

AN ELEMENT OF THERMOPLASTIC
MATERIAL

The present invention relates to an element of thermoplastic material and to a method of manufacturing the element.

In the manufacture of products from thermoplastic material, the starting material is in most cases a substantially flat blank. An end product may be formed from the blank substantially in one deformation step, or a premoulding may be formed which is reshaped later to form the end product. The shaping of the blank is effected, according to methods known at present, either by a blow-moulding process or by a thermo-forming process. Where the element to be formed is a hollow body with a closed bottom, such as a cup, blow-moulding generally produces a bottom having a thick section. In the thermo-forming process, either negative thermo-forming or positive thermo-forming can be used. In the negative thermo-forming process, a hollow body having a thin bottom is produced whilst a thick bottom is produced in the positive thermo-forming process.

In negative thermo-forming, a warm sheet or a warm film is placed over cavities, after which the material of the film or the sheet is pressed and

sucked into the cavities by external pressure and internal reduced pressure. This has the result that the material is stretched and becomes thin, when it is sucked into the particular cavities. If the
5 cavity is in the shape of a cup, a thin stretched bottom and a wall thickness which increases towards the top edge of the cup are obtained.

In positive thermo-forming the cup mould forms a projecting body and the material of the film or
10 sheet is pressed and sucked over this projecting body. This has the result that the material on the upper part of the projecting body, that is to say the bottom of the cup, remains thick and essentially unstretched, whilst the thickness of the material
15 decreases towards the top edge of the cup.

To obtain an adequate material thickness in the bottom part of the cup in negative thermo-forming, a sufficient thickness in the starting material must be chosen. To obtain an adequate thickness in the
20 edge zone of the cup by positive thermo-forming, which is necessary for the stability of the cup, a sufficient thickness of starting material must likewise be chosen. In negative thermo-forming, the areas of material between the shaped cups remain
25 uninfluenced and are subsequently severed, after the

manufacture of the actual cups. In positive thermo-forming, the material between the cups is drawn into recesses and severed from the cups formed. In positive thermo-forming, cup bottoms are thus obtained which have substantially the same thickness as the starting material. Both forming processes require an unnecessarily high consumption of material, which is of economic importance in the mass production of articles.

10 The present invention, which seeks to minimize the disadvantages described above, is particularly suitable for the manufacture of elements from thermoplastic material of the polyester or polyamide type. Examples of such materials are polyethylene terephthalate, 15 polyhexamethylene-adipamide, polycaprolactam, polyhexamethylene-sebacamide, polyethylene 2,6- and 1,5-naphthalate, polytetramethylene 1,2-dihydroxybenzoate and copolymers of ethylene terephthalate, ethylene isophthalate and similar 20 polymers. The description of the invention below relates mainly to polyethylene terephthalate, called PET in the further text, but the invention is not restricted exclusively to the use of either this material or other materials already mentioned; instead, 25 it is also suitable for many other thermoplastic materials.

For a better understanding of the invention and of the problems of the known methods, several characteristic properties of the polyester polyethylene terephthalate are described below. From the literature, for example "Properties of Polymers", by D.W. van Krevelen, Elsevier Scientific Publishing Company, 2nd compl. revised edition 1976, it is known that the properties of the material change when amorphous polyethylene terephthalate is oriented. Some of these changes are shown in the diagrams, Figures 14.3 and 14.4 on pages 317 and 319 in the book "Properties of Polymers". The symbols used in the discussion below correspond to the symbols in that book.

PET, like many other thermoplastic materials, can be oriented by stretching the material. Normally this stretching takes place at a temperature above the glass transition temperature T_g of the material. The strength properties of the material are improved by orienting. The literature shows that, in the case of the thermoplastic PET, an increase in the stretching ratio Λ , that is to say the quotient of the length of the stretched material and the length of the unstretched material, also leads to an increase in the improvement of the material properties. When the stretching ratio Λ is increased from about

2 to a little more than 3 particularly large changes in the material properties are obtained. The strength in the direction of orientation is here markedly improved, whilst at the same time the density ρ and likewise the crystallinity χ_c rises and the glass transition temperature T_g is raised. It can be seen from the stress-strain diagram on page 317 that, after stretching, with Δ assuming the value of 3.1, a stress of 10 cN/tex applied to the material produces a very small elongation, whilst after stretching with Δ assuming the value of 2.8 the elongation is substantially larger. In the text, the term "step" is sometimes used to designate orienting which is obtained by stretching, or a reduction in thickness by at least 3 times, and which leads to the marked improvements of the material properties, indicated above.

