TECHNICAL GUIDE TO

Injection Molding

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INTRODUCTION

Injection molding is one of the most widely used process for converting thermoplastic materials into finished products. The molding process requires an injection molding machine, polymer resin and a mold. The resin is melted in the barrel and then injected into the mold, where it cools and solidifies into the final products. In our day to day life, we can see many products manufactured by this process starting from components used in household appliances, consumer electronics to automotive applications. Many medical devices, including valves and syringes, are manufactured using injection molding as well.

Injection Molding Process

An injection molding machine consists of two units, the injection unit and the clamping unit. In injection unit, a solid polymer is plasticated by applying both temperature and frictional heat as developed during movement of the reciprocating screw. The molten polymer is then injected into the mold through a nozzle to form finished part. In clamping unit, the molds can be placed either in vertical or horizontal position depending on the size or type of application required. Depending on the nature of the polymer being molded, cold or hot runner systems can be chosen for carrying the molten polymer into the mold cavities.

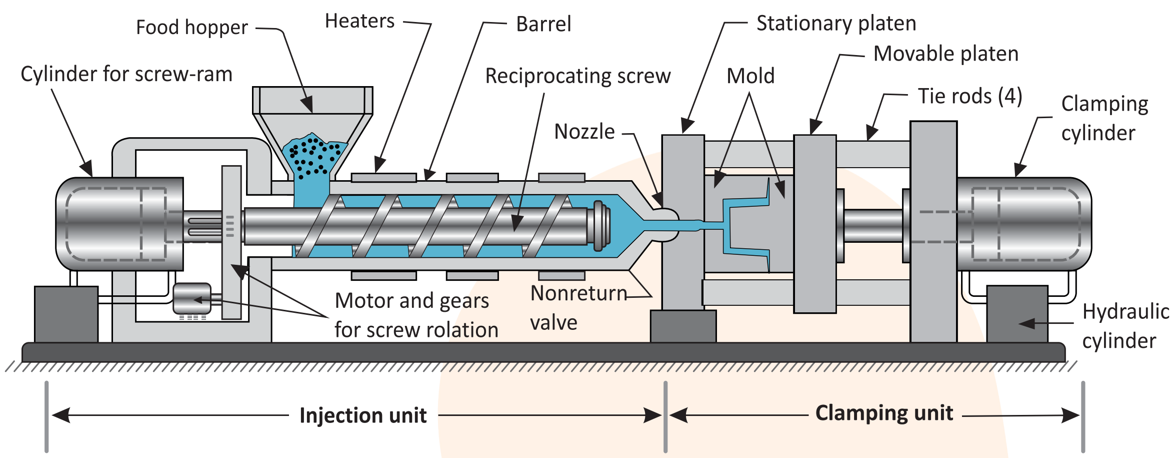

Fig. 1 – Injection Molding Machine

Types of Injection Molding Machine

The injection molding machines are classified by the type of driving system used. Below are the different types of Injection Molding Machine, used in industry.

- **Hydraulic:** Injection molding driving system is based upon hydraulic principle
- **Mechanical:** This type machines use the toggle system for building up tonnage on the clamp side of the machine
- **Electric:** All the machine movement like screw, barrel, tonnage build up done by electric power
- **Hybrid:** This type Injection molding machines claim to take advantage of the best features of both hydraulic and electric systems

Injection Molding Steps

Although injection molding process seems to be quite simple at first sight, there are overall seven steps involved.

