HMEL®

HMEL POLYSURE

TECHNICAL GUIDE TO

PP & HDPE Raffia Process

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INTRODUCTION

By definition, Raffia is a fibre made from palm leaves, which is used to manufacture mats and fabrics. Here we are describing the PP & HDPE Raffia process, which is basically an extrusion technique to manufacture synthetic stretched tapes from extruded film, using Polypropylene (PP) or High Density Polyethylene (HDPE) resin. Stretched tapes are prepared by uniaxial orientation with high width to-thickness ratio. These stretched tapes are subsequently used to manufacture woven raffia fabrics using Flat & Circular Looms.

These tapes can be converted into twines, ropes and woven knitted fabrics. Applications for stretched tapes have extended from woven sacks to tarpaulins, primary carpet backing, industrial fabric, geotextile fabrics, concrete reinforcement, etc. The woven fabric is used to produce various type of packaging bags / sacks, which are considered to be the toughest packaging bags. PP/HDPE woven sacks are often laminated to cater wider applications.

Raffia Attributes & Properties

Raffia bags have become popular for the following properties.

- Lightweight compared to conventional Jute / Cotton bags
- Higher Mechanical strength – more load bearing capacity
- Resistance towards Moisture, Fungal & Rotting attack
- Cost effective superior alternate packaging
- Longer Life because of inert nature
- Easily Recyclable & Reusable
- FDA Compliant

Overview of Raffia Process

Raffia process, which involves conversion of raw material into woven sacks or bags, includes tape manufacturing followed by fabric weaving. Woven fabric further goes for lamination. Laminated woven fabric undergoes printing, cutting and stitching. Below Figure depicts the process involved in raffia process.

- Tape Extrusion
- Weaving of Tapes
- Lamination (Optional)
- Finishing - Printing, Cutting, Stitching (Optional)

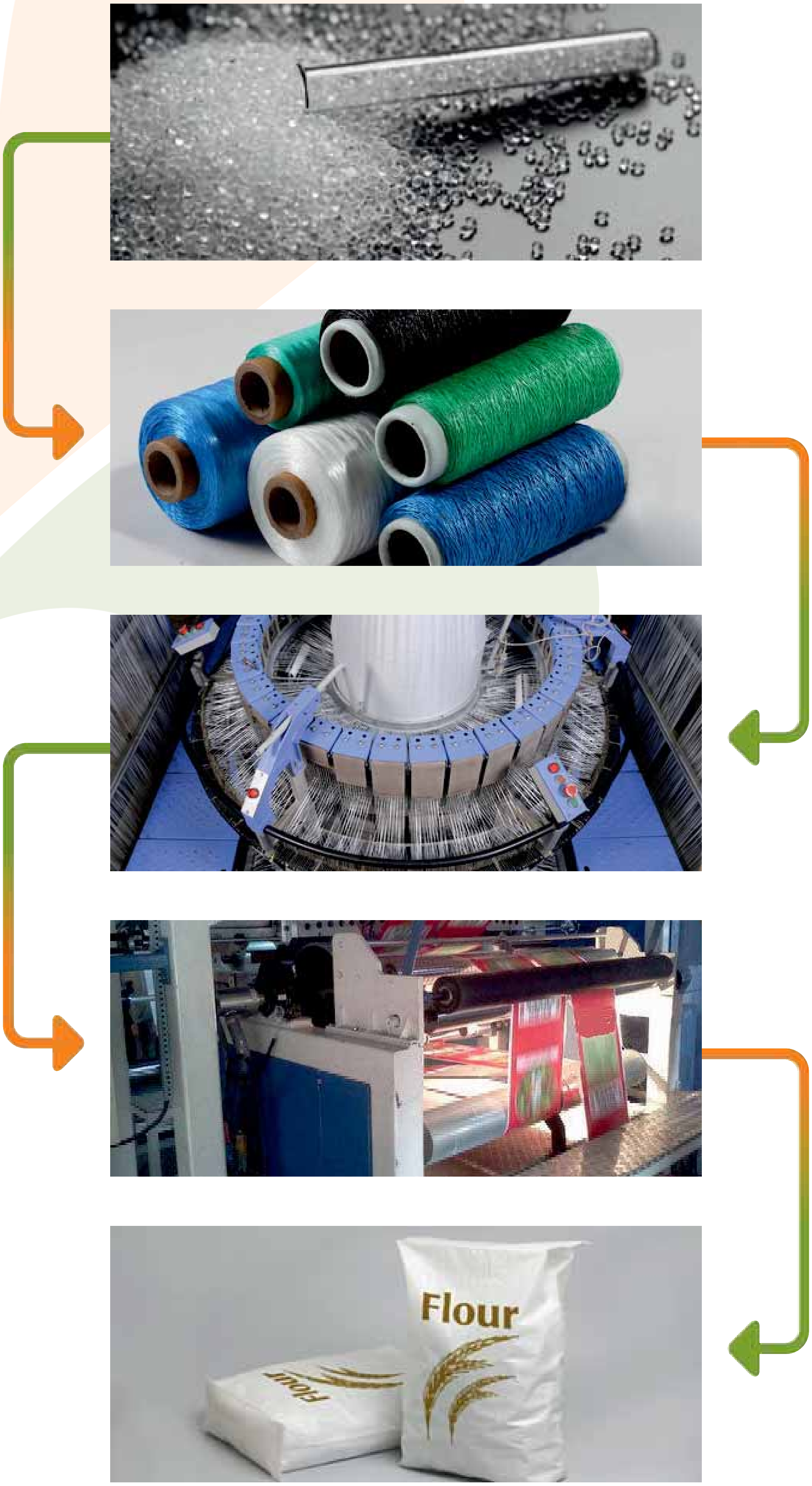

Fig. 1 – Steps involved in Raffia Product Manufacturing

A. Tape Extrusion Process

The tape extrusion technique for PP & HDPE raffia is almost similar in nature, except for the tape stretching mechanism. Tape manufacturing process involves multiple steps mentioned in Figure 2.

Fig 2. Steps involved in tape manufacturing process

Film Extrusion

The PP & HDPE resins are processed with required percentage of Filler / Color / Performance Masterbatches based on the end user application in Single Screw Extruder. There are few applications, where standalone resin is also processed. Typically, Screw diameter for PP extruder is 150 mm (Max) with output of 900 kg/ hour & screw diameter for HDPE Extruder is 120 mm (Max.) with output of 500 kg/ hour. Recently, there are few extruders available with universal screw, which is capable to process both PP & HDPE resin.