The diagrams quoted above show changes which are obtained on mono-axial orientation of the material. In biaxial orientation, similar effects are obtained in both directions of orientation. Orientation is carried out as a rule by successive stretchings.

Improved material properties, corresponding to those which are obtained by the "step" defined above, are also obtained if an amorphous material is stretched until it flows, and before flowing, the

material is at a temperature which is below the glass transition temperature T_g . In a rod being drawn, a reduction of the diameter of about three times results in the flow zone. On drawing, the
5 flow zone is continuously displaced into the amorphous material, whilst at the same time the material, which has already undergone the state of flowing, absorbs the tensile forces of the test rod without an additional permanent stretching.

10 According to a first aspect of the present invention there is provided an element of thermo-plastic material having a hollow body and an edge part surrounding a top opening of the hollow body, wherein the element has been formed from a blank
15 of material which is amorphous or has a crystallinity of less than 10%, at least part of the body having been shaped by drawing at least one zone of the blank until flow sets in, said zone being located within an area of the blank defining said edge part,
20 the material of the body which has flowed assuming a crystallinity of between 10% and 25% whilst the material of the undrawn part of the body and of the edge part retains its original value of crystallinity of less than 10%.

25 An element of the invention is suitable for many

applications, for example, it may be a cup similar to those described above. In addition, the element may form a pre-moulding for reshaping to form containers or other parts. This reshaping may be performed,
5 for example, by a blowing process or by mechanical working such as pressing or extending.

Where the element of the invention is a cup it can be considered to consist of an edge part and a cup part. The material is preferably of more or less
10 uniform thickness and orientation in the entire bottom of the cup part. In an embodiment of the invention, the material in the bottom part of the cup moreover consists completely or partially of material of the same thickness as that of the material of the wall.
15 The remaining sections of material have the thickness and material properties of the starting material. In certain applications, the bottom is more or less completely flat, whilst in other applications the bottom consists of parts which are axially displaced
20 relative to the axis of the cup. In this case, in some embodiments, annular edge sections are formed adjoining the lower edge of the wall, whilst in other embodiments central bottom sections are displaced further away from the upper opening edge of the
25 element.

In general, an element of the invention consists of an edge part which surrounds a top opening of a hollow body which is sunk relative to the edge part. The material in the edge part is mainly amorphous or has a crystallinity of less than 10%. The body has a wall and a bottom. The wall may consist of material which has been drawn at a temperature below the glass transition temperature T_g , until flow sets in, and in which the crystallinity is between 10 and 25%. In an embodiment, the bottom consists of mainly amorphous material or of material having a crystallinity of less than 10%. In other embodiments of the invention, the bottom consists of material which has been drawn at a temperature below the glass transition temperature T_g and at a crystallinity between 10 and 25%, until flow sets in, that is to say of a material having properties which are substantially identical to the material properties of the wall of the element. Alternatively, the bottom may have sections which have been drawn until flow sets in and which alternate with sections of mainly amorphous material or material having a crystallinity of less than 10%. The sections of the bottom, may be displaced in the axial direction relative to the lower edge of the wall.

The present invention also extends to a method of manufacturing an element as defined above, the method comprising the steps of clamping areas of the blank such that at least one zone is defined within and completely surrounded by said clamped areas, applying a pressing tool against said zone, the contact surface of said pressing tool having an area smaller than that of said zone whereby a closed intermediate strip of material is defined between the part of the zone in contact with the contact surface and the clamped areas, and moving the pressing tool relative to the clamped areas such that the material of said intermediate strip is stretched to such an extent that flow takes place and the material of said intermediate strip is oriented, the movement of said pressing tool drawing said intermediate strip to form at least a part of the body of the element.

In an embodiment, a substantially flat blank of thermoplastic material, having a crystallinity of less than 10%, is clamped at a temperature below the glass transition temperature T_g between counter-holders, such that a zone is formed which is completely surrounded by clamped areas of the blank. A pressing tool, the contact surface area of which is smaller

than the surface area of the zone, is applied against this zone. Thus, a closed intermediate strip is formed between the clamped areas of the blank and that part of the zone which is in contact with the pressing tool. Subsequently, a drive mechanism moves the pressing device relative to the counter-holders, with the pressing device remaining in contact with the zone. The material in the intermediate strip is thus stretched in such a way that flow of the material occurs, the material being oriented, whilst at the same time the thickness of the material is reduced by about 3 times in the case of PET. The wall of the element is formed during the stretching process.