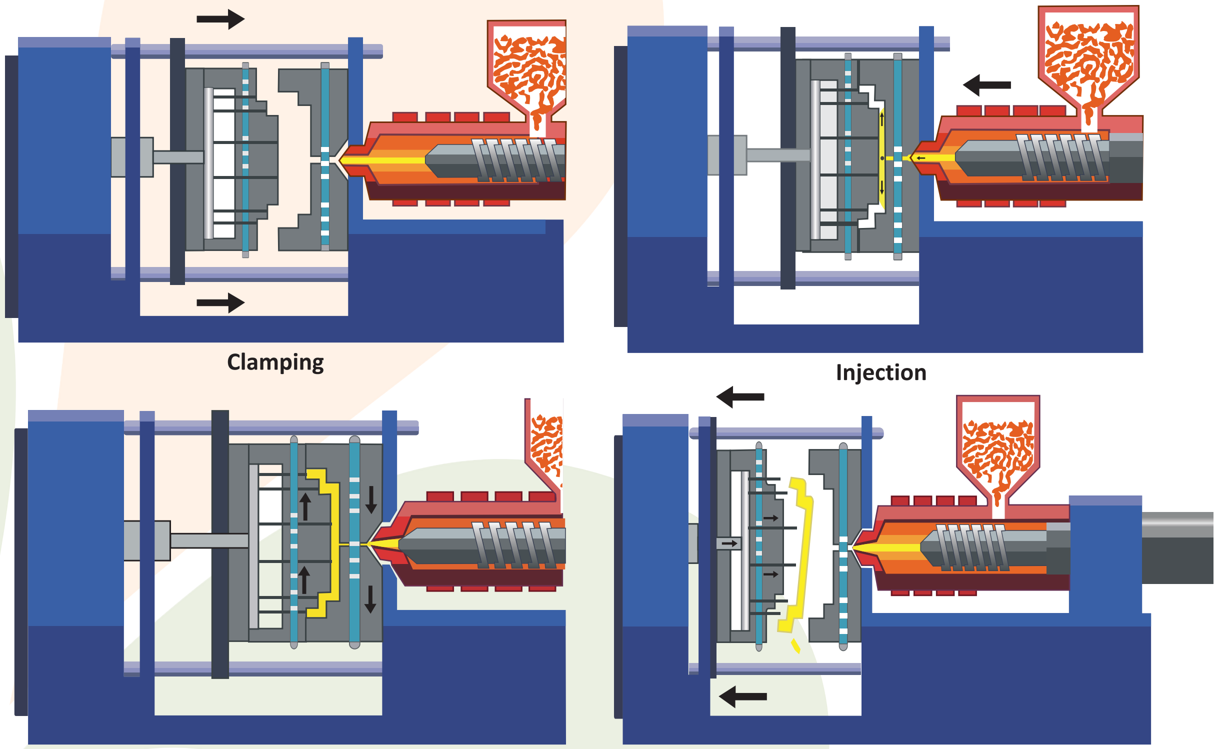

Fig. 2 – Injection Molding Steps

- **Clamping –** The clamping unit consists of one stationary and one movable metal plate. The mold is fixed between these plates. The movable plate helps to close and open the mold. The process begins with the mold being clamped together under pressure to accommodate the injection and cooling processes.
- **Feeding –** Plastic granules are fed into the pre-heated barrel. The plastic granules are melted, mixed and conveyed forward with the reciprocated screw and accumulated before the nozzle for subsequent step.
- **Injection –** The molten polymer inside the barrel of the machine is injected under pressure into the mold through sprue, runners and gates.

  Sprue: A sprue is a channel which transfers the molten plastics injected from the injector nozzle into the mold. There are two types of Sprue – Hot Sprue & Cold Sprue.

  Runner: A runner is a channel that guides molten plastics into the cavity of a mold. Two types of runners are used in mold for injection molding process. (1) Cold Runner Mold used for small types of products, this molds are easy to produce in low cost. (2) Hot Runner Mold is used where no temperature drop is allowed during processing, which helps in faster cycle time. As far as the shape is concerned, the runner can be Full Round, Trapezoidal or Half Round.

  Gate: Gate is an entrance through which molten plastics enters the mold cavity. In Hot Runner Mold, gates are Open Gate & Valve Gate type. In Cold Runner system, gates are Edge Gate, Fan Gate, Tunnel Gate and Diaphragm Gate.
- **Dwelling –** Once the molten polymer is injected into the mold, more pressure is exerted to ensure all mold cavities are filled. Mold is an arrangement, in one assembly, of one (or number of) hollow cavity spaces, built to shape of the desired product.
- **Mold Cooling –** The molten polymer inside the mold gets cooled and solidified by circulating cooling agent like water across the mold.
- **Mold Opening –** The movable plate is separated from the fixed plate to separate the two parts of the mold.
- **Ejection –** The molded component is ejected from the mold by using ejector pins.

The entire injection molding process is the combination of above steps as described. The total time required to complete all the stages of the injection molding cycle from mold closure to ejection is called Cycle Time. Cycle time in injection molding process is very important as the rate of production and the quality of the parts produced depend on it.

Typical Example of Cycle time:

1. Mold Closing Time – 7.8%
2. Fill Time – 2.0%
3. Pack & Hold Time – 13.1%
4. Cooling & Recovery Time – 65.4%
5. Mold Opening Time – 7.8%
6. Ejection Time – 3.9%