Fig 3. T Die Assembly

After passing the extruder barrel zone, the molten polymer is homogenised by melt pump followed by multiple screen pack, which are hold by breaker plate. Then the polymer mass is extruded by coat hanger die or T Die to produce a wide thin film, having typical width of 800 – 2000 mm depending upon the machine. The film thickness is maintained by adjusting the die bolt manually or automatically.

Film Quenching

Film produced after extrusion goes through quenching process inside the water bath and nip roll system. The gap between the die lip and the water surface is called air gap, which plays a critical role on tape properties. There will be a drop in film width in each side of the die because of stress relaxation, which is termed as neck-in. Higher the neck-in lower the film width. The suggested water temperature is 25 - 40°C & air gap 30 – 40 mm. For high output machines chillers are recommended whereas for lower output lines cooling towers are installed to ensure the supply of quench water. After quenching, the film is allowed to pass through multiple rolls & aspirator to remove water from the film surface. The surface finish of the roll is very critical for good film quality.

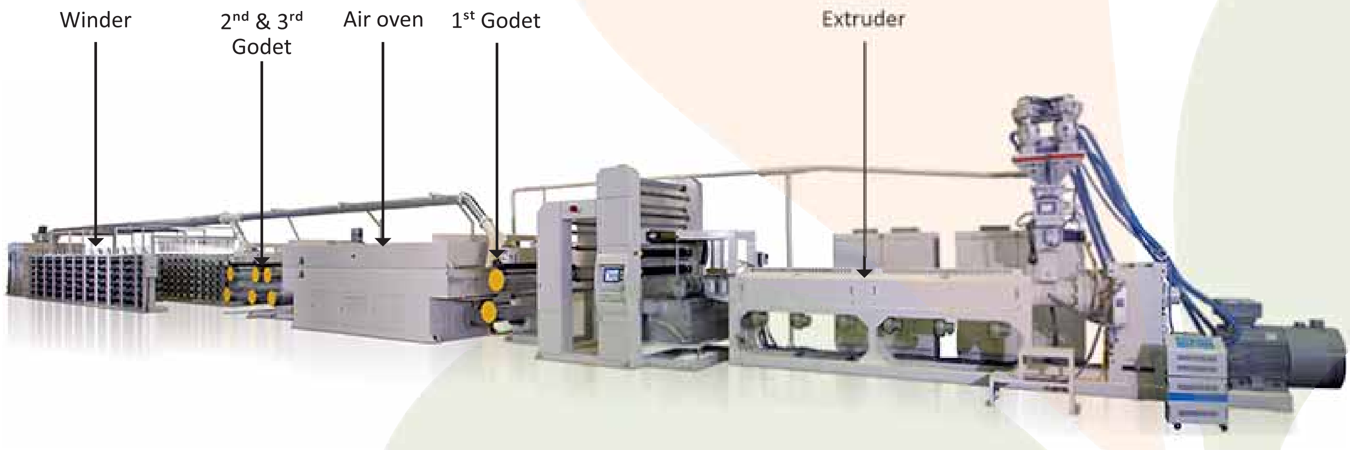

Fig 4. Raffia tape extrusion plant

Film Slitting

The film is slit into number of tapes by thin metal blades as per desired width depending on application. The blades are equally placed on a tie bar using spacers, which play a major role (Spacer Width) to achieve the final tape width. Slitting is done at an angle of 30-60° with the film. Spacer Width (SW) is a function of Stretch Ratio (SR) & Final Tape Width (A2) (SW=√SRxA2).

Edge Trim Recycling

After slitting operation, the tapes which are at the edges or sides have to be trimmed because of their dimension and thickness variations as compared to the other tapes in bulk. Edge or side trims are pneumatically conveyed to a large shredder and the ground flacks are conveyed to the extruder through a cyclone separator. Edge trimmers come after the first godet / holding unit and sucks the side / edge trims before the tapes enter the stretching stage.

Fig 5. Edge trim recycling unit

Stretching & Annealing of Tapes

This is the most critical part of the Raffia tape extrusion process because the final tape property is dependent on the extent of tape stretching. The tapes are softened by heating & stretched by increasing the rpm of multiple godets.

The tapes are heated and oriented in the machine direction by passing over the hot plate or through a hot air oven. In some process hot oil is circulated inside the godet for preheating purpose. For stretching of HDPE tapes, Hot Plate is recommended, which is electrically heated. Hot Air Oven is recommended for PP tapes stretching, where the hot air is circulated to maintain the uniform temperature. Length of heating system ranges from 4 m to 6 m.

The multiple roller systems are used for stretching the tapes. After slitting operation first two roller assembly is termed as the First Godet or the Holding Unit. Then tape passes through Hotplate / Hot air oven and finally allowed to pass through another roller system, called Second Godet or the Stretching Unit. The ratio of second godet to first godet's speed is called Stretch Ratio. The differential speeds, allow the tapes to get stretched to the required level and is controlled by the stretching temperature.

In Duotec Process (for PP tape extrusion only), another set of rollers are placed in between 1st godet and Hot air oven, where partial stretching is done. Final stretching is completed in Hot air oven, placed between 2nd & 3rd godet. Because of two step stretching, higher Stretch Ratio is maintained in Duotec process. Stepwise stretching also allows higher filler loading in the tapes without breakage or wastage.

Stretching tapes in presence of heat media results in molecular chain orientation & thus greatly increase the mechanical strength of tapes. Recommended stretching rate for PP is 5 - 8 times and temperature of 150°C -180 °C. For HDPE, stretching rate is 4 - 6 times and temperature of 120°C - 130°C.

