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DRAWINGS ATTACHED

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(72) Inventor GRAHAME MELVIN READE



(54) PROCESS AND APPARATUS FOR THE PRODUCTION OF TUBULAR FILMS FROM THERMOPLASTIC MATERIALS

- (71) We, IMPERIAL CHEMICAL INDUSTRIES LIMITED of Imperial Chemical House, Millbank, London, S.W.1., a British Company, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
- 10 The present invention relates to an improved apparatus and process for the production of tubular films of thermoplastic materials and in particular biaxially oriented films of linear thermoplastic polyesters especially polyethylene terephthalate.
- 15 It has already been proposed to produce biaxially oriented tubular films from polyethylene terephthalate by first quenching an extruded tube by withdrawing it over a cooled mandrel at a rate greater than that at which it is being extruded. The tube is then heated to its stretching temperature and stretched in its direction of extrusion by withdrawing the tube at a rate greater than that at which it is withdrawn over the mandrel; the tube is also stretched in a direction transverse to its direction of extrusion by introducing air under pressure to within the tube.
- 20 We have found that it is not possible to produce film at a speed that is required for commercial operation using such a process because the extruded tube tends to stick to the mandrel. Furthermore we have found that the apparatus may be suitably adapted so that the tube does not stick to the mandrel but the seal formed between the mandrel and the tube is not then sufficient to prevent the air pressure used to expand the tube from forcing the tube away from the mandrel and thus creating a high pressure within the tube at its point of extrusion; this cannot be tolerated because the tube will burst as it is molten at this point.
- 25 Therefore, in order to provide a satisfactory film making process two criteria must be satisfied. Firstly, the tube must slide along the surface of the mandrel whilst being in sufficiently close proximity to the mandrel to ensure effective sizing and cooling of the tube. Secondly, a seal must be formed within the tube to prevent the air pressure used to expand the tube from bursting at its point of extrusion.
- 30 The majority of oriented films of thermoplastic materials are biaxially oriented and if a tubular process is used these are generally produced by stretching an extruded tube in its direction of extrusion as well as in its transverse direction. In order to produce oriented film it is necessary to stretch the unoriented tube between specific temperature limits which are below the melting point of the thermoplastic. The force required to stretch the cooled unoriented tube is greater than the force required to stretch the molten tube and it is therefore necessary to prevent the forces which stretch the tube to orient it in its direction of extrusion from stretching the tube as it emerges from the extrusion die where it is molten. Thus the speed of travel of the tube must be controlled between its point of extrusion and the zone where it is stretched to orient it.
- 35 The present invention is directed towards providing an apparatus and process for the production of oriented films of thermoplastic materials which satisfies the requirements set out above.
- 40 According to the present invention an apparatus is provided for the production of tubular films from melts of thermoplastic materials comprising an annular extrusion orifice and an internally cooled sizing mandrel of smaller diameter than the extrusion orifice and mounted coaxially with the extrusion orifice and means for withdrawing the tube over the mandrel at a rate greater than its rate of extrusion, said mandrel having
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ing a matt surface and being tapered over at least the part of its length which is in contact with the contracting tube, said taper being sufficient to accommodate the contraction of the tube as it cools to the solid state and a seal positioned within the tube at the end of the mandrel where the tube has been cooled sufficiently not to stick to the seal, means situated beyond said withdrawing means to heat the tube to its stretching temperature, means to introduce air under pressure to within the tube at a position beyond said seal in the direction of travel of the tube and means to collapse the expanded tubular film.

The molten tube must be withdrawn from the extrusion die onto the mandrel at a greater rate than at which it is extruded. In this way the tube is drawn down onto the surface of the mandrel which sizes the tube to the required diameter. The amount by which the speed of travel of the tube must be increased depends upon the diameter of the tube and the difference between the diameter of the tube and the diameter of the mandrel at the point where it is first contacted by the tube. Preferably, when the diameter of the extruded tube is about 1/2" the tube is withdrawn over the mandrel between 1.05 and 10 times preferably between 1.05 and 5 times faster than the rate at which it is extruded. If the draw ratio is less than 1.05 the tube is not drawn down sufficiently onto the mandrel and is not properly sized. If, however, the draw ratio is greater than 10 the tube tends to stick to the mandrel.