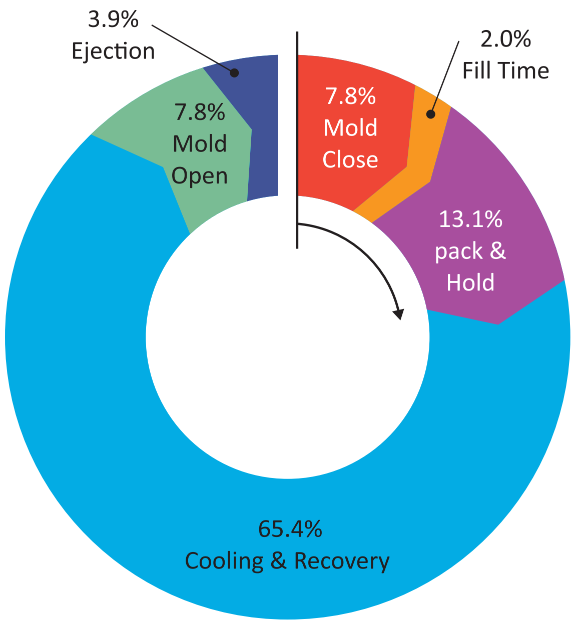

Fig. 3 – Injection Molding - Cycle Time

Injection Molding Important Variables

- **Injection Pressure:** The pressure by which reciprocating screw injects polymer melt into the closed mold
- **Holding Pressure:** The pressure applied on molten polymer inside the mold.
- **Clamping Pressure:** Force needed to hold the mold closed during injection
- **Back Pressure:** Back pressure is created by the molten polymer during the return action of the screw after injecting the material.
- **Injection Time:** It is the time, the molten polymer takes to fill the mold completely.
- **Cooling Time:** The time required for the molten resin to cool and solidify inside the mold.
- **Shot Weight:** The mass of polymer delivered in one complete filling of mold which is the combined mass of molded parts, sprue, runners, and flash.
- **Melt Cushion:** The polymer melt residing at the front of reciprocating screw when it is in forward position

Injection Molding Parameters & Their Significance

Processing Temperature

The barrel temperature should be 10-20°C higher than the minimum temperature required to fill the mold but it should not exceed the resin degradation temperature. Temperature for feed section should be at least 10°C less than the nozzle temperature. For better mixing, bell-shaped temperature profile is recommended, indicating that feed zone and front zone temperatures are lower than the center zone. Too high barrel temperature can lead to problems like flashing, shrinkage and void formation. Too low or too high temperatures can cause brittle parts, promote flow marks, weld lines, poor surface finish, lamination, and short shots.

Injection Pressure

Injection pressure with 75% of machine capacity gives best results. Although, the highest pressure and fastest fill rate are the best condition, but it should be appropriate for proper filling of the mold cavity and to avoid problems with shrinkage, voids & pigment dispersion. In case of semi-crystalline polymers, high injection pressure tends to minimize mold shrinkage. However, very high pressure is responsible for flash, mold sticking, mold-in stress and can even damage the expensive mold.

Injection Speed

Injection speed greatly influences the degree of molecular orientation in the molded component which shows impact on the mold shrinkage and weld line development. Higher injection speed improves the surface quality like high gloss and weld-line strength of the molded part. However, very high speed causes excessive temperature rise in the gate location resulting decomposition of the polymer.

Injection Time

Injection time should be always more than gate sealing time which is the time taken by the resin to solidify at gate location. If injection pressure is withdrawn before gate is sealed, the molten resin will flow back from the gate causing issues like warpage, sink marks and void problems.

Mold Temperature

Too high mold temperature can cause shrinkage, warpage, sink marks and cavity sticking problems. Mold cooling should be uniform as differential cooling can result to part warpage. Relatively higher mold shrinkage occurs in case of semi-crystalline polymers and it depends on factors like barrel temperature, mold temperature, injection pressure, injection speed, injection time and molded product thickness. Molded product with higher thickness shows higher shrinkage due to cooling pattern difference in skin and core region.

Back Pressure

Back pressure is required to ensure consistency in shot of the material, better melt homogeneity, better filling of the screw flights to prevent black specks and degradation. It also removes internal bubbles, improve gloss and shrinkage of the surface. Minimal back pressure should be applied and it should not go beyond 20% of the maximum injection molding pressure or as recommended by the OEM. Higher back pressure can only be used in case of pigment mixing or required melting due to shear. However, higher back pressure can also lead to fibre breakage in reinforced resins, degradation of polymers like PVC and acetal.

Cooling Temperature & Time

The molded component should be cooled to the point at which it retains its shape and can be safely ejected from the mold. Any further cooling will only lead to unnecessary cycle time enhancement. Improper or insufficient cooling time can lead to part defects like shrinkage, warpage and sink marks.

Mold Venting

Mold Venting is the release of excess mold pressure. This is an essential step in Injection molding process, otherwise it causes burning of material with compressed air. Below are the typical calculations of huge pressure generation if mold venting is not done.

Cavity space (V1) = 100 cc; Atmospheric Pressure (P1) = 1atm; Compressed air Volume after Mold Filling (V2) = 1 cc (Say); Inside air must be allowed to escape to fill the whole space by inrushing plastic

As per theory of P1 X V1 = P2 X V2, Pressure of compressed air = 100 atm

Hence to avoid huge pressure (100 atm) generation mold venting is essential.

Injection Molding Attributes

Injection molding process have several advantages like:

- Versatility in processing different raw materials with various product Color & Surface
- Faster production with higher efficiency & Low rejection rate – Less wastage
- Capable to design complex part with accuracy in weight of articles
- Option in article sizes by changing the mold
- Choice of ultimate strength of articles
- Stability of processing parameters
- Minimum post molding operations

Effect of Resin Variables on Injection Molded Product Performance

Effects of various inherent properties of resins on molded product performances are summarized below.