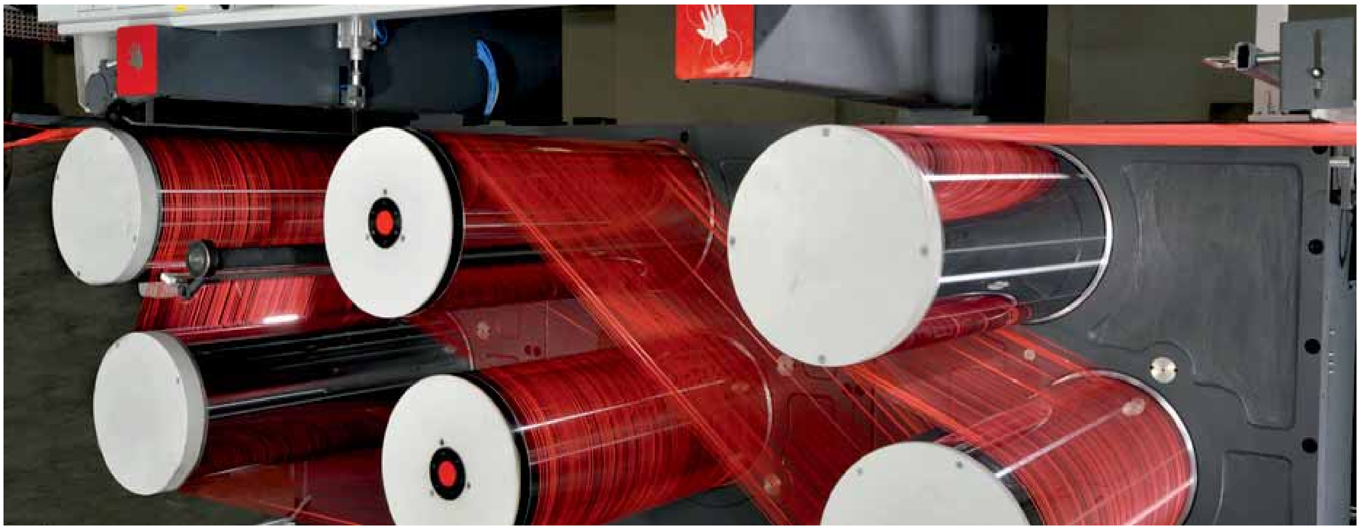

Fig 6. Raffia tape Annealing Process

Annealing of stretched tape is carried out to retain the orientation, reduce the shrinkage and to remove the residual stresses imparted during stretching process. Annealing is done by another set of roller, called 3rd Godet or the Annealing Unit, which is operated at a slightly lower speed (~5% lower) than the 2nd godet. The speed of the 3rd godet is called Line Speed of Raffia line. Typical line speed of raffia line is from 300 to 500 MPM (metres per minutes).

Tape Extraction Unit

Tape breakages happen primarily before stretching, after the tapes pass through 1st godet and after stretching, as they transit from the 2nd godet to the 3rd godet. These tapes have to be extracted or else they will interrupt the winding operation. This is done with help of a vacuum suction unit. The concept of combined vacuum suction box for first and discharge side of second godet is accomplished for power saving. The tape extraction unit with suction nozzle at the exit of the holding unit and of the annealing unit with piping up to the waste collection box and with mounted suction blower are generally provided as standard.

Fig 7. Tape Extraction Unit

Fibrillator – Optional Ancillary Unit

Fibrillated tapes are required for the production of high tenacity yarns used for the production of sewing/stitching threads and ropes. They are typically used to stitch or sew the handles of FIBC and jumbo bags. A Fibrillator Unit is used for the production of such tapes. Fibrillator unit is generally placed between the hot air oven and the combined stretching & annealing unit for production of fibrillated tapes. The needle roller has an independent drive. The needle bars of desired pitch can be user selected and are replaceable. The design also allows production of fibrillated and non-fibrillated tapes together.

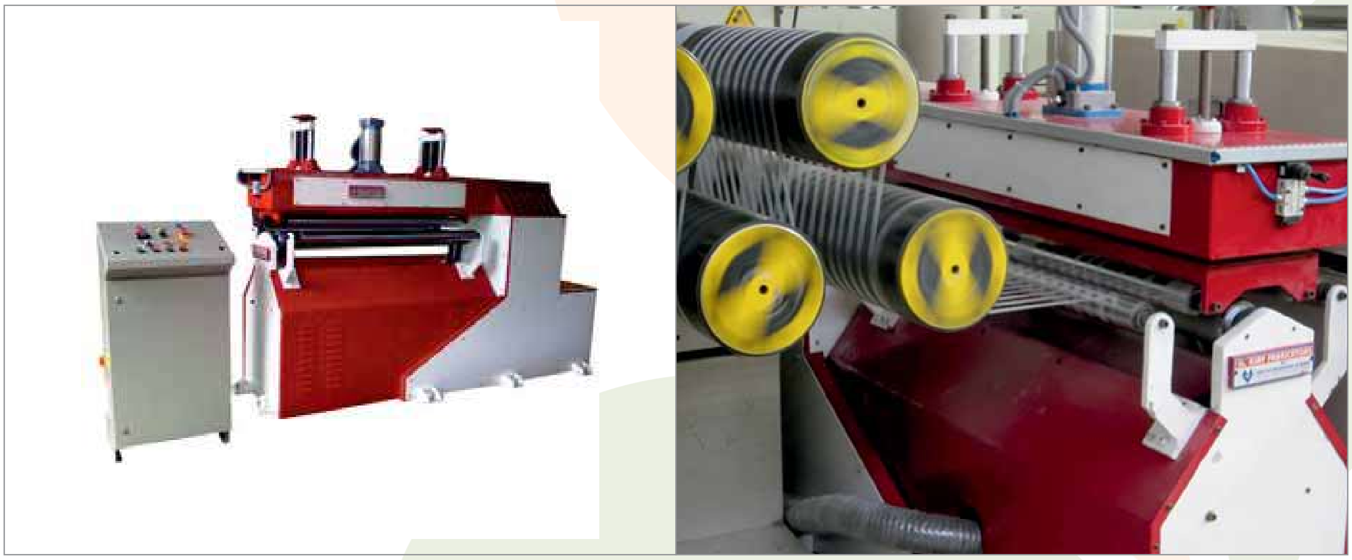

Fig 8. Fibrillator Unit

Tape Winding

Film tapes are wound upon tension controlled cross-winding heads with continuously variable speed adjustment. Perfectly wound tape bobbins are important to achieve high productivity at loom section. Tape-winding units are provided with three or four rows of winding heads called Cheese Winders and two winding frames, designated as LHS (Left Hand Side) and RHS (Right Hand Side), facing each other.

B. Weaving of Tapes

Weaving the tapes into a fabric is very much similar to the textile weaving operation. The flat tapes are weaved by circular or flat weaving machines, called "Looms" to prepare the fabric. In a loom, shuttles carry the thread of the weft yarn while warp direction yarns are fed by creels. Shuttles are thrown or passed back and forth through the shed, between the yarn threads of the warp, in order to weave in the weft direction. Looms are classified depending on the number of Shuttles being used.