Since the circumference of the contact surface of the pressing device is smaller than the inner circumference of the clamping devices, the material which adjoins the edge of the pressing tool is subjected to the greatest stress, for which reason the flow of the material normally starts at this point. This effect is further reinforced by the fact that the transition from the contact surface of the pressing tool to the side walls of the pressing device is made relatively sharp-edged. When flow has set in, the zone of flow of the material is gradually

shifted in the direction of the clamping devices.

In some embodiments, the pressing step is interrupted when the flow zone has reached the pressing tools.

In other embodiments, the pressing step continues,

5 renewed flowing of the material taking place adjoining the edges of the pressing tool and being displaced from these zones towards the centre of the material. When all the material which is in contact with the contact surface of the pressing tool has
10 undergone flow, that material between the clamping devices which is located next to the inner circumference of the clamping devices is utilised for a further drawing step in some embodiments. To make this possible, a somewhat elevated temperature
15 in the material is normally required. The starting temperature, however, is still below the glass transition temperature T_g .

In some embodiments, accelerated cooling of the drawn material is necessary. In this case, the
20 pressing tool may be provided with a cooling device which is arranged in such a way that the zones of the material, which flow during drawing of the material, are in contact with the cooling device.

The flow of the material may be caused to start
25 adjoining the clamping devices. This is accomplished

by providing the clamping devices with heating devices which raise the temperature of those material sections where flow is to start. The temperature in the material, however, is still below the glass transition temperature T_g of the material. When the state of flow has been established, this continues in the direction of the contact surface of the pressing device and, in some cases, it continues past the transition from the side walls to the contact surface of the pressing tool.

To ensure that the clamping devices retain the blank in the future edge sections of the element, the clamping devices are generally provided with cooling devices.

It is also possible by using a number of drawing steps one after the other, both in the wall and in the bottom of the body, to obtain material sections which alternately consist of material sections which have been drawn until flow sets in and have in this way been given a reduced wall thickness, and undrawn material sections which have retained their wall thickness. In material sections located in the bottom of the body, a displacement of the material in the axial direction of the body may also take place in conjunction with the drawing step.

Embodiments of the present invention will hereinafter be described, by way of example, with reference to the accompanying drawings, in which:-

FIGURES 1 and 2 show alternative bands of thermoplastic material which are suitable for reshaping,

FIGURE 3 shows a longitudinal section of an element of the invention having a bottom part of the body consisting mainly of amorphous material,

FIGURES 4 to 8 show progressive steps in the formation of an element using clamping devices, and

FIGURES 9 and 10 show steps in the formation of an element using alternative clamping devices.

Figure 1 shows a plan view from above of a thermoplastic band or blank 14' in the form of a flat plate. The material of the blank has a crystallinity of less than 10% and preferably less than 5%. A number of material zones are represented in the blank 14' and these material zones are formed when the blank is drawn to form elements of the invention. Thus the blank 14' has a number of inner material zones 15' each surrounded by a material zone 17' in the form of a frame. Similarly, the material zones 17' are each enclosed by an outer zone 16' also in the form of a frame. Figure 2 shows an alternative thermoplastic band

or blank 14". In the blank of Figure 2, the inner material zone 15" is circular and the enclosing zones 17" and 16" are annular.

5 When a blank 14' or 14" is drawn to form an element, the outer material zone 16 is that zone which is clamped between clamping devices, such as devices 30a and 30b in Figure 4. The inner material zone 15 is that zone which, on drawing of the blank, is in contact with a pressing tool, for example, in contact with the face 21 of the pressing tool
10 20 in Figure 4. The intermediate material zone 17 is that zone which, on drawing of the blank, is brought into a state of flow. The width of the clamped zone 16 is preferably selected such that the flow of the material on drawing extends as far as the zone 16.

15 An element 10 consisting of an edge part 12 and a body 13 is shown in Figure 3. The body 13 consists of a wall 18 and a bottom 11. In the figure, the wall 18 is formed of drawn material having a reduced thickness as compared with the thickness of the starting material. The bottom 11 is
20 formed of material which, while retaining its material properties, has been displaced relative to the edge part 12 in the axial direction of the body. Moreover, a zone 19 is represented in which material from the edge part 12 had been brought into a state of flow.