Sl.No.	Resin Properties	Indicator	Product Property
1	**Molecular Weight is directly responsible for strength of polymer.**		
1.1	Molecular Weight ↑	MFI ↓	Strength ↑
1.2	Molecular Weight ↓	MFI ↑	Strength ↓
2	**Molecular weight distribution** is a function of catalyst system and polymerisation process. PP and PE with broad MWD is easier to process due to more shear sensitivity than the one with narrow MWD.		
2.1	MWD (Broad)	FRR ↑	Not preferred for IM process
2.2	MWD (Narrow)	FRR ↓	Warpage ↓ Dimensional Stability ↑
3	**Stereo regularity** measured by Isotacticity		
3.1	Isotacticity ↑	Xylene solubility ↓	Stiffness ↑ Impact Strength ↓
3.2	Isotacticity ↓	Xylene solubility ↑	Stiffness ↓ Impact Strength ↑

Table 1 – Correlation between Resin and Product Property

Polysure PP, HDPE & LLDPE Grade Offerings for Injection Molding Application

Polysure PP

HMEL Polysure PP grades serves the injection moulding sector with complete range of grades starting from 12 MFI to 65 MFI in Homopolymer sectors for various applications like general purpose IM, furniture, housewares, TWIM, high clarity containers including medical syringe application. Polysure PP Homopolymer grades are produced by both Novolen Technology & LyondellBasell Spheripol – II technology and offer several advantages to the producers' w.r.t excellent processability, aesthetics, low warpage, higher productivity etc.

Whereas in case of Polysure PP Copolymer, the presence is from 3 MFI to 65 MFI for various application of automotive, battery, housewares, appliances, furniture, luggage, TWIM including high end medical syringe application. All the copolymers grades are produced by LyondellBasell Spheripol – II technology which offers several advantages to the producers' w.r.t excellent processability, optimum stiffness - impact balance, aesthetics, low warpage, higher productivity etc.

HMEL Polysure PP Grade Basket

Grade	MFI*	Typical Applications	Special Characteristics
Polysure PP – Homopolymer			
M12RR / M12RR1	12.0	General Purpose IM, Closures, Furniture, Houseware, Toys	Good Aesthetics & Low Warpage
M18NH / M18NH1	18.0	Thin Wall Injection Molded Containers, Household items	Low Cycle Time & Good Stiffness
M20CR / M20CR1	20.0	Medical Syringes, High Clarity Consumer Products	Low Cycle Time & Good Clarity
M50NR / M50NR1	50.0	TWIM, Housewares, Compounding	Smooth Processing & Low Cycle Time
M65NR /M65NR1	65.0	Multi cavity Molding, TWIM, Housewares, Compounding	Excellent Flowability & Low Cycle Time
Polysure PP - Random Copolymer			
RM12CR	12.0	High Clarity Containers, Laboratory Products, ISBM Bottles	Low Cycle Time, Excellent Clarity & Stiffness
RM30CR	30.0	High Clarity Consumer Products, ISBM bottles, Medical Applications	Excellent Clarity with Antistatic Additive
Polysure PP - Impact Copolymer			
CM03RR	3.5	Automotive Components, Furniture, Crates	Good Stiffness - Impact Balance
CM08RR	8.0	Paint Pail, Furniture, Industrial Components	Good Stackability & Impact Strength
CM10TE	9.5	Battery Casing, Under Hood Automotive Components	Optimum Stiffness - Impact Balance & Thermal Stability
CM12RR	12.0	Housewares, Automotive Components, Luggage, Paint Pail, Appliances, Compounding	Good Stiffness - Impact balance & Easy Processing

Grade	MFI*	Typical Applications	Special Characteristics
Polysure PP - Impact Copolymer			
CM12RE	12.0	Luggage, Automotive Components, Compounding	No Break Grade with Superior Toughness
CM25NR	25.0	Rigid Packaging, Automotive Components, Compounding	Low Warpage & Low Cycle Time
CM40NR	40.0	TWIM, Appliances, Housewares, Compounding	Reactor Grade, Good Stiffness - Impact balance
CM65NR	65.0	Compounding, TWIM, Appliances, Housewares	Reactor Grade, Low Warpage & Low Cycle Time

**MFI in g/10 as per ASTM D1238*

Table 2 – Characteristics of Polysure PP IM Grades

Properties of Polysure PP Homopolymer

Sl. No	Property	Test Method	Unit	M12RR	M12RR1	M18NH1	M20CR1
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	12	12	18	20
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	35	35	34	34
3	Tensile Elongation at Yield, Type I Specimen		%	10	12	12	12
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1450	1550	1600	1600
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	30	30	35	35
6	Vicat Softening Point (10N)	ASTM D1525	°C	153	154	151	151
7	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	95	100	110	110