The apparatus of the present invention may be used to produce uniaxially or biaxially oriented films. If uniaxially oriented material is being produced the tube should only be stretched in either its direction of extrusion or the direction transverse thereto after it has been reheated to the stretching temperature. However, this invention is primarily concerned with the production of biaxially oriented films and the tube should then be stretched both in its direction of extrusion and in the direction transverse thereto. This may conveniently be achieved by removing the expanded tube from the expansion zone with a pair of nip rolls which are driven at a greater peripheral speed than the speed at which the tube is withdrawn over the mandrel. In this way the longitudinal orientation of the tube is achieved by stretching the tube between the means which withdraws the tube over the mandrel and the rolls which collapse the expanded tube. In this way the means which withdraws the tube over the mandrel prevents the longitudinal stretching force from affecting the tube at its point of extrusion.

The sizing mandrel must be of smaller

diameter than the diameter of the extrusion orifice. The extruded molten tube is pulled down onto the mandrel by the force which withdraws the tube over the mandrel and thus the greater the force the more the molten tube will tend to contract. The tube is cooled as it is in contact with the mandrel which must therefore be tapered at least along its length which is in contact with the shrinking tube to accommodate the shrinkage of the tube as it is being hauled over the mandrel. The amount of shrinkage that must be accommodated depends on the diameter of the tube and the rate of shrinkage depends on the rate of cooling. We have found that in order to allow a tube of initial diameter about 1/2" to slide down over the mandrel, it should be tapered so that the diameter decreases by at least 0.0008" per inch, of the length of the tapered section of the mandrel a taper of two thousandths of an inch for every inch of its length is particularly suitable. The length of the mandrel is not important providing it is sufficiently long to cool the tube so that it will not stick to the seal. When the tube has been fully cooled and is completely shrunk it will no longer contract and, assuming the tapered section of the mandrel extends beyond the point where the tube is fully cooled, the tube will part from the surface of the mandrel.

We have found that simply using a tapered mandrel is not sufficient to enable the tube to slide down over the mandrel and it is necessary to also roughen the surface of the mandrel to prevent the tube sticking. The surface of the mandrel may be roughened in any suitable manner. For example the mandrel may be grit blasted or sand blasted to form the rough surface. The mandrel may be coated with a particulate material to provide roughness and this coating may be instead of or in addition to mechanical roughening of the surface. The coating which is applied may conveniently be a ceramic coating or polytetrafluoroethylene. If the mandrel is coated to provide roughness the coated mandrel may itself be further abraded to give the required surface to the mandrel. The degree of mattness of a surface may conveniently be defined as showing a Centre Line Average as specified in British Standard 1134 of 1950. We have found that a mandrel having a surface roughness defined by a Centre Line Average of between 20 and 90 micro-inches is particularly suitable. If the Centre Line Average is less than 20 micro-inches the tube tends to stick to the mandrel whereas if the Centre Line Average is greater than 90 micro-inches the inside of the tube tends to be scratched.

The combination of the rough surface 130

and the taper of the mandrel allows the tube to be drawn over the mandrel without sticking. However, we have found that the forces urging the tube onto the mandrel which arise from the combination of the necking in of the tube due to the force withdrawing the tube over the mandrel and the thermal contraction are not sufficient to prevent the high air pressure which is used to expand the tube forcing the tube away from the mandrel. If this happens air under pressure passes into the zone adjacent the extrusion die where the tube is molten. The tube is very weak at its point of extrusion where it is molten and would burst if the relatively high air pressure used to expand the tube was allowed to pass between the mandrel and the tube. Accordingly, we have found that it is necessary to provide a seal within the tube that prevents the air under pressure passing between the tube and the mandrel. The seal which may conveniently be a circular disc fitted to the mandrel is positioned towards the bottom end of the mandrel where the tube has cooled sufficiently not to stick to the seal. In a preferred form of the apparatus of the present invention the tapered mandrel is longer than is required to accommodate the shrinkage of the tube so that when the tube is fully shrunk it diverges from the mandrel and the seal is provided at the bottom of the mandrel and fills the gap between the tube and the tapered mandrel. Conveniently the seal is a rubber lip seal.

It is difficult to manufacture a seal of the diameter and size required to make a completely effective seal which is not so big that it will stick to the tube. This is especially true as the seals must last for long periods of time and also be effective despite minor variations in tube diameter. Accordingly, in a preferred form of our apparatus we provide a vent to atmosphere through the core of the mandrel from a point adjacent the seal through which any air which passes the seal may flow. If necessary a vacuum may be applied to this vent.

