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(54) A PREDOMINANTLY MONAXIALLY ORIENTED FILM OF A THERMOPLASTIC MATERIAL AND A PROCESS OF PREPARING SAME

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 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 follow-
 ing statement:—

This invention relates to a substantially
 monaxially oriented film of a thermoplastic
 material, extruded through an annular die,
 and to a method of and apparatus for manufac-
 turing such film.

It is known to make such films by a blown
 film or trapped bubble process, in which a
 tube is extruded through an annular die, in-
 flated by air to the required size, cooled with
 externally blown air or other coolants, col-
 lapsed to a flat tube by haul-off rollers, and
 wound into rolls of flattened tubular film.
 Tubular films have also been produced using
 apparatus including internal and/or external
 mandrels to supplement or replace the air
 cooling.

The tubular films can be subsequently
 stretched further in order to obtain a higher
 degree of orientation within the film.

A method of making substantially mon-
 axially oriented films of thermoplastics mater-
 ial is disclosed in U.S. patent specification
 3,342,657 which describes a process of prepar-
 ing a monaxially oriented continuous strip of
 thermoplastics film in which the direction of
 orientation is at an angle to the longitudinal
 direction of the film, by extruding a tube of
 thermoplastic material in its formative state
 from a rotary annular die, rotating the tube as
 it is advanced from the die, cooling, reheating
 and longitudinally orientating the tubular film,
 and finally cutting the rotating oriented tube
 into strip form along substantially helical
 paths.

British patent specification 1,072,174 dis-
 closes a process for making a tube of thermo-
 plastic material, which after having just left
 an annular die, is pulled over a slowly rotating
 calibrating mandrel, so that the tube is sub-
 jected to a limited rotary movement and lon-
 gitudinal movement in the direction towards
 nip rolls. The helix angles formed in the tube
 obtained do not exceed 10°, there being no
 relative rotational motion between the die
 and the pinch rolls. U.S. patent specification
 3,576,935 teaches a method of preparing a
 tube of thermoplastics material by using an
 annular die, a mandrel and a nip-roll, with
 one of the three parts rotating slowly, while
 the remaining two parts are kept stationary.
 The slow rotation of the one part may be
 alternately in opposite directions.

When the stretching or orientating opera-
 tion is carried out below a certain temperature,
 dependent on the particular polymer, an
 opaque film results owing to the formation of
 microvoids. If higher temperatures are used
 the formation microvoids will not occur. If a
 monaxially oriented tubular film is folded flat,
 cold stretched and then cut spirally, a sub-
 stantially monaxially oriented opaque film hav-
 ing the structure illustrated in Figure 1 of the
 accompanying drawing is obtained.

In Figure 1, numeral 1 indicates the direc-
 tion of orientation and numeral 2 the side
 folds of the originally folded tube. The side
 folds are parallel to the oblique orientation
 direction. With this structure periodic varia-
 tions occur in the final product and are caused
 by non uniform stretching at the edges of the
 laid flat film, and the fold creases formed as
 the tubing is collapsed by passing through the
 nip rollers. As a result the film thickness and
 impact strength in the region of the creases 2
 are different to the thickness and impact
 strength of the remainder of the film.

In accordance with the present invention
 there is provided a substantially monaxially

oriented tubular film tube or composite film tube of a thermoplastics material extruded through an annular die, wherein the direction of orientation within the tube follows a helical path, which is inclined to the axis of the tube at an angle of at least 10°.

These tubular films having a helical orientation are naturally transparent or translucent instead of opaque if prepared from a non pigmented resin.

In the manufacture of such films the stretching of the flattened tubular film downstream of the nip rolls can be eliminated and the fold creases formed by the nip rollers are at an angle to the orientation direction.

In accordance with another aspect of the invention there is provided a method of making the film comprising extruding a tubular film of thermoplastics material above its melting temperature through an annular film die, inflating the tubular film with a gas, radially supporting the tubular film with at least one cooled mandrel, partially cooling the film with a stream of gas directed against the external surface of the tubular film between the die and mandrel nearest thereto, collapsing the tube to flat form and hauling it off with a nip roll assembly, and rotating either the die or the nip roll assembly in a plane perpendicular to the

axis of extrusion, continuously in one direction at a constant speed relative to the other of the die or nip roll assembly, whereby the film is stretched helically and the direction of orientation is at an angle of at least 10° to the tube axis. The invention also provides apparatus for performing the method comprising die means for extruding a tube of thermoplastic material, means for maintaining sufficient gas pressure within said tube to prevent it collapsing, rotatable assembly for hauling off said tube, one or more mandrels including at least one rotatable mandrel, means for cooling the or at least one of the mandrels, and means for blowing gas on to the outer surface of the film between die and mandrel nearest to the die, the die means, the rotatable mandrel and haul-off assembly being rotatable in respective planes perpendicular to the axis of extrusion.