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

Sl. No	Property	Test Method	Unit	M50NR1	M65NR1
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	50	65
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	32	32
3	Tensile Elongation at Yield, Type I Specimen		%	10	10
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1500	1350
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	25	25
6	Vicat Softening Point (10N)	ASTM D1525	°C	150	150
7	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	105	100

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

Table 3 – Properties of PP Homopolymer IM Grades

Properties of Polysure PP Random Copolymer

Sl. No	Property	Test Method	Unit	RM12CR	RM30CR
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	12	30
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	34	29
3	Tensile Elongation at Yield, Type I Specimen		%	12	10
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1100	1000
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	70	50
6	Vicat Softening Point (10N)	ASTM D1525	°C	130	130
7	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	80	75

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

Table 4 – Properties of PP Random Copolymer IM Grades

Properties of Polysure PP Impact Copolymer

Sl. No	Property	Test Method	Unit	CM03RR	CM08RR	CM10TE	CM12RE
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	3.5	8	9.5	12
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	27	25	24	21
3	Tensile Elongation at Yield, Type I Specimen		%	9	6	6	7
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1100	1100	1200	950
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	160	170	95	No Break
6	Notch Izod Impact Strength (-20°C)		J/m	-	-	-	100
7	Vicat Softening Point (10N)	ASTM D1525	°C	150	150	150	142
8	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	90	95	100	85

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

Sl. No	Property	Test Method	Unit	CM12RR	CM25NR	CM40NR	CM65NR
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	12	25	40	65
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm/min)	MPa	22	27	28	26
3	Tensile Elongation at Yield, Type I Specimen		%	7	7	5	5
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1000	1500	1500	1350
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	120	85	65	60
6	Vicat Softening Point (10N)	ASTM D1525	°C	145	151	150	150
7	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	90	100	96	95

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

Table 5 – Properties of Polysure PP Impact Copolymer IM Grades

Polysure PE (HDPE & LLDPE)

Polysure HDPE

HMEL Polysure HDPE grades serves the injection moulding sector with complete range of grades starting from 2 MFI to 30 MFI in HDPE sectors for various applications like Caps & Closure, Small industrial parts, Heavy-duty Crates, Helmets, Industrial products, housewares and defence applications. Polysure HDPE grades are produced by Gas Phase Univation Technology. The grades exhibit a superior organoleptic property, low warpage, long service life, excellent rigidity and impact strength.

HMEL Polysure HDPE Grade Basket:

Grade	MFI*	Density**	Typical Applications	Special Characteristics
M0252S	2.0	0.952	Caps & Closure, Small industrial parts	Superior Organoleptic Properties & Low warpage
M0861S	8.0	0.961	Heavy-duty Crates, Helmets & Industrial products	Good Rigidity & Impact strength
M0861SU	8.0	0.961	Crates, Luggage, Helmet, Defence Application	UV Stabilized for Long Service Life
M2050S	20.0	0.950	Houseware items, Food Container, Filler Masterbatch	Dimensional Stability & Minimum Warpage
M3050S	30.0	0.950	TWIM, Food Container, Filler Masterbatch	Minimum Warpage & Good Filler Dispersibility

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

Table 6 – Characteristics of Polysure HDPE IM Grades

Polysure LLDPE

HMEL Polysure LLDPE grades serves the injection molding sector with 20 MFI & 50 MFI grades for various applications like TWIM, housewares and general purpose injection molding. Polysure LLDPE grades are produced by Gas Phase Univation Technology. The grades exhibit good filler dispersibility, superior dimensional stability and excellent processability.

HMEL Polysure LLDPE Grade Basket

Grade	MFI*	Density**	Typical Applications	Special Characteristics
M2024L	20.0	0.924	Master Batch, TWIM, Housewares Items	Good Filler Dispersibility & Dimensional Stability
M5026L	50.0	0.926	Master Batch, Housewares Items, Thin Wall Containers	Excellent Filler Dispersion & Processability

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

Table 7 – Characteristics of Polysure LLDPE IM Grades

Properties of Polysure HDPE & LLDPE

Sl. No	Property	Test Method	Unit	M0252S	M0861S	M0861SU	M2050S	M3050S
1	Melt Flow Index (190°C & 2.16 kg)	ASTM D1238	g/10 min	2	8	8	20	30
2	Density (23°C)	ASTM D1505	g/cc	0.952	0.961	0.961	0.950	0.950
3	Tensile Strength at Yield, Type IV Specimen	ASTM D638 (50 mm / min)	MPa	26	31	31	22	22
4	Tensile Elongation at Break, Type IV Specimen		%	700	350	350	350	350
5	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1000	1200	1200	900	850
6	Notched Izod Impact Strength (23°C)	ASTM D256A	J/m	200	75	75	30	25
7	Vicat Softening Point (10N)	ASTM D1525	°C	125	128	128	126	126
8	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	80	75	75	78	78