In a preferred embodiment of the apparatus of the present invention means are provided for controlling the pressure within the tube adjacent the extrusion die. Conveniently there is a gap between the mandrel and the extrusion die which defines a channel which can be communicated to atmosphere through the body of said die. Alternatively, gas may be supplied to the interior of the tube through the channel, or a vacuum may be applied whichever is appropriate. This pressure control system may be used as a safeguard. For example, if the molten tube is liable to burst because the internal pressure is too high the zone adjacent the die may be vented to atmos-

phere or a vacuum may be applied. Alternatively, if the tube tends to stick to the mandrel, because of the high radial forces pulling the molten tube onto the mandrel air under pressure may be supplied to within the tube to counterbalance some of the radial forces. As mentioned above, thermoplastic materials and in particular polyethylene terephthalate are very weak when they are molten and thus if air under pressure is introduced to within the tube the pressure drop across the tube should be very small.

The means which withdraws the tube over the mandrel controls the speed of travel of the tube before it is fed to the zone in which it is stretched to orient it. As mentioned previously the apparatus of the present invention is particularly concerned with the production of biaxially oriented film in which the tube is stretched in its direction of extrusion as well as being expanded by internal air pressure. If the tube is stretched to orient it in its direction of extrusion it is essential that the stretching forces should not effect the tube as it is emerging from the extrusion die where it is molten. Accordingly, the device which hauls the tube over the mandrel also controls the speed of travel of the tube to prevent the longitudinal stretching forces from drawing off the molten tube. The most convenient method for introducing the air which expands the tube to within the tube is to pass it through a pipe which extends through the mandrel. Generally the pipe does not pass through the device which controls the speed of the tube and in this embodiment the device which withdraws the tube over the mandrel should not collapse the tube across its entire width but should allow air to pass. Our preferred device therefore consists either of a pair of nip rolls of width less than that of the collapsed tube which only collapse the tube at its centre; alternatively a pair of moving belts which grip the exterior of the tube to control its speed but do not collapse it may be used. If such devices are used the tube will not be creased at its edges which is a disadvantage that occurs if the tube is collapsed over its entire width.

The main purpose of the mandrel is to cool the extruded tube and it is preferable that the mandrel itself should be cooled by circulating cooling water within the mandrel. In order to speed up the cooling of the tube an external water bath may be positioned around the tube as it is passing over the mandrel.

The cooled tube then passes into a heating zone where it is heated to the stretching temperature. This temperature will depend upon the nature of the material, however, in the case of polyethylene tereph-

thalate the temperature should be above the glass transition temperature and below the melting point. We have found that if polyethylene terephthalate is being stretched a temperature in the range of 85°C to 105°C may conveniently be used. The tube may be heated by any suitable means, for example it may be heated by hot air or by passage through at least one circular infrared heater which surrounds the tube.

The tube may then be stretched in the direction transverse to that in which it is extruded by air introduced under pressure to within the tube and may be simultaneously stretched in its direction of extrusion by driving the means which collapses the expanded tube faster than the device which withdraws the tube over the mandrel. The amount by which the tube should be stretched depends upon the nature of the thermoplastic material but for the production of biaxially oriented polyethylene terephthalate we prefer that the tube should be stretched between 3 times and 4 1/2 times in both its direction of extrusion and in the direction transverse thereto.

It will be appreciated that the amount of cooling that is necessary and the pressure required to expand the tube will depend upon the initial thickness of the extruded tube and the speed at which it is travelling. However, we have found that in order to produce polyethylene terephthalate film at a commercially usefual rate it is necessary to use an apparatus according to the present invention.

This invention also provides a process for the production of tubular films using an apparatus of the type described comprising melt extruding a tube of a thermoplastic material, withdrawing the tube over an internally cooled, matt surfaced sizing mandrel which is coaxial with the extrusion orifice and of smaller diameter than the diameter of the extrusion orifice at a greater rate than its speed of extrusion, said mandrel being tapered over at least the length in which it is in contact with the contracting tube to allow for the contraction of the tube as it cools to the solid state and passing the tube over a seal positioned within the tube at a point where the tube has been cooled sufficiently not to stick to the seal, heating the tube to its stretching temperature and introducing gas under pressure to within the tube at a position beyond the seal and finally collapsing the expanded tubular film.

The tubular films produced by the process of the present invention are shrinkable and may therefore be used in shrink wrapping applications. However, for many applications it is desirable that the shrinkage of the film at elevated temperatures

should be reduced. The film may readily be rendered more dimensionally stable at elevated temperatures by holding the film under tension while it is heated. In the case of polyethylene terephthalate suitable temperatures are in the range 150°C to 230°C. This may conveniently be achieved by passing the expanded tube through a device of the type described in our Dutch Specification No. 70-00020.