25 In Figures 4 to 8, the formation of an element is

illustrated. As is shown in Figure 4, the blank 14 is held between a number of clamping devices 30. A pressing tool 20 having a press contact face 21 is located between the clamping devices 30. In Figure 4, the pressing tool 20 is in a position in which the press contact face 21 is located directly on the upper surface of the blank 14. Figure 5 shows the pressing tool after an initial downward movement, flow of the material of the blank having started. In Figure 6, the pressing tool 20 has been moved downwardly to such an extent that an element as shown in Figure 3 has been formed. In Figure 7, the pressing tool 20 has been moved further downwardly, further flow of the material having taken place. An element 10' has thus been formed, the body 13' of which has a bottom 11' of which the central portions are formed of amorphous undrawn material which is surrounded by drawn oriented material in which flow has taken place. Finally, in Figure 8, the pressing tool 20 has been moved to such an extent that virtually the entire material in the bottom 11" of the body 13" has undergone flow. An element 10" has thus been formed in which both the wall and the bottom of the body have a reduced wall thickness because the material has been in the state of flow and has at the same time been oriented.

The material of the element which has been in a state of flow and has been oriented assumes a crystallinity of between 10% and 25%, and preferably of between 12% and 20%.

In Figures 9 and 10, an alternative embodiment of the clamping devices is shown. The clamping devices 33a and 33b of Figures 9 and 10 are provided with cooling channels 31 and heating channels 34.

5 In Figures 9 and 10, only the feedline for the heating channels 34 is shown, the discharge line for the heating channels being located behind the feedline in the figures and being indicated by an upwardly pointing arrow. Both the cooling channels and the
10 heating channels are covered by plates 35, the external surface of which at the same time represents the contact surface of the clamping devices for clamping the blank.

An insulation 32 separates the cooled zone of
15 the clamping devices from the heated zone. In certain applications, the heating channels are also used as the cooling channels.

Figures 9 and 10 also show an alternative embodiment of a pressing device 20a which is also
20 provided with cooling channels 22. The cooling channels are covered by a cooling jacket 23 which at the same time forms the outer contact surface of the pressing device. Figure 9 shows a position of the pressing device 20a which corresponds to the
25 position shown in Figure 5, and Figure 10 shows a

position of the pressing device 20a which corresponds to the position shown in Figure 8. The pressing device has an outer surface with a rotationally symmetrical curvature, which is shaped in such a way that, on drawing within the flow range, the drawn thermoplastic material of the blank is always in contact with the cooling jacket, whilst that material which has not yet been in the state of flow is completely without contact with any device in the zone between the pressing device and the clamping device.

By heating the material with the aid of the heating channels 34 the readiness of the material to flow is increased. Heating is limited, however, inasmuch as the temperature of the material must always be lower than the glass transition temperature T_g . Heating makes it possible to allow the drawing step of the material to continue a little into the zone between the jaws of the clamping devices, as shown in Figure 10. In another application, the increased readiness of the material to flow is exploited so as to obtain, during the drawing step, initial flow of the material in the zone next to the inner edges of the clamping devices. After initial flow has taken place, the flow zone is gradually

displaced, as the pressing device gradually moves downwardly as illustrated, in the direction away from the clamping devices towards the bottom of the pressing device. The result of this is that flow
5 always propagates in the same direction, and a new start of flow such as takes place when the embodiment of the invention shown in Figures 4 to 8 is used, is avoided.

The above description of the element, and a
10 process and apparatus for producing the element, merely represents examples of the application of the invention. The invention allows of course that a number of successive drawing steps take place, zones of drawn and undrawn material forming alter-
15 nately. For example, the wall may be formed with sections which contain undrawn material, whilst the bottom of the body may be formed of sections, for example annular sections, which contain undrawn
20 material and which are displaced in the axial direction of the body relative to the lower edge of the wall of the body.

Material which has been oriented by flowing possesses improved strength properties in the direction of orienting, which largely corresponds to the
25 direction in which the material is drawn. Heating

of the material to a temperature which is below the glass transition temperature T_g makes it easy, in a blowing process, to shape the element by stretching the material in a direction substantially at right angles to the said direction of orienting. An element shaped in this way provides, for example, a container having a middle shell surface of a diameter which exceeds the diameter of the top opening, and having a bottom in which the transition between the lower edge of the shell surface and the bottom surface defines a supporting surface. The bottom surface may be slightly concave and may consist of annular material zones which are displaced relative to one another in the axial direction of the container. The element is also suitable for shaping according to a process similar to deep-drawing, which is used in the manufacture of metal products.