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

Sl. No	Property	Test Method	Unit	M2024L	M5026L
1	Melt Flow Index (190°C & 2.16 kg)	ASTM D1238	g/10 min	20	50
2	Density (23°C)	ASTM D1505	g/cc	0.924	0.926
3	Tensile Strength at Yield, Type IV Specimen	ASTM D638 (50 mm / min)	MPa	12	10
4	Tensile Strength at Break, Type IV Specimen		MPa	8	8
5	Tensile Elongation at Break, Type IV Specimen		%	300	150
6	Notch Izod Impact Strength (23°C)	ASTM D256	J/m	500	450
7	Flexural Modulus (1% Secant)	ASTM D790A	MPa	400	350
8	Vicat Softening Point (10N)	ASTM D1525	°C	94	90

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

Table 8 – Properties of Polysure HDPE & LLDPE IM Grades

Key Attributes of Polysure PP, HDPE and LLDPE Molding Grades

- Excellent processability & reduced cycle time resulting better productivity
- Optimum balance between impact strength and stiffness
- Low warpage & excellent dimensional stability
- Superior gloss & good aesthetics
- Superior organoleptic properties
- Excellent stackability

Processing Guidelines

Parameters for Polysure PP
- Barrel Temperature: 220 - 280°C
- Mold Temperature: 30 - 40°C

Parameters for Polysure HDPE
- Barrel Temperature: 200 - 240°C
- Mold Temperature: 25 - 30°C

Parameters for Polysure LLDPE
- Barrel Temperature: 180 - 220°C
- Mold Temperature: 20 - 30°C

Storage & Handling

Bags should be stored in dry & dust free environment at temperature below 50°C. Prevent 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.

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.

Applications of Injection Molding

Considering unique properties of polyolefin like excellent chemical & moisture resistance, hinge capabilities, good impact stiffness balance, availability of food grades and low cost, Polypropylene and Polyethylene are used for variety of diversified applications as summarized below:

Polysure PP Homopolymer

- Furniture, Houseware Items, Toys
- Auto Components
- Medical Syringe

Polysure PP Copolymer

- Industrial & Automotive Battery Boxes
- Furniture, Paint Pails
- Auto Components
- Medical Syringe
- Luggage

Fig. 4 – Applications of Polypropylene Injection Molding Grades

Polysure HDPE

- Household Goods, Food Containers
- Crates, Bins & Industrial Components
- Caps & Closures
- Heavy-duty Crates, Helmets & Industrial products

Polysure LLDPE

- Houseware Items
- Thin Wall Containers

Fig. 5 – Applications of Polyethylene Injection Molding Grades

Troubleshooting Guide of Common Molding Problems

Troubleshooting is the art of providing remedy of defects generally arises during any process. The goal is to correctly identify the problem causing the defect and to take fast, corrective action when products do not meet their performance requirements.

While making any injection molded component, several defects may result from either machines, material, molds or operator which are discussed in details as below:

PROBLEM	POSSIBLE CAUSES	TYPICAL SOLUTIONS
VOIDS	▪ Failure to fill mold completely ▪ Poor venting of mold ▪ Moisture in Polymer	▪ Decrease injection speed ▪ Provide additional mold vents ▪ Dry material
BRITTLENESS	▪ Degraded material from barrel ▪ Melt and mold temperatures low	▪ Check for material contamination ▪ Decrease injection and back pressure ▪ Increase melt and mold temperatures
EXCESSIVE FLASH	▪ High injection pressures ▪ Low clamping pressure ▪ Melt temperature too high	▪ Decrease injection pressure ▪ Increase clamping pressure ▪ Decrease barrel & Mold temperature
FLOW MARKS, WELDLINE	▪ Melt temperature too low ▪ Injection speed too low	▪ Increase melt & nozzle temperature ▪ Increase injection speed ▪ Adjust the size of sprue/runner/gate
SINK MARKS	▪ Insufficient injection pressure and dwell time ▪ High melt or mold temperature	▪ Increase injection pressure ▪ Increase holding time & cushion size ▪ Decrease melt and mold temperature
PART OR SPRUE STICKING	▪ Over packing ▪ Under packing	▪ Decrease injection pressure ▪ Increase clamp pressure ▪ Decrease barrel and nozzle temperature
GATE BLUSH, DELAMINATION	▪ Melt fracture ▪ Insufficient Opening of Gate	▪ Adjust injection speed ▪ Modify gate geometry ▪ Increase melt and/or mold temperature
SHORT SHOT	▪ Insufficient packing pressure ▪ Low injection speed & time ▪ Clogging of nozzle and gates	▪ Increase Injection & Back pressure ▪ Increase injection speed ▪ Increase melt & Nozzle temperature ▪ Increase shot size and confirm cushion
WARPAGE	▪ Part ejected too hot ▪ Higher Stress on Product ▪ Over packing in gate area	▪ Increase cooling time ▪ Decrease injection pressure ▪ Increase gate size as much as possible
SHRINKAGE	▪ Part is not fully packed ▪ Insufficient cooling time	▪ Increase cavity pressure and hold time ▪ Maintain adequate cushion ▪ Increase runners or gates size ▪ Delay gate sealing
BURNING	▪ Air in the mold ▪ Degraded resin	▪ Decrease cavity pressure ▪ Clean vents, increase number of vents ▪ Reduce melt temperature
NOZZLE DROOL	▪ Excessive nozzle or melt temperature	▪ Reduce Nozzle Tip temperature ▪ Adjust the Processing temperature
SPLAY	▪ Streaks on surface caused by volatiles such as moisture or degraded material	▪ Remove moisture, dry resin ▪ Reduce melt temperature