The films which are so-called helically stretched films, have a direction of orientation within the tube which follows a helical path and is inclined to the direction of scratch lines formed by contact of the polymer with the mandrels.

Several different apparatus arrangements may be used for manufacturing spirally stretched films and some possible variations of apparatus including upper and lower mandrels or a single mandrel are as follows:

Mark	I	II	III *
Nip rolls	Rotating	Stationary	Rotating
Upper mandrel	Rotating	Stationary	Stationary
Lower mandrel	Stationary	Rotating	Rotating
Die	Stationary	Rotating	Stationary
Mark	IV	V	VI
Nip rolls	Stationary	Rotating)	Rotating
Upper mandrel	Rotating	Rotating)	Rotating
Lower mandrel	Rotating	Rotating in opposite direction)	(only one mandrel present)
Die	Rotating	idem)	Stationary

By a rotating die it is meant a die rotating separately or in combination with a rotating extruder. Thus in the possible arrangement given above where the die rotates additional variations include a die non-rotatably attached to an extruder and both rotating as a single unit. Furthermore, it should be understood that the upper and/or lower mandrels can be supplemented by additional mandrels attached to the

upper mandrel or the lower mandrel, or the extruder assembly

) ' The die and lower mandrel together with a framework housing the nip rollers and upper mandrel rotate in one direction, whereas the nip rollers and upper mandrel rotate in the opposite direction within the framework.

* Nip roll assembly rotates in the direction

opposite to that in which the lower mandrel rotates.

Thermoplastic materials that can be extruded through an annular die are disclosed in "Plastic film technology" by W. R. R. Park, pages 21—22 (1969). Examples of said materials are polyethylene, polypropylene, vinyl polymers such as polyvinylchloride, polystyrene, polyvinylidene chloride, vinylchloride/vinylidenechloride, copolymers, superpolyamides, e.g. adipic acid-hexamethylene diamine condensation polymers and polyesters such as polyethylene terephthalate.

Obviously thermoplastic materials that can be extruded through an annular die may contain customary additives such as plasticizers, colouring materials, pigments, fillers, etc. It is also possible to use the above and other polymers so that the film is a combination of more than one polymer.

The preferred thermoplastic materials for making spirally oriented films are polyolefins.

No special requirements exist regarding the materials of which the mandrels are constructed and they may contact the film internally or externally.

The diameter of the mandrels is not critical, but from a practical point of view their size is related to the diameter of the die. Under certain conditions it is preferable to have two mandrels of the same diameter but this need not be the case.

Owing to shrinkage of the polymer as it cools resulting in frictional forces acting between the film and the mandrels, the mandrels having a slight taper can be used to advantage to reduce these forces. The surface roughness and individual contact lengths on the mandrels are arranged to give continuous production at the desired level of friction and cooling. The use of a knife edge at the bottom side of any mandrel may also be of advantage. Preferably the mandrel has a surface roughness of at least 5 micro inches CLA.

Cooling of the mandrels may be achieved by the normal method of passing water at the required temperature and at an appropriate rate through the mandrel system.

Slight creasing of the film during the deflation step may occur. Introducing a differential speed relationship between the elements can help to overcome this defect. In addition, creating a vacuum between the mandrels and the film or otherwise pressurising the film on to the mandrel can be used advantageously in combating this problem, as can gas pressure between the mandrel farthest from the die and the nip roll assembly.

The distance between the die and the lower mandrel is chosen in dependence upon their relative diameters for a given size and the desired physical properties of the product.

An air ring through which air is directed on

to the outer surface of the extrudate at a position between the die and the lowest mandrel partially cools the outer surface of the film, and gives additional stability to the process. The exact position of this air cooling will be chosen in dependence upon several factors, such as, melt temperature, type of material used, output rate of material, distance between the lower mandrel and the die, and the direction, velocity and volume of air discharged from the air ring.

Preferably, in addition to the air ring, gas, normally air, under controlled conditions, preferably fills all the spaces formed between the film and each two adjacent apparatus parts.

Means may be provided for reheating the film and may be advantageous since the stretching step can be performed in two stages, and additional heat may be required for bonding together opposite sides of the tubular film during production to form a double layer flat film.

The angle of orientation in the tubular material may be adjusted by changing the relative rotational speeds of the haul-off or nip rollers and rotating members of the system. Preferably the direction of orientation is about 45° to the fold lines of the flattened tube.

The method may be carried out by using known bonding techniques prior to wind-up and after slitting in a conventional lamination step so that the final hauled-off film is a cross-laminate ready for use.