Fig 9. Circular loom - weaving of tape into fabric

Typically, 4 shuttle looms are used for open mesh (leno weave) packaging fabric (fruits & vegetable); 6 shuttle for a vast range of packaging applications such as cement, fertilizer, polymer granules, chemicals, grains, animal feed, seeds and husk and 8 & 10 shuttle for the production of wide width fabric for Jumbo bags (FIBC's), tarpaulins and geotextiles.

C. Lamination of Fabric

This is an optional step for raffia process as it is not required for all types of end use applications. Lamination is the coating of thin thermoplastic film onto raffia substrate for enhancing the performance. Coating can be done on either one side or both sides of the raffia substrate. Coating on two sides of tubular fabric is done through turn bar arrangement. Lamination provides moisture barrier properties. Thickness of the coating film can be different based on end use requirements.

D. Finishing - Printing, Cutting, Stitching

This is also an optional step for Raffia process as it is not required for all types of end use applications. The laminated rolls of raffia fabrics are carried out for Printing, Cutting & Stitching operation as per requirement. This step involves converting the woven fabric into finished sacks / bags, used for packing industry

Application of Raffia Products

Plastic raffia or Woven sack sector is one of the key segments of plastics processing industries in India which contributes in the growth and consumption of commodity plastics like polyethylene (PE) & polypropylene (PP). The Plastic Woven sack industry can be classified into following major product packaging categories depending upon the end use applications.

Woven Sacks for Cement & Fertiliser

Sacks for Food Grain Packaging

Polymer Packaging Bags

Leno bags for fruit & vegetable packaging

Flexible Intermediate Bulk Containers (FIBC)

Tarpaulins of different types & applications

Wrapping fabrics for industrial uses

Geotextiles / agro-textiles applications

Other tailor made applications of woven fabrics in postal, parcel, courier applications etc.

Fig 10. Various applications of PP & HDPE Raffia

Resin Selection

Although both PP and HDPE can be used for manufacturing of stretched tapes but there are a number of factors which favours the selection of PP material over HDPE. PP is having the lowest density among most of synthetic polymers, which provides light weight products. Additionally, higher softening point of PP helps in hot filling of products (Cement Industry) in woven sacks. On the other hand, HDPE has superior weatherability compared to PP, which helps to cater specific application like Fertiliser bag which demand outdoor exposure for longer durations. However PP can be used for Fertiliser Bag application with the dosing of UV stabiliser.

Tape Extrusion Process demands following attributes

- Smooth processability & Higher Output
- Higher Filler intake & uniform dispersion
- Low water carryover from the water bath
- Higher Tenacity without sacrificing Elongation
- Low Fibrillation Tendency
- Longer Filter life

Resin Characteristics

- MFI Range: 2 to 4 (for PP) & 0.5 to 1.2 (for HDPE)
- Moderately broad molecular weight distribution
- Low water carryover in water bath quench
- Optimum Isotacticity Index for PP
- Very good thermal Stability
- Free of gels and fish eyes
- Good colour stability
- FDA Compliance

Polysure PP & HDPE Grade Offerings for Raffia Application

Polysure PP: R03RR & R03RR1 are Polypropylene homopolymer grades, produced by Latest Novolen Technology & Spheripol – II technology respectively. These grades are primarily suitable for tape extrusion process applications. R03RR & R03RR1 combines extremely low water carry-over with Exceptional processability, Good balance of tenacity & elongation for the production of tapes.

Polysure HDPE: R0150S & R0151D are High Density Polyethylene resin produced by Gas Phase Univation Technology & MarTECH Slurry Technology respectively. Both the grades exhibit the very good process ability & high tenacity without compromising the tape elongation.

Sector	Grade	MFI*	Density**	Typical Applications	Special Characteristics
Polysure PP	**R03RR / R03RR1**	**3.40**	**0.900**	Woven sacks for Cement, Food grain, Sugar packaging, Leno bags, Box Strapping, FIBC	Low Water Carryover & Excellent Tenacity
Polysure HDPE	**R0150S**	**1.00**	**0.950**	Raffia, Stretch tapes, Woven sacks, Tarpaulin	Good Processability & High Tenacity
	R0151D	**0.55**	**0.951**	Fertilizer bags, Food Grain bags, Tarpaulin, Wrapping fabric	Excellent Processability & High Tenacity

**MFI in g/10 as per ASTM D1238 **Density in g/cc as per ASTM D1505 at 23°C*

Table 1 – Polysure PP & HDPE grade offering

Properties of Polysure PP R03RR / R03RR1

Sl. No.	Property	Test Method	Unit	R03RR	R03RR1
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	3.5	3.4
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	35	35
3	Tensile Elongation at Yield, Type I Specimen		%	12	12
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1500	1550
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	40	40
6	Vicat Softening Point (10N)	ASTM D1525	°C	153	156
7	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	95	95

**All the mechanical properties are tested on Injection molded Test Specimen, prepared in accordance with ASTM D4101*

Table 2 – Polysure PP typical property offering

Properties of Polysure HDPE R0150S / R0151D

Sl. No.	Property	Test Method	Unit	R0150S	R0151D
1	Melt Flow Index (190°C & 2.16 kg)	ASTM D1238	g/10 min	1	0.55
2	Density (23°C)	ASTM D1505	g/cc	0.950	0.951
3	Tensile Strength at Yield, Type IV Specimen	ASTM D638	MPa	25	26
4	Tensile Strength at Break, Type IV Specimen		MPa	35	35
5	Tensile Elongation at Break, Type IV Specimen		%	1000	>800
6	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1200	1200
7	Notched Izod Impact Strength (23°C)	ASTM D256A	J/m	400	250
8	Vicat Softening Point (10N)	ASTM D1525	°C	123	-
9	ESCR (F50), 100% Igepal	ASTM D1693B	Hour	-	80

**All the mechanical properties are determined on Compression Molded Test Specimen, prepared in accordance with ASTM D4703*

Table 3 – Polysure HDPE typical property offering

Key attributes of Polysure PP & HDPE Grades

Preferred customers' Choice for smooth processing

Suitable for High line speed raffia applications

Higher Tape Tenacity & Elongation

Ability to take higher Filler content

Low water carryover

Processing Guidelines

Parameters for Polysure PP

- Barrel Temperature: 180 - 260°C
- Die Temperature: 250 - 270°C
- Quench Temperature: 30 - 40°C
- Oven Temperature: 155 - 160°C

Parameters for Polysure HDPE

- Barrel Temperature: 190 - 240°C
- Die Temperature: 220 - 240°C
- Quench Temperature: 25 - 30°C
- Hot Plate Temperature: 120 - 130°C

Storage & Handling

Bags should be stored in dry & dust free environment at temperature below 50ºC and Prevent from direct exposure to sunlight & heat to avoid quality deterioration.