Table 8 – Troubleshooting solutions for Injection Molding 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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HMEL POLYSURE

TECHNICAL GUIDE TO
PP & PE Compounding & Masterbatch Process

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INTRODUCTION

Compounding is a process of melt blending plastics with other additives. This process changes the physical, thermal, electrical or aesthetic characteristics of the plastic. Typically, this process is performed in the molten state with a goal to achieve a homogeneous blend, and is a crucial step in the polymer development process. The need for lightweight, more durable and low emission materials plus the increasing demands on design is forcing the polymer and plastics industry to develop new and innovative materials. Polymer material and compound development takes place in every step of the polymer R&D process to produce materials with different properties to the base material or to produce material with desired qualities, using various additives.

Compounding is basically done to enhance the performance of specific resin with specialty polymers or additives. In few cases compounding is carried out with PP / PE resin with calcium carbonate or additives or colour pigments to prepare the Filler Masterbatches or Additives Masterbatches or Color Masterbatches respectively, which are used in various plastic processing techniques. For Masterbatches, the carrier resin is generally present at lower percentages as compared to main ingredient.

Compounding Process Description

Compounding is defined as the process of incorporating additives, modifiers into PP / PE resin for achieving uniformity on a scale appropriate to the quality of the articles subsequently made from the material. It is also known as hot or melt blending. Compounding starts with a base resin or polymer in which extensive range of additives, fillers, and reinforcing agents are incorporated in molten form and mixed into extruder.

By incorporating an extensive range of additives, fillers, and reinforcing agent, a wide range of properties can be achieved. For example, glass fibers can be added at various levels to increase stiffness of a resin that is more flexible than the application requirement.

Compounding is generally done in Twin screw extruder, which is the most popular technology extensively used in the industry. Moreover, kneader & single screw based conventional technologies are also quite familiar for compounding / masterbatches preparation.

Mixing of the ingredients into the polymer matrix should be even and homogenized. This must include dispersive as well as distributive mixing where the additives no longer form any agglomerate and attain their primary particle size.

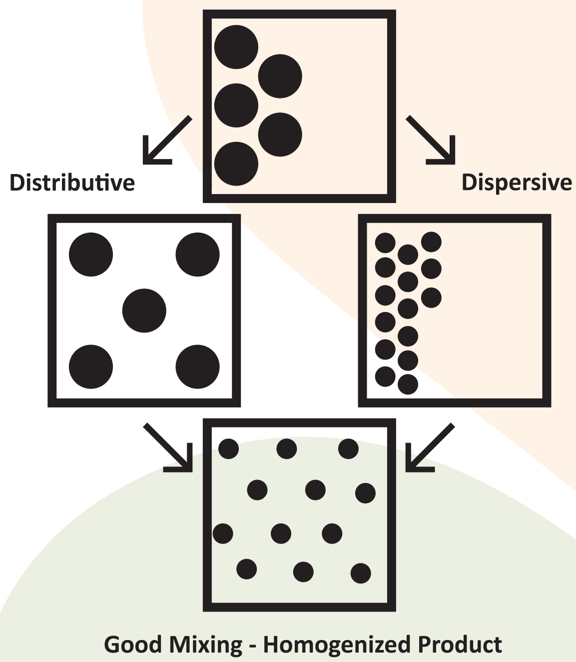

Fig. 1 – Distributive & Dispersive Mixing

A. Compounding by Twin Screw Extruder

The process of compounding actually consists of several different unit operations happening inside the extruder. The basic process can be defined with the Three M s' – Melt, Mix, Meter. The difference between normal extrusion and compounding extrusion is that in the latter, there is special emphasis on Mixing whereas in the former, emphasis is on Melting and Metering. In "normal" extrusion, either the mixing section is absent or if present, it is quite insignificant. This also suggests that compounding extruders, by virtue of the extra mixing section, tend to have a higher L/D as compared to normal extruders.

The compounding process consists of following steps, which are followed sequentially.

- Feeding of Resin with additives / fillers through gravimetric / volumetric feeder into extruder.
- Melt mixing of polymer and additives inside extruder barrel under heating
- Compounded melt take shape of strand and cooled into water bath
- Strand cut into pellet using pelletizer

Feeding System: The feeding of the polymer is done through multiple or single feeder. Typically, the principal polymer is fed through main feeder at the feed zone of the extruder and the other ingredients (e.g. Additive / Filler / Glass fiber / performance enhancer, etc.) are fed through the side feeders, which are placed at the top or side of the main extruder. The feeding system are either Gravimetric or Volumetric in nature depending upon the process accuracy requirement. The gravimetric feeders are more precise to execute the required dosing of the ingredients.