The freeze line, that is, the region in which crystallisation occurs is preferably wholly on a mandrel or in a region between two adjacent mandrels.

The ultimate tensile strength (UTS) of the film increases, coupled with a reduction in the elongation, as the final film becomes thinner.

Increasing the volume of air cooling appears to slightly increase the UTS also.

An apparatus embodying the invention and incorporating a two mandrel system, is described below, by way of example, with reference to Figure 2 of the accompanying drawing which is an elevational view of the apparatus.

As shown in Figure 2 the apparatus comprises an annular film die 1, a mandrel support system 2, a lower mandrel 3, an upper mandrel 4, water and air services 5 passing through the die, mandrel water pipes 6, an internal heater 7, nip or hauling-off rollers 8, and an air-ring 10. The tubular film produced by the apparatus is designated with the numeral 9. The deflation system for deflating the tube is not shown in the drawing.

Examples of results obtained using the Mark I, III, IV and VI apparatus arrangements previously described as given in the following Table.

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Table of Examples

Apparatus	Mark I	Mark I	Mark I	Mark I	Mark I	Mark IV	Mark VI
Polymer	Polypropylene 1.	Polyethylene 3.	Polyethylene 2.	Polyethylene 2.	Polyethylene 2.	Polyethylene 2.	Polyethylene 2.
Output (kg/hr)	14	14	19	17	17	17	17
Diameter of mandrel(s)(mm)	76	178	102	102	102	178	178
Die to melt contact with mandrel (mm)	102	102	102	102	102	175	175
Distance between mandrels (mm)	10	10	10	10	10	N.A.	N.A.
Surface finish of mandrels CLA μ inches	30	25	25	25	25	25	25
Water flow rate to upper mandrel (1/hr)	136	230	230	230	230	230	230
Water flow rate to lower mandrel (1/hr)	136	180	180	180	180	N.A.	N.A.
Temperature of water supply to mandrels (°C)	17	17	16	20	17	20	20
Rotational speed of mandrel farthest from the die (r.p.m.)	48	0	65	0	59	53	53
Rotational speed of mandrel nearest to the die (r.p.m.)	0	45	0	14	5	absent	absent
Die rotational speed (r.p.m.)	0	0	0	0	59	0	0
Haul-off speed (m/min.)	20	10.8	21	22	19	24	24
Haul-off assembly rotational speed (r.p.m.)	48	34	65	24	0	43	43
Orientation angle (°)	30	60	45	19	45	45	45
Film thickness (μ m)	55	42	50	45	45	23	23

Table of Examples (Continued)

Apparatus	Mark I	Mark I	Mark I	Mark III	Mark IV	Mark VI
Polymer	Polypropylene 1.	Polyethylene 3.	Polyethylene 2.	Polyethylene 3.	Polyethylene 2.	Polyethylene 2.
U.T.S. MN/m ²	100	55	75	60	70	175
Elongation %	115	310	155	280	175	45

Notes: (i) In the above examples a 60 mm extruder fitted with a $3\frac{1}{2}$ in spiral fin die, of die gap 1.14 mm, was used. A conventional air-ring, fitted to the die was employed to give improved melt strength and stability to the polymer between the die and the mandrel system.

(ii) N.A. — not applicable.

1. Polypropylene MFI low load (2.16 kg) = 0.37 g/10 mins, high load (21.6 kg) = 66 g/10 mins, density = 905 kg/m³
2. Polyethylene MFI low load (2.16 kg) = 0.28 g/10 mins, high load (21.6 kg) = 18.3 g/10 mins, density = 960 kg/m³
3. Polyethylene MFI low load (2.16 kg) = 0.34 g/10 mins, high load (21.6 kg) = 20.5 g/10 mins, density = 959 kg/m³

The monaxially oriented film tubes may be bound internally in face to face engagement to form a double layer flat film by known methods, as disclosed for example in U.S. patents 3,342,657 and 3,576,935 and British patent 1,072,174. These include spot-welding, diff-welding, puncturing, hub-welding, crystal-welding and co-extrusion. When the collapsed tubes are bound together the direction of the orientation of one layer makes an angle with the direction of the orientation of the other layer. Preferably the lines of orientation of the two layers makes an angle to each other and the lines of orientation and the scratch lines in each layer defines an angle of 1—89°. It is

most preferred that the lines of orientation of the layers are at right angles to each other.

A helically stretched tubing produced using the Mark I system was laminated by the following technique:—A polyurethane 2-component adhesive system was introduced on to the inner surface of the tubing by conveying the adhesive through the mandrel system and spraying it on to the tube surface, whilst manufacturing the tubing. During the deflation and nipping stages the tubing was collapsed into flat form thus bringing opposite sides of the tube into contact one with the other. The final bonding stages were completed during storage of the flat tubing in reel form.