It will be appreciated that many embodiments are possible in accordance with the invention. In one embodiment, drawing of the body of the element is effected by a number of successive drawing steps, the contact area of the pressing device decreasing for each drawing step. The result of this is that, in particular if the pressing device tapers in the direction of the contact surfaces, the width of the material zone 15 is adapted to the extent to which the drawing step has proceeded.

A process of manufacturing articles of thermoplastic material and a container manufactured thereby are described and claimed in our copending application No. 8018900 (2052363A) to which reference is made.

- 5 A process of manufacturing articles of thermoplastic material and containers manufactured thereby are described and claimed in our copending application No. 8018901 (2052364A) to which reference is made.

Claims:



1. An element of thermoplastic material having a hollow body and an edge part surrounding a top opening of the hollow body, wherein the element has been formed from a blank of material which is amorphous or has a crystallinity of less than 10%, at least part of the body having been shaped by drawing at least one zone of the blank until flow sets in, said zone being located within an area of the blank defining said edge part, the material of the body which has flowed assuming a crystallinity of between 10% and 25% whilst the material of the undrawn part of the body and of the edge part retains its original value of crystallinity of less than 10%.
2. An element as claimed in Claim 1, wherein the blank is a flat plate or a blank shell and the material thereof has a crystallinity of less than 5% and wherein the material of the body which has flowed assumes a crystallinity of between 12% and 20%.
3. An element as claimed in Claim 1 or 2, wherein the hollow body has a bottom having a central section, the bottom having been formed such that central zones of the blank have, on drawing of the element, been



displaced relative to the edge part whilst retaining the original material properties both of the central section of the bottom and of the edge part.

4. An element as claimed in any of Claims 1 to 3, wherein the element is formed from a polyester or a polyamide.

5. An element as claimed in Claim 4, wherein the element is formed from polyethylene terephthalate, polyhexamethylene-adipamide, polycaprolactam, polyhexamethylene-sebacamide, polyethylene 2,6-naphthalate and polyethylene 1,5-naphthalate, polytetramethylene 1,2-dihydroxybenzoate and copolymers of ethylene terephthalate, ethylene isophthalate or other similar polymers.

6. A method of manufacturing an element as claimed in any preceding claim from a blank of thermoplastic material having a crystallinity of less than 10%, the method comprising the steps of clamping areas of the blank such that at least one zone is defined within and completely surrounded by said clamped areas, applying a pressing tool against said zone, the contact surface of said pressing tool having an area smaller than that of said zone whereby a closed intermediate strip of material is defined between the part of the zone in contact with the contact surface and the clamped areas,



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and moving the pressing tool relative to the clamped areas such that the material of said intermediate strip is stretched to such an extent that flow takes place and the material of said intermediate strip is oriented, the movement of said pressing tool drawing said intermediate strip to form at least a part of the body of the element.

7. A method as claimed in Claim 6, wherein movement of the pressing tool is continued until substantially all of the material in said zone has undergone flow such that substantially all of said hollow body is formed of material which has flowed.

8. A method as claimed in Claim 6 or 7, wherein said clamped areas form a closed frame completely surrounding said intermediate strip, and movement of said pressing tool causes flow of the material to start at the pressing tool.

9. A method as claimed in any of Claims 6 to 8, wherein the width of the clamped areas is selected such that flow of the material on drawing extends as far as the said areas.

10. A method as claimed in any of Claims 6 to 9, wherein immediately before the drawing step, the material is at a temperature which is below the glass transition temperature, for example, at room temperature.



11. A method as claimed in any of Claims 6 to 10, wherein the material is subjected, at least during the drawing step, to accelerated cooling in the flow zone.
12. A method as claimed in Claim 11, wherein the pressing tool is provided with cooling devices which are arranged in such a way that, on drawing the material the zones in which the material flows are in contact with the cooling devices.
13. An element as claimed in Claim 1, formed from polyethylene terephthalate, wherein the element is cup-shaped and has a monoaxially oriented side wall, the material of which has a crystallinity of between 10% and 25%.
14. An element of thermoplastic material as claimed in Claim 1, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.
15. A method of manufacturing an element of thermoplastic material as claimed in Claim 6, substantially as hereinbefore described with reference to the accompanying drawings.

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