The present invention is illustrated but in no way limited by reference to the drawings accompanying the provisional specification in which:

Figure 1 is a diagrammatic illustration of an apparatus according to the present invention.

Figure 2 is a cut away view of the extrusion die used in the apparatus of Figure 1.

Figure 3 is a cut away view of the mandrel and water bath quenching system used in the apparatus of Figure 1

Figure 4 is a cross section of the mandrel used in the apparatus illustrated in Figures 1 to 3.

Referring to Figure 1 which is only a diagrammatic representation of the apparatus of the present invention. The apparatus consists of an extruder 1 which forces molten thermoplastic material through a filter 2 into a cross head extrusion die 3. The extrusion die 3 has an annular extrusion orifice through which the tube 4 is extruded. A mandrel 5 passes through the centre of the extrusion die and the extruded tube is cooled by contact with the mandrel.

A pipe 6 extends throughout the length of the mandrel and through which air under pressure may be introduced to within the tube at a position beyond the mandrel. A second pipe 7 also extends through the mandrel and is used to record the pressure of air within the tube. The mandrel is cooled by circulating water through the centre of the mandrel and pipe 8 is provided for the introduction of the cooling water which flows through the mandrel and out along pipe 9. A seal (not shown in Figure 1) is provided at the bottom of the mandrel and the inside of the tube is vented to atmosphere at a position just above the seal through pipe 10. The mandrel is tapered over the whole of its length beyond the extrusion die and also has a roughened surface.

As well as being cooled internally the tube 4 is cooled externally by passage through a water bath 11 which surrounds the tube. Water is continually introduced into the water bath through pipe 12 and flows out through pipe 13. After passing through the water bath the tube passes through a chamber 14 where vacuum is applied to the outside of the tube through

pipe 15 to remove any water from the outside of the tube. The end of the mandrel lies within the water bath and is not therefore shown in Figure 1.

- 5 The tube 4 is drawn over the mandrel and through the water bath by nip rolls 16 which are driven at a faster peripheral speed than the speed at which the tube is extruded. These nip rolls are of width
10 less than the width of the collapsed tube so that they grip the tube but do not collapse it over its entire width. In this way the air under pressure which is introduced through the pipe 6 can pass the rolls 16
15 into the zone in which the tube is stretched to orient it.

- The tube 4 then passes through a circular infra-red heater 17 which surrounds the tube and rapidly heats the tube to the temperature at which it may be stretched to orient it. This rapid heating however raises the temperature of the outside of the tube more quickly than the temperature of the remainder of the tube and so the heated
20 tube is passed through an oven 18 where the tube temperature becomes more uniform. The tube then passes through a second infra-red ring heater 19 to ensure that the temperature of the tube is the optimum for stretching. The tube is then stretched in its direction of extrusion by the nip rolls 25 which are rotating at a greater peripheral speed than the rolls 16. The tube is also stretched in the direction transverse to its direction of extrusion by the air under pressure introduced through pipe 6.
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- The diameter of the expanded tube 20 is partially controlled by an air ring 21. Cold air is directed from the air ring onto the expanded tube to set the tube at the required diameter and to prevent any further expansion. Sensing devices 22 are also provided to determine if the tube is at the required diameter and this information relayed to the source supplying air under pressure through pipe 6 so that suitable adjustments may be made if necessary.
45

- The expanded tube 20 is then cooled by passage through a cooling tube 23 where it is cooled by air at room temperature and finally collapsed by the nip rolls 25; the rolls 24 are provided to guide the tube as it is being collapsed. The flat tubular film may then be wound into a reel 26. If a film of improved dimensional stability is required the film should be held under tension while it is heated to the appropriate stabilising temperature. This may conveniently be achieved by passing the tube through a device of the type described in our Dutch Specification No. 70.00020 in which case the nip rolls 25 should be replaced by a pair of rolls which do not collapse the tube across its entire width
60 through a device of the type described in our Dutch Specification No. 70.00020 in which case the nip rolls 25 should be replaced by a pair of rolls which do not collapse the tube across its entire width
65 and the tube fed directly to the stabilising

device.