Regulatory Requirements

Polysure Polypropylene grades are manufactured complying the requirements specified in IS 10910 on "Specification for Polypropylene & its Copolymers for safe use in contact with Foodstuff, Pharmaceutical & Drinking water". Furthermore, the Additives added in this grade formulation compiles to the "Positive list of constituents for Polypropylene, Polyethylene and their Copolymers for its safe use in contact with Foodstuffs & Pharmaceuticals' as laid down under IS 16738:2018. In general, the additives & constituents used in the grade are in line with requirement laid down under FDA: CFR Title 21,177.1520, Olefin Polymers.

Polysure Polyethylene grades are manufactured complying the requirements specified in IS 10146 on "Specification for Polyethylene for its safe in contact with Foodstuff, Pharmaceutical & Drinking water". Furthermore, the Additives added in this grade formulation compiles to the "Positive list of constituents for Polypropylene, Polyethylene and their Copolymers for its safe use in contact with Foodstuffs & Pharmaceuticals' as laid down under IS 16738:2018. In general, the additives & constituents used in the grade are in line with requirement laid down under FDA: CFR Title 21,177.1520, Olefin Polymers.

Effect of Resin Variable on Tape Properties

Effect of polymer variable on properties of Tapes are as below.

Sl.No.	Resin Properties	Indicator	Tape Property
1	**Molecular Weight** directly responsible for strength of polymer.		
1.1	Molecular Weight ↑	MFI ↓	Tenacity ↑ % Elongation ↑
1.2	Molecular Weight ↓	MFI ↑	Tenacity ↓ % Elongation ↓
2	**Molecular weight distribution** is a function of catalyst system and polymerisation process. Resin with broad MWD is easier to process due to more shear sensitivity than the one with narrow MWD.		
2.1	MWD (Broad)	FRR ↑	Processability↑
2.2	MWD (Narrow)	FRR ↓	Processability↓
3	**Stereo regularity** measured by Isotacticity		
3.1	Isotacticity ↑	Xylene solubility ↓	Tape strength ↑ % Elongation ↓
3.2	Isotacticity ↓	Xylene solubility ↑	Tape strength ↓ % Elongation ↑

Table 4 – Correlation between Resin & Product Property

Raffia Process Related Definition & Calculation

- **Tape Denier:** Weight of 9000 meter tape in Gram
- **Tape Dtex:** Weight of 10,000 meter tape in Gram
- **Tenacity:** Breaking Force in Gram of one Denier tape. Reported in GPD (Gram/denier) unit.
- **Spacer width:** Distance between two consecutive tape slitting blades. Reported in MM Unit.
- **Calculation of Tape Line Output:**
  No. of tape extruded in tape Plant = 243
  Tape Line Speed = 410 MPM
  Tape Denier = 800 g
  Tape Line Output = (Line Speed X No. of Tape X Denier X 2)/300000 Kg/Hour
  = (410 X 243 X 800 X 2)/300000 Kg/Hour
  = 531 Kg/Hour

Troubleshooting Guide for Raffia

Raffia Process is a complex phenomenon involving multiple steps. Many a times, Processing & Performance related difficulties are faced during manufacturing of Raffia tapes. Although these issues vary from machine to machine, but here the probable Cause and Remedy for few generic issues of Raffia process have been recommended.

PROBLEM	POSSIBLE CAUSES	TYPICAL SOLUTIONS
FILM PUNCTURE	■ Foreign Contamination ■ Unmelted / Degraded Polymer ■ Blister / Fish eye on Film	■ Change screen pack ■ Check heat stability of masterbatch ■ Adjust extrusion temperature profile ■ Check Raw Material Moisture
DENIER VARIATION	■ Extruder surging ■ Film thickness variation ■ Spacer thickness variation ■ Improper drive Performance	■ Regulate melt pump speed ■ Adjust the Die Bolt for uniform die gap ■ Check spacer & Blade thickness ■ Check uniformity of die temperature
TAPE BREAKAGE	■ Excessive stretch ratio ■ Low orientation temperature ■ Rough Film Surface ■ Extruder surging	■ Adjust stretch ratio ■ Increase orientation temperature ■ Die Lip Cleaning ■ Regulate Melt pump RPM
LOW TENACITY	■ Inadequate stretch ratio ■ Low orientation temperature ■ Too soft film	■ Increase stretch ratio & Oven temperature ■ Increase Air Gap ■ Decrease Processing temperature
TAPE FIBRILLATION	■ Tape is too stiff ■ Higher Stretching	■ Use anti fibrillation masterbatch ■ Adjust the Stretch ratio
SHRINKAGE IN FABRIC	■ Residual stress in tape ■ Lower delta in 2nd & 3rd godet RPM	■ Adjust the annealing godet RPM ■ Check cooling efficiency of roller
WATER CARRYOVER	■ Rough Film Surface ■ Faulty Additivities in Polymer	■ Reduce water bath temperature ■ Adjust processing temperature ■ Change Resin & Masterbatches

Table 5 – Troubleshooting solutions of Raffia process

Customer Services & Development Center

HMEL has chartered on a goal to emerge as a responsible player in the Petrochemical Industry. HMEL has set up a state-of-the-art Customer Services & Development Center (CSDC) at Noida to strengthen its customer value proposition through Research & Development.

HMEL's CSDC is equipped with sophisticated and advanced testing equipment and is aptly designed to have flexibility which allows diverse modes of testing. We are committed to produce consistent quality products in line with industry needs & always stand by our customers for all-round support for product, application and market development initiatives.

Accreditation of CSDC

- This center is accredited to **ISO/IEC 17025:2017** by National Accreditation Board for Testing and Calibration Laboratories (NABL), Govt. of India.
- Further, Customer Services & Development Center (CSDC), Noida has been recognized and registered as one of the key scientific and industrial R&D facility by **Department of Scientific & Industrial Research (DSIR),** Ministry of Science and Technology, Govt. of India.

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TECHNICAL GUIDE TO

High Density Polyethylene Monofilament Process

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INTRODUCTION

Monofilament yarn, as evident by its name, consist of a single solid filament. Monofilament yarns are usually circular and solid in cross section. The diameter range of monofilament yarns is in the range of 100–2000 µm. Monofilaments are used in woven / knitted fabric / nets & for synthetic rope used in fastening, greenhouses, orchards, fences, construction, animal husbandry, etc.