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**WHAT WE CLAIM IS:—**

1. A substantially monaxially oriented tubular film tube or composite film tube of a thermoplastics material extruded through an annular die, wherein the direction of orientation within the tube follows a helical path which is inclined to the axis of the tube at an angle of at least 10°.
2. A laminate formed by internally bonding together opposite side portions of a tubular film according to claim 1, in face to face contact whereby the orientation direction of one layer makes an angle with the orientation direction of the other layer.
3. A laminate formed from at least two substantially monaxially oriented layers of thermoplastics materials each extruded through an annular die, wherein the orientation directions of the layers are at an angle to each other, and the orientation direction of each layer and scratch lines formed in that layer by contact with a support mandrel during manufacture thereof are at an angle within the range of 1° to 89° to each other.
4. A laminate according to claim 2 or 3 wherein the orientation directions of two of the layers are at right angles to each other.
5. A method of manufacturing a substantially monaxially oriented film of thermoplastic material in accordance with claim 1, comprising extruding a tubular film of thermoplastics material above its melting temperature through an annular film die, inflating the tubular film with a gas, radially supporting the tubular film with at least one cooled mandrel, partially cooling the film with a stream of gas, directed against the external surface of the tubular film between the die and mandrel nearest thereto, collapsing the tube to flat form and hauling it off with a nip roll assembly and rotating either the die or the nip roll assembly in a plane perpendicular to the axis of extrusion, continuously in one direction at a constant speed relative to the other of the die or nip roll assembly, whereby the film is stretched helically and the direction of orientation is at an angle of at least 10° to the tube axis.
6. A method according to claim 5, wherein the film is supported by a single mandrel which is rotated in said one direction at a speed which is different to the speed at which the die or the nip roll assembly is rotated.
7. A method according to claim 5, wherein the tubular film is supported internally by two separate mandrels.
8. A method according to claim 5 to 7, wherein the film is a polyolefinic film.
9. A method according to claim 5, 7 or 8 wherein there are two or more mandrels, the nip roll assembly and the internal mandrel farthest from the die are rotated, and the internal mandrel nearest to the die and the die are kept stationary.
10. A method according to claim 5, 7 or 8 wherein there are two or more mandrels, the mandrel nearest to the die and the die are rotated and the nip roll assembly and the mandrel farthest from the die are kept stationary.
11. A method according to claim 5 or 7 wherein there are two or more mandrels, the mandrel nearest to the die and the nip roll assembly are rotated in opposite directions and the mandrel farthest from the die and the die are kept stationary.
12. A method according to claim 5, 7 or 8, wherein there are two or more mandrels, the mandrel farthest from the die, the mandrel nearest to the die, and the die are rotated and the nip roll assembly is kept stationary.
13. A method according to claim 5 or 7 or 8 wherein there are two or more mandrels, the nip roll assembly and the mandrel farthest from the die are rotated in one direction within a framework which is rotated in the opposite direction, and the mandrel nearest to the die and the die are rotated in the opposite direction.
14. A method according to any of claims 5 to 13 wherein at least one mandrel has a knife edge facing the die and has a surface roughness of at least 5 micro inches CLA.
15. A method according to claim 6, wherein the nip roll assembly is rotated and the die is kept stationary.
16. A method according to any of claims 5 or 7 to 14, wherein the mandrel nearest to the die and/or the mandrel farthest from the die are cooled.
17. A method according to any of claims 5 or 7 to 14, wherein air is blown on to the outer surface of the extrudate between the die and the mandrel nearest to the die through an air ring.
18. Apparatus for performing the method according to claim 5, comprising die means for extruding a tube of thermoplastic material, means for maintaining sufficient gas pressure within said tube to prevent it collapsing, rotatable assembly for hauling off said tube, one or more mandrels including at least one rotatable mandrel, means for cooling the, or at least one of the mandrels, and means for blowing gas to the outer surface of the film between die and mandrel nearest to the die, the die means, the rotatable mandrel and haul-off assembly being rotatable in respective planes perpendicular to the axis of extrusion.
19. Apparatus according to claim 18, including means for introducing gas into spaces defined within the tube and between spaced parts of the apparatus, and means for heating the inner surfaces of the tube.
20. A substantially monaxially oriented tubular thermoplastics film according to claim 1 and substantially as herein described.
21. A method of manufacturing monaxially oriented thermoplastics film substan-

tially as herein described.

22. Apparatus for making substantially mon-
axially oriented thermoplastics film substan-
tially as herein described with reference to
5 Fig. 2 of the accompanying drawing.

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