Figure 2 is a cut away view of the extrusion die showing the die in section; the mandrel is not shown in section. Figure 2 shows the polymer melt 30 flowing along the extruder barrel 1 into the cross head extrusion die 3. The polymer is extruded as a tube 4 which is hauled down onto the mandrel 5; the taper on the mandrel begins at the dotted line 29. As is illustrated in Figure 2 there is a gap 27 between the mandrel 5 and the die body 3; this gap is vented to the exterior of the die body by pipe 28 and thus air under pressure or vacuum as is appropriate may be applied to the area between the tube 4 and the mandrel 5.
75
80

Figure 3 is a cut away view of the mandrel and water bath quenching system showing the water bath in section; the mandrel is not shown in section. As in Figure 2 the mandrel begins to taper at the dotted line 29. Both the tube and the mandrel pass through the water bath 11 which consists of two sleeves 31 and 32 mounted coaxially around the tube. Cooling water is introduced to the water bath through pipe 12 and flows upwards along the channel between the cylinder 31 and the tube 4, over the top of cylinder 31 and downwardly along the channel between cylinders 31 and 32 and out of the water bath through pipe 13. A circular seal 33 is provided at the bottom of the water bath to prevent the water flowing down the tube. However, some water will be carried downwards by the movement of the tube and a chamber 14 is provided which surrounds the tube below the water bath. Vacuum is applied to chamber 14 through pipe 15 to remove residual water from the outside of the tube. A second circular seal 34 is provided at the bottom of chamber 14.
85
90
95
100
105

Figure 3 also illustrates that the tube diverges from the mandrel when it is fully cooled and shows a circular seal 36 which prevents the air under pressure which is introduced through pipe 6 passing upwards between the tube and the mandrel. The mandrel is vented to atmosphere through hole 35 which is connected to atmosphere via pipe 10 (Figure 4) which passes through the mandrel. Thus, any air passing the seal may be removed from within the tube through vent 35 and pipe 10.
110
115
120

Figure 4 is a sectional view of parts of the mandrel showing the top part of the mandrel and the lower tapered part. As will be seen the mandrel is hollow and water is circulated throughout the centre of the mandrel. The water is introduced into the mandrel through pipe 8 and flows in an upward direction along the channel between pipe 8 and the walls of the mandrel 5 and out of the mandrel along pipe 9.
125
130

is a seal which prevents water flowing out at the bottom of the mandrel; pipe 10 passes through the seal 37 and opens into the vent 35 thus providing a communication between vent 35 and the atmosphere pipes 6 and 7 extend within pipe 10 and pass beyond vent 35 and through the seal 36. 38 is a further seal which prevents air passing upwardly into the vent 35. 39 is a nut which holds the seal in place and also enables the seal to be readily replaced.

The mandrel used in the apparatus illustrated in Figures 1 to 4 is matt surfaced.

The present invention is illustrated by the following example:—

EXAMPLE

The apparatus used to produce the film was as illustrated in the accompanying drawings. The extrusion die was $7/8$ inches in diameter, the annular die gap was 0.02 inches wide, the total length of the mandrel was 27 inches and the tapered section was 11 inches long. The initial diameter of the mandrel was 0.4375 inches and it tapered regularly over 11 inches to a diameter of 0.4175 inches. The mandrel had a matt surface as defined by Centre Line Average of 63 micro inches. Cold water was circulated through the mandrel at a rate of about 14 gallons per hour and through the external water bath at a rate of 27 gallons per hour.

Polyethylene terephthalate having an intrinsic viscosity of 0.62 as measured in a 1% solution in *ortho*-chlorophenol at 25°C was extruded from the die at 270°C and at an output of 18 $3/4$ lbs/hr. The molten tube was withdrawn from the extrusion die by nip rolls 16 which did not collapse the tube across its entire width and which were rotating at a peripheral speed of 29 feet/minute. The tube first contacted the mandrel about 2 inches below the bottom of the extrusion die, this point was one inch above the top of the water bath at which point the tube was 15 thousandths of an inch thick.

The temperature of the tube was then raised to a temperature in the range 85°C to 95°C and stretched to orient it both in its direction of extrusion and in the direction transverse thereto. The tube was stretched in its direction of extrusion by the nip rolls 25 which were rotating at a peripheral speed of 93 ft per minute and in the direction transverse thereto by an air pressure of 8 pounds per square inch introduced to within the tube through pipe 6 this air pressure expanded the tube to a diameter of 45 millimeters. After the apparatus had been running for half an hour the surface of the mandrel was found to have a Centre Line Average of 54 micro-inches, which remained substantially constant.

The final film was of 110 gauge average thickness; had a yield stress in its direction of extrusion of 13,000 pounds per square inch and of 20,000 pounds per square inch in the transverse direction. The break strength in the direction of extrusion was 25,000 p.s.i. with an 80% elongation at break strength in the transverse direction was 30,000 p.s.i. with a 40% elongation at break.