Monofilament is defined as a continuous strand of synthetic fibre produced in a melt spinning process. The polymer is melted in the extruder and conveyed under pressure to the spinning unit, then it is quenched, stretched and annealed to get the filament of enhanced properties.

Synthetic monofilament fabrics, because of their ductility and memory, may be flexed repeatedly without work hardening and fatigue. They may be folded or dented with less chance of damage compared with a metal cloth. They are also lighter in weight.

High Density Polyethylene, by virtue of its physical and chemical properties, are suitable to produce monofilaments catering to a wide variety of end use applications.

Monofilament Extrusion Process Description

Monofilament process involves multiple steps, which are described below.

A. Polymer Extrusion
B. Die Assembly
C. Quench Bath
D. Orientation
E. Winding

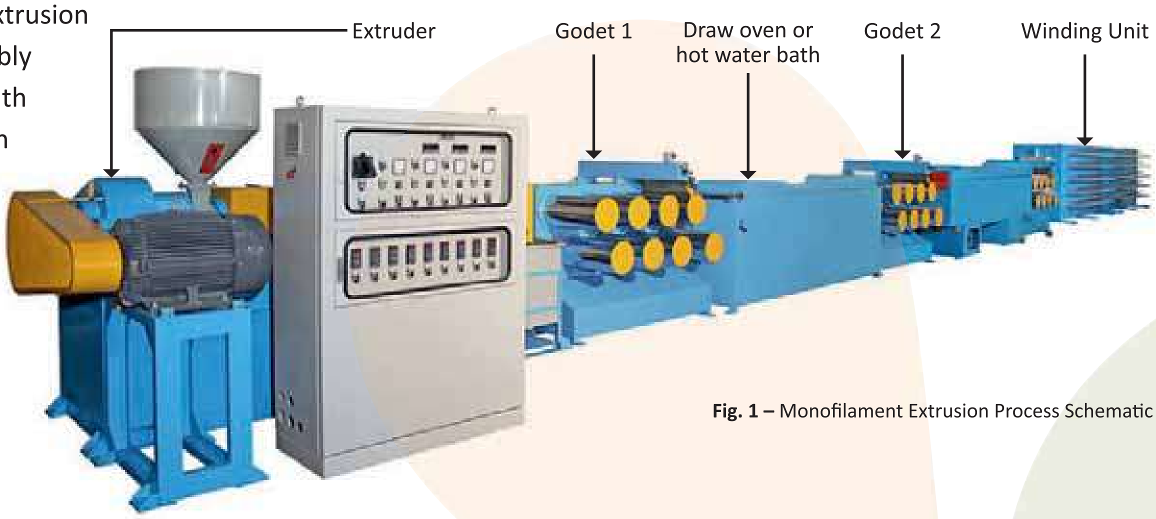

Fig. 1 – Monofilament Extrusion Process Schematic

A. Polymer Extrusion

Extrusion is the basic process for converting pelletized raw material into a homogeneous melt and delivered to a die, which extrudes a large number of monofilament yarns. The extruder consists essentially of a cylindrical heated barrel within which rotates a close-fitting Archimedean screw. The polyethylene pellets along with other required ingredients (color or performance enhancing additive masterbatches if any), are fed to one end of the screw from a feed-hopper and are forced forward by the rotating screw, being melted partly by heat conducted through the walls of the barrel from external band heater and partly by frictional heat generated by the shearing action of the screw.

The molten and compacted polymer is then forced through an annular die consisting of series of holes. The monofilaments are extruded downwards into a tank of water (quench tank) from which they go to pull-rolls to be drawn and oriented.

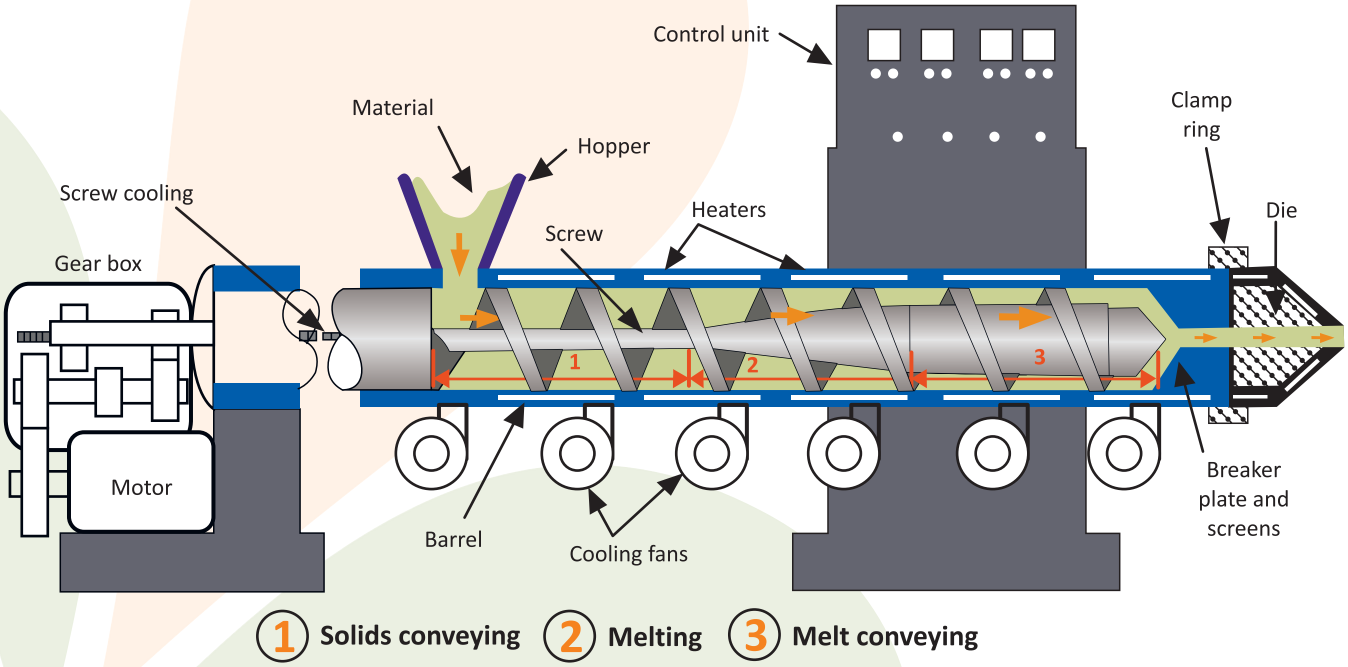

Fig. 2 – Single screw extruder

B. Die Assembly

Circular dies are used in monofilament extrusion to distribute the melt uniformly to the individual monofilament channels.

