two components in a 3-dimensional geometry.
- Research has to be done on making a film of two (non-) adhesive components. Possibilities to investigate are:
    - the use of the laserprinting technique with thermoplastic powder instead of toner.
    - the latest possibilities in Rapid Prototyping. Here a polymer is used and with the inkjet technique small droplets are printed at a temperature of 110 °C.
    - the use of thermo-printing. If polymer powder is divided on a carrier it can be transferred on another carrier with fast heating or maybe through electrostatic principles.
- More experiments have to be carried out to get more insight in the possibilities. But because there is no expertise on the new technologies, it's hard to buy an expensive setup to do some tests and see if it also works for polymers. Therefor more cooperation is proposed with research-laboratories who have more applied knowledge in this field. These could be developers in copiers and laserprinters and developers in the new Rapid Prototyping techniques.

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