WHAT WE CLAIM IS:—

1. An apparatus for the production of tubular films from melts of thermoplastic materials comprising an annular extrusion orifice and an internally cooled sizing mandrel of smaller diameter than the extrusion orifice and mounted coaxially with the extrusion orifice and means for withdrawing the tube over the mandrel at a rate greater than the rate of extrusion of the tube, said mandrel having a matt surface and being tapered over at least the part of its length which is in contact with the contracting tube, said taper being sufficient to accommodate the contraction of the tube as it cools to the solid state and a seal positioned within the tube at the end of the mandrel where the tube has been cooled sufficiently not to stick to the seal, means situated beyond said withdrawing means to heat the tube to its stretching temperature, means to introduce air under pressure to within the tube at a position beyond said seal in the direction of travel of the tube and means to collapse the expanded tubular film.

2. An apparatus according to claim 1 in which the means to collapse the expanded tube withdraws the tube at a rate greater than that at which the withdrawing means withdraws the tube over the mandrel.

3. An apparatus according to either of claim 1 and claim 2 in which the mandrel is tapered to an extent that its diameter decreases at least 0.0008 inch for each inch of the length of the tapered section of the mandrel.

4. An apparatus according to any one of the preceding claims in which the surface of the mandrel has a Centre Line Average roughness of from 20 to 90 micro-inches, as hereinbefore defined.

5. An apparatus according to any of the preceding claims in which the surface of the mandrel is grit blasted.

6. An apparatus according to any of the preceding claims in which the surface of the mandrel is coated with particulate material.

7. An apparatus according to claim 6 in which the particulate material is a ceramic.

8. An apparatus according to claim 6 or claim 7 in which the coating is polytetrafluoroethylene.

9. An apparatus according to any one of the preceding claims in which the mandrel is of a length greater than that required to



is a seal which prevents water flowing out at the bottom of the mandrel; pipe 10 passes through the seal 37 and opens into the vent 35 thus providing a communication between vent 35 and the atmosphere pipes 6 and 7 extend within pipe 10 and pass beyond vent 35 and through the seal 36. 38 is a further seal which prevents air passing upwardly into the vent 35. 39 is a nut which holds the seal in place and also enables the seal to be readily replaced.

The mandrel used in the apparatus illustrated in Figures 1 to 4 is matt surfaced.

The present invention is illustrated by the following example:—

EXAMPLE

The apparatus used to produce the film was as illustrated in the accompanying drawings. The extrusion die was $7/8$ inches in diameter, the annular die gap was $C.02$ inches wide, the total length of the mandrel was 27 inches and the tapered section was 11 inches long. The initial diameter of the mandrel was 0.4375 inches and it tapered regularly over 11 inches to a diameter of 0.4175 inches. The mandrel had a matt surface as defined by Centre Line Average of 63 micro inches. Cold water was circulated through the mandrel at a rate of about 14 gallons per hour and through the external water bath at a rate of 27 gallons per hour.

Polyethylene terephthalate having an intrinsic viscosity of 0.62 as measured in a 1% solution in *ortho*-chlorophenol at 25°C was extruded from the die at 270°C and at an output of $18\ 3/4$ lbs/hr. The molten tube was withdrawn from the extrusion die by nip rolls 16 which did not collapse the tube across its entire width and which were rotating at a peripheral speed of 29 feet/minute. The tube first contacted the mandrel about 2 inches below the bottom of the extrusion die, this point was one inch above the top of the water bath at which point the tube was 15 thousandths of an inch thick.

The temperature of the tube was then raised to a temperature in the range 85°C to 95°C and stretched to orient it both in its direction of extrusion and in the direction transverse thereto. The tube was stretched in its direction of extrusion by the nip rolls 25 which were rotating at a peripheral speed of 93 ft per minute and in the direction transverse thereto by an air pressure of 8 pounds per square inch introduced to within the tube through pipe 6 this air pressure expanded the tube to a diameter of 45 millimeters. After the apparatus had been running for half an hour the surface of the mandrel was found to have a Centre Line Average of 54 micro-inches, which remained substantially constant.

The final film was of 110 gauge average thickness; had a yield stress in its direction of extrusion of 13,000 pounds per square inch and of 20,000 pounds per square inch in the transverse direction. The break strength in the direction of extrusion was 25,000 p.s.i. with an 80% elongation at break strength in the transverse direction was 30,000 p.s.i. with a 40% elongation at break.