The die is positioned directly over the cooling tank, with the filaments flowing downwards into a quench bath. Uniform heating around the entire die, transfer pipes, and adapters is critical to guarantee uniform melt temperature and viscosity, resulting in consistent polymer flow out of each die hole.

Inside the die, there is a screen pack for filtering the melt and mixer plates to uniformly distribute the melt in the die. Screen packs use several layers of different mesh screens to filter contamination that might block the die hole or reduce the polymer flow through a particular die hole.

Fig. 3 – Monofilament die

In the melt phase, the polymer chains are initially arranged in a random or disordered state and the extrusion process through narrow die holes initiates orientation of the molten polymer chains in the extrusion direction. Die-land lengths tend to be two to five times the filament diameter.

C. Quench Bath

The quench tank water level is approximately one inch from the die exit, with essentially no draw between the die and the water level, other than to reduce the die swell. Filaments fall vertically to the bottom of the quench tank, where a cradle separates them. Each filament passes through the line as a discrete unit, never touching its neighbour. This requires each strand to have sufficient melt strength and strand integrity to be processed.

In monofilament process, the product diameter is very small with a large number of ends. Due to the small product diameter, cooling is accomplished very quickly in a small space. The material coming out from the die plate is cooled in the quenching bath. Its purpose is to cool the filament quickly to get a tougher molecular structure of smaller crystallites. The quenching bath temperature is maintained below the crystalline melting point of the material.

As the filaments exit the quench tank, they are pulled through a comb guide and across one or more vacuum strippers to remove surface water from the strand. Sponges and/or cloth might be used near the vacuum to help remove water. The filaments must be dry before they enter the drawing unit, as moisture interferes with uniform filament heating.

Fig. 4 – Quench Tank

D. Orientation of Filament

The filaments pass through one or more baths similar to quench tank and held at the orientation temperature. Drawing happens in the ovens between godet rolls. Some lines have two sets of godet rolls with one oven, while other lines have multiple sets of godet rolls and ovens. As the ovens and godet rolls increase, the line flexibility increases, providing capabilities of running more complex products under more stringent conditions with better control.

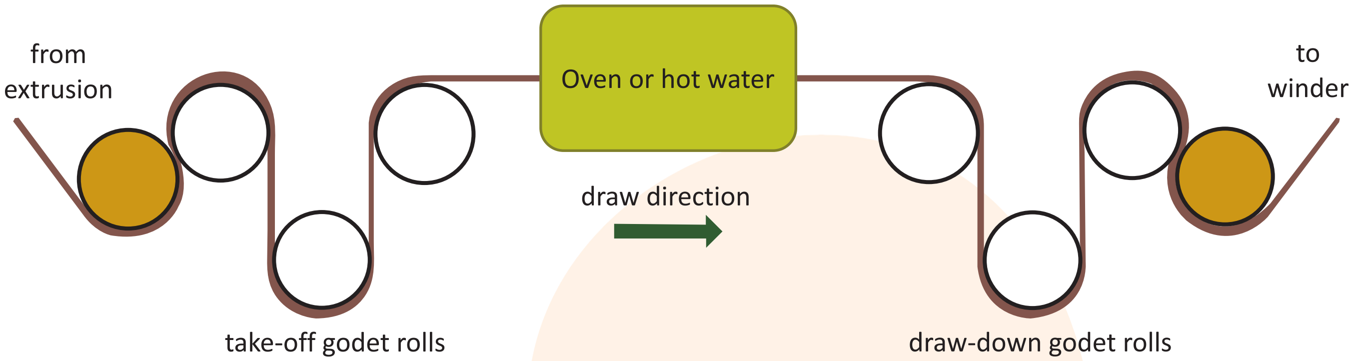

Fig. 5 – Filament drawing with stretch ratio

A speed difference between consecutive godet rolls draws the fibre, with the oven heat used to facilitate the drawing process. Usually there are two sets of large godet rolls, one on either end of the orientation stage. The stretching is done by running the second set of rolls much faster than the first. The stretch ratios range from 2:1 to 12: 1. The first and second rolls are used for stretching the filaments.

Drawing or pulling the extruded monofilament further orients the polymer chains in the machine direction resulting in closer packing of polymer chains within the fibre applying heat. During the drawing process polymer chain mobility increases, and the fibres are easier to draw. Continuous drawing through the process reduces the diameter. Obviously, the die is designed to provide the correct final filament diameter based on the draw ratio required to provide the desired filament performance.

Monofilaments are subjected to heat setting to stabilise the orientation and residual stresses, which lead to shrinkage. Godet rolls are normally heated to facilitate the stretching and annealing process, which allows the filament to relax at high temperature. Godet rolls can be used in an extensive range of combinations, set-ups, and other arrangements to precisely control phases of the drawing process.

E. Winding

After the filaments are drawn, the product filaments wound onto individual spools or bobbins where they are used directly or combined to produce different products such as ropes, fishing net, mosquito nets, etc. In some cases, bunch of monofilaments are wound as a bundle which are subsequently unwound to single filament for further processing.

Fig. 6 – Filament Winding Unit

Monofilament Advantages Over Multifilaments

- Smooth surface
- No capillary action on thread
- Great stiffness and durability
- Less tissue drag than multifilament
- Do not have interstices that may harbour bacteria
- The process is more simple as compared to multifilament process

Monofilament Resin Selection

One of the best aspects of Monofilament process is its versatility. Many polymers (Nylon, PP, PE, PVC etc.) are used in monofilament processing. Each material has applications and functions for which it works best.

High Density Polyethylene (HDPE) is the most common commodity polymer used for various monofilament applications like artificial grass, fishing twine, mosquito nets, ropes, etc. The pre requisites for making strong high density polyethylene fibres are long molecular chain which can provide sufficient cohesive forces when stretched, oriented and crystallized, during conversion of the initial undrawn filament in whatever form to fully drawn yarn. PP is also used in monofilament processing for various applications.

The most important advantages of HDPE in monofilament applications are as follows:

- **Rot-resistance:** Seawater, acids, alkalis and other materials commonly encountered in use have no deleterious effects on polyethylene fibres.
- **Resilience:** High density polyethylene fibres are very resilient and easy to use. They do not harden when wet, nor do they freeze or harden even in the most severe weather conditions.
- **Abrasion resistance:** Abrasion resistance of high density polyethylene fibres is good and they are very durable.
- **Coloration:** The light and wash fastness of the color on HDPE monofilament are very high.