WHAT WE CLAIM IS:—

1. An apparatus for the production of tubular films from melts of thermoplastic materials comprising an annular extrusion orifice and an internally cooled sizing mandrel of smaller diameter than the extrusion orifice and mounted coaxially with the extrusion orifice and means for withdrawing the tube over the mandrel at a rate greater than the rate of extrusion of the tube, said mandrel having a matt surface and being tapered over at least the part of its length which is in contact with the contracting tube, said taper being sufficient to accommodate the contraction of the tube as it cools to the solid state and a seal positioned within the tube at the end of the mandrel where the tube has been cooled sufficiently not to stick to the seal, means situated beyond said withdrawing means to heat the tube to its stretching temperature, means to introduce air under pressure to within the tube at a position beyond said seal in the direction of travel of the tube and means to collapse the expanded tubular film.

2. An apparatus according to claim 1 in which the means to collapse the expanded tube withdraws the tube at a rate greater than that at which the withdrawing means withdraws the tube over the mandrel.

3. An apparatus according to either of claim 1 and claim 2 in which the mandrel is tapered to an extent that its diameter decreases at least 0.0008 inch for each inch of the length of the tapered section of the mandrel.

4. An apparatus according to any one of the preceding claims in which the surface of the mandrel has a Centre Line Average roughness of from 20 to 90 micro-inches, as hereinbefore defined.

5. An apparatus according to any of the preceding claims in which the surface of the mandrel is grit blasted.

6. An apparatus according to any of the preceding claims in which the surface of the mandrel is coated with particulate material.

7. An apparatus according to claim 6 in which the particulate material is a ceramic.

8. An apparatus according to claim 6 or claim 7 in which the coating is polytetrafluoroethylene.

9. An apparatus according to any one of the preceding claims in which the mandrel is of a length greater than that required to

- accommodate the shrinkage of the tube so that when the tube is fully shrunk it diverges from the mandrel and the seal is positioned at the end of the mandrel to fill the gap between the tube and the tapered mandrel.
10. An apparatus according to any one of the preceding claims in which the seal is in the form of a circular disc.
11. An apparatus according to claim 10 in which the seal is a rubber lip seal.
12. An apparatus according to any one of the preceding claims including means for control the pressure within the cooled tube before it passes over said seal.
13. An apparatus according to claim 12 in which the pressure control means comprises a vent to atmosphere through the core of the mandrel from a point adjacent said seal.
14. An apparatus according to claim 13 including means for applying suction to said vent.
15. An apparatus according to any one of the preceding claims including means for controlling the pressure within the tube adjacent the extrusion die.
16. An apparatus according to claim 15 in which the pressure control means comprises a vent to atmosphere through the body of said die.
17. An apparatus according to claim 16 including means for applying suction to said vent.
18. An apparatus according to claim 15 in which means are provided to supply gas under pressure to the inside of the tube adjacent the extrusion die.
19. An apparatus according to any one of the preceding claims in which means are provided to cool the external surface of the tube as it is passing over said mandrel.
20. An apparatus according to claim 19 in which said cooling means is a liquid bath.
21. An apparatus according to claim 20 in which said bath comprises a pair of sleeves disposed coaxially around the tube, the innermost surface of the inner of said sleeves together with the tube defining a channel for the upward passage of cooling liquid in contact with said tube and the channel between said coaxial sleeves serving as a drain to receive the spent cooling liquid.
22. An apparatus according to claim 21 which includes means to remove residual liquid from the external surface of the tube downstream from said water bath.
23. An apparatus according to claim 18 in which said removal means comprises a chamber around the tube and means for applying vacuum to said chamber.
24. An apparatus according to any one of the preceding claims in which the means for withdrawing the tube over the mandrel does not collapse the tube across its entire width.
25. An apparatus according to claim 24 in which the withdrawal means comprises a pair of nip rolls of width less than that of the collapsed tube so that only the central portions of the collapsed tube are brought together in the nip.
26. An apparatus according to claim 24 in which the withdrawal means comprises a pair of moving belts which engage the external surface of the tube.
27. An apparatus according to any one of claims 24 to 26 in which the means for withdrawing the tube over the mandrel operates to withdraw the tube over the mandrel at a rate of between 1.05 and 10 times faster than the rate at which the tube is extruded.
28. An apparatus according to claim 27 in which said withdrawal means withdraws the tube over the mandrel at a rate of between 1.05 and 5 times faster than the rate at which the tube is extruded.
29. An apparatus according to any one of the preceding claims in which said means to heat the tube to its stretching temperature comprises means to distribute hot air or gas onto the external surface of the tube.
30. An apparatus according to any one of claims 1 to 28 in which said heating means comprises at least one circular infrared heater disposed around the tube.
31. An apparatus according to any one of claims 1 to 28 in which said heating means comprises an oven disposed around the tube.
32. An apparatus according to any one of the preceding claims in which the means to introduce air to within the tube comprises a pipe passing through the core of the mandrel and having a discharge orifice so positioned as to discharge air into the tube beyond said seal in the direction of travel of the tube.
33. An apparatus according to any one of the preceding claims including means for sensing the dimensions of the expanded tube and means for adjusting the pressure of air within the tube to control said dimensions.
34. An apparatus according to any one of the preceding claims including means to cool the expanded tube.
35. An apparatus according to claim 34 in which said cooling means comprises a chamber around the tube and means to supply air at the required temperature to the interior of said chamber.
36. An apparatus according to any one of the preceding claims in which the means to collapse the expanded tube comprises a pair of nip rolls which extend across the entire width of the collapsed tube.



37. An apparatus constructed and arranged substantially as herein described and shown in the accompanying drawings.

38. A process for the production of tubular film comprising melt extruding a tube of a thermoplastic material, withdrawing the tube over an internally cooled, matt surfaced sizing mandrel which is coaxial with the extrusion orifice and of smaller diameter than the diameter of the extrusion orifice at a greater rate than the speed of extrusion of the tube, said mandrel being tapered over at least the length in which it is in contact with the contracting tube to allow for the contraction of the tube as it cools to the solid state and passing the tube over a seal positioned within the tube at a point where the tube has been cooled sufficiently not to stick to the seal, heating the tube to its stretching temperature and introducing gas under pressure to within the tube at a position beyond the seal and finally collapsing the expanded tubular film.

39. A process according to claim 38 in which the film is stretched longitudinally by collapsing the expanded tube at a rate greater than that at which the tube is withdrawn over the mandrel.

40. A process according to claim 38 or claim 39 in which the mandrel is mechanically roughened.

41. A process according to claim 38 or claim 39 in which the mandrel is coated with a particulate material.

42. A process according to claim 41 in which the particulate material is ceramic.

43. A process according to claim 41 or claim 42 in which the particulate coating material is polytetrafluoroethylene.

44. A process according to any one of claims 38 to 43 in which the tube is withdrawn over a mandrel which is tapered to an extent that its diameter decreases by at least 0.0008 inch for each inch of the length of the tapered section of the mandrel.

45. A process according to any one of claims 38 to 44 in which the tube is withdrawn over a mandrel having a Centre Line Average roughness of from 20 to 90 micro-inches, as hereinbefore defined.

46. A process according to any one of claims 38 to 45 in which the tube is withdrawn over a tapered mandrel of a length greater than that required to accommodate the shrinkage of the tube so that when the tube is fully shrunk it diverges from the mandrel and engages the seal which is positioned at the end of the mandrel to fill the gap between the tube and the tapered mandrel.

47. A process according to any one of claims 38 to 46 in which any gas leaking to the upstream side of said seal is removed through a vent through the core of said mandrel.

48. A process according to any one of claims 38 to 47 in which gas under super-atmospheric pressure is supplied to within the tube emerging from the extrusion orifice.

49. A process according to any one of claims 38 to 47 in which the pressure of gas within the tube emerging from the extrusion orifice is reduced to sub-atmospheric pressure.

50. A process according to any one of claims 38 to 49 in which the tube is externally cooled by passage through a liquid bath surrounding said tube as the tube is passing over said mandrel.

51. A process according to any one of claims 38 to 50 in which the tube is withdrawn over the mandrel at a rate of from 1.05 to 10 times faster than the rate at which the tube is extruded.

52. A process according to claim 51 in which the tube is withdrawn over the mandrel at a rate of from 1.05 to 5 times faster than the rate at which the tube is extruded.

53. A process according to any one of claims 38 to 52 in which the thermoplastic material is polyethylene terephthalate.

54. A process according to claim 53 in which the tube is heated to a stretching temperature of from 85 to 105°C after passing over the mandrel.

55. A process according to claim 54 in which the heated tube is stretched between 3 times and 4½ times in both its direction of extrusion and in the direction transverse thereto.

56. A process substantially as hereinbefore described with particular reference to the drawings accompanying the Provisional Specification.

57. A process substantially as hereinbefore described with particular reference to the accompanying Example.

58. Biaxially oriented thermoplastic film when produced by a process according to any one of claims 38 to 57.

59. Uniaxially oriented thermoplastic film when produced by a process according to claim 38.

60. Oriented tubular polyethylene terephthalate film when produced by a process according to any one of claims 38 to 57.

P. C. BAWDEN,

Agents for the Applicants.