- **Dimensional stability:** High Density Polyethylene nets do not shrink on immersion in water. They retain their shape and mesh size.
- **Cleanliness:** High Density Polyethylene filaments are smooth-surfaced and do not cling to sand particles, marine growth and other unwanted materials.
- **Resistance to extreme cold:** High Density Polyethylene retains its flexibility at very low temperatures and does not become rigid under freezing conditions. The wet knot strength of twines increases as the temperature decreases.

Effect of Resin Variables on Monofilament Process

Sl.No.	Resin Properties	Indicator	Monofilament Product Properties
1	**Molecular Weight** impacts mechanical, environmental resistance and processing of polymer.		
1.1	Molecular Weight ↑	MFI ↓	Die Swell ↑ ESCR ↑ Tenacity ↑
1.2	Molecular Weight ↓	MFI ↑	Die Swell ↓ ESCR ↓ Tenacity ↓
2	**Molecular weight distribution** is a function of catalyst system and polymerisation process. PE with broad MWD is easier to process due to more shear sensitivity than the one with narrow MWD.		
2.1	MWD (Broad)	FRR ↑	Processability ↑ ESCR ↑
2.2	MWD (Narrow)	FRR ↓	Processability ↓ ESCR ↓
3	**Density of polyethylene** determines various filament properties		
3.1	Density ↑	Melting point ↑	Stiffness ↑ Resistance to Creep ↑ ESCR ↓
3.2	Density ↓	Melting point ↓	Stiffness ↓ Resistance to Creep ↓ ESCR ↑

Table 1 – Correlation between resin & Monofilament property

Polysure HDPE Grade Offerings for Monofilament Sector

Polysure HDPE

Polysure Y0154S High Density Polyethylene grade is produced by HDPE Univation gas phase technology & primarily designed for monofilament extrusion process.

Y0154S grade combines exceptional processability with high mechanical & thermal stability with excellent elongation properties.

Product	Grade	MFI*	Density**	Typical Applications	Special Characteristics
Polysure HDPE	**Y0154S**	**1.0**	**0.954**	Yarn, Monofilament for Nets, Twines, Ropes	Excellent Spin-ability & Low Die Build-up

** MFI in g/10 min as per ASTM D1238 ** Density in g/cc as per ASTM D1505*

Table 2 – Characteristics of Polysure HDPE Monofilament Grade

Typical Properties of Polysure HDPE Y0154S

Sl. No	Property	Test Method	Unit	Y0154S
1	Melt Flow Index (190°C & 2.16 kg)	ASTM D1238	g/10 min	1
2	Density (23°C)	ASTM D1505	g/cc	0.954
3	Tensile Strength at Yield, Type IV Specimen	ASTM D638	MPa	26
4	Tensile Strength at Break, Type IV Specimen		MPa	35
5	Tensile Elongation at Break, Type IV Specimen		%	900
6	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1250
7	Notched Izod Impact Strength (23°C)	ASTM D256A	J/m	500
8	Vicat Softening Point (10N)	ASTM D1525	°C	123

**All the mechanical properties are determined on Compression Molded Test Specimen, prepared in accordance with ASTM D4703*

Table 3 – Properties of Polysure HDPE Monofilament Grade

Processing Guidelines

- Barrel Temperature : 190 - 240°C
- Die Temperature : 220 - 240°C
- Quench Temperature : 25 - 30°C

Storage & Handling

Bags should be stored in dry & dust free environment at temperature below 50ºC and be prevent from direct exposure to sunlight & heat to avoid quality deterioration.

Regulatory Requirements

Polysure Polyethylene grades are manufactured complying the requirements specified in IS 10146 on "Specification for Polyethylene for its safe in contact with Foodstuff, Pharmaceutical & Drinking water". Furthermore, the Additives added in this grade formulation compiles to the "Positive list of constituents for Polypropylene, Polyethylene and their Copolymers for its safe use in contact with Foodstuffs & Pharmaceuticals' as laid down under IS 16738:2018. In general, the additives & constituents used in the grade are in line with requirement laid down under FDA: CFR Title 21,177.1520, Olefin Polymers.

Applications of HDPE Monofilament Products

HDPE monofilaments are used in many applications. Like fishing and aquaculture, shade net, geotextiles construction industries etc.

Fig. 7 - HDPE Monofilament Products

Troubleshooting Guide for Monofilament Process

Many a times, we face processing & performance related difficulties during manufacturing of monofilament. Although these issues may vary from machine to machine, but most of them can be addressed easily with proper selection of resin or little adjustment in operating parameters. The probable cause and remedy for few generic issues arise during monofilament process are recommended here.

PROBLEM	POSSIBLE CAUSES	TYPICAL SOLUTIONS
LOW TENACITY	■ Low orientation	■ Increase stretch ratio ■ Use proper orientation temperature.
FILAMENT DIAMETER VARIATION	■ Surging in extruder ■ Draw down variation	■ Run extruder at high pressure, check smoothness of all moving parts ■ Adjust whole system in terms of drawing
FILAMENT BREAKAGE	■ Melt temperature too high or low ■ Draw down variation ■ Moisture in material ■ Contamination ■ Die build up	■ Adjust extruder temperatures ■ Slow down the system ■ Use a hopper dryer ■ Change screen pack ■ Clean the die and lower the temperature
POOR FILAMENT SURFACE	■ Presence of moisture ■ Melt fracture	■ Dry the material ■ Reduce the linear speed or use lower viscosity material

Table 4 – Troubleshooting solutions for Monofilament Process

Monofilament Plant

Customer Services & Development Center

H**MEL** has chartered on a goal to emerge as a responsible player in the Petrochemical Industry. HMEL has set up a state-of-the-art Customer Services & Development Center (CSDC) at Noida to strengthen its customer value proposition through Research & Development.

HMEL's CSDC is equipped with sophisticated and advanced testing equipment and is aptly designed to have flexibility which allows diverse modes of testing. We are committed to produce consistent quality products in line with industry needs & always stand by our customers for all-round support for product, application and market development initiatives.

Accreditation of CSDC

- This center is accredited to **ISO/IEC 17025:2017** by National Accreditation Board for Testing and Calibration Laboratories (NABL), Govt. of India.
- Further, Customer Services & Development Center (CSDC), Noida has been recognized and registered as one of the key scientific and industrial R&D facility by **Department of Scientific & Industrial Research (DSIR),** Ministry of Science and Technology, Govt. of India.

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