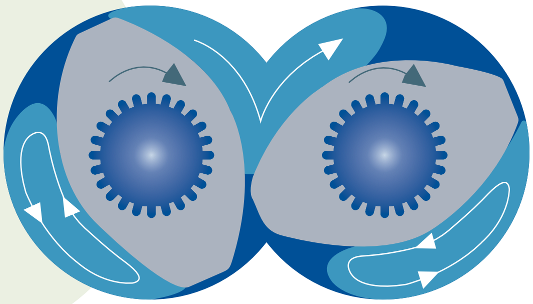

Fig. 2 – Melt Mixing through Co- Rotating Twin Screw

Melt Mixing inside the Barrel: The ingredients are heated, melted & conveyed toward the metering zone of the extruder. Proper vent ports are kept on the extruder for venting the unwanted gaseous substance from the molten polymer. In twin screw extruder intermeshing type of screw are used for better melt mixing. Twin-screw Extruders are normally starve fed devices, which means that you may never fill-up the feed hopper and control the output just by setting the Screw RPM. When run with full hoppers, a modern co-rotating, parallel, fully intermeshing twin-screw extruder will surely be overloaded (few exceptions, though). In practice, these extruders run with their flights 100% full only in specified areas of the extruder. Theoretically, "higher the percentage of filling of flights, better it is for the material that is being compounded".

Fig. 3 – Twin Screw Compounding Extruder

Extruding & Pelletizing of Compounded Material: The compounded material is extruded through the slit die after passing through required screen pack, housed on breaker plate. The low die build-up of resin helps to run the extruder continuously. The extruded strands are solidified, passing through water bath. After solidification, stands are cut into compounded pellets by pelletiser. In case of high speed compounding line under water, cutter / pelletiser is being used, where solidification & pelletisation is done simultaneously inside the closed system. Then the pellets are separated from water, followed by drying. The shapes of the pellets are depending on the design of cutting teeth & speed of the cutter.

Fig. 4 – Extruded Strand & Water Bath

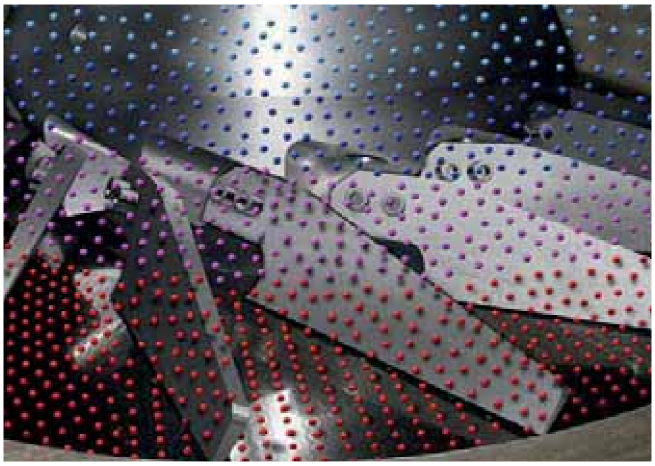

Fig. 5 – Underwater Pelletiser

B. Compounding by Kneader & Single Screw Setup

This technique becomes useful when the percentage of ingredients (color pigment / additive / Filler) is higher than the carrier polymer. In case of Filler masterbatch preparation, this process is very helpful as it can easily produce masterbatches with more than 80% Calcium Carbonate by using only ~ 20% of Polymer.

In such cases, the dispersion of the ingredients in polymer matrix is done by kneader, where semi molten mass is mixed with the high percentage of ingredients under higher amount of shear. The kneading operation is carried out in a batch process under heated condition.

Because of shear thinning, the polymer matrix along with the ingredients turns into a semi solid material. This soft mixture is transferred to hopper of single screw extruder for further homogenised melt mixing inside the extruder barrel.

The extruding, stand cutting & pelletisation mechanism is similar with the twin screw process. In case of masterbatch process the water absorption is higher during the pelletisation stage, where proper drying is to be carried out.

Types of Ingredients Used in Compounding Process

Ingredients	Functions
Antioxidants	Help prevent "oxidation", which is the process of polymer reacting with oxygen. Oxidation can cause loss of impact strength and elongation. It also imparts surface cracks and discolouration. Antioxidants help prevent thermal oxidation reactions when plastics are processed at high temperatures.
Antistatic agents	Help to prevent the build-up of static electric charge. Plastics are generally insulating and have the capacity to build up static charges on the surface which greatly disturb processing procedures and can be an issue for hygiene and aesthetics.
Fillers/extenders	Natural substances used to improve strength and lower the cost of the material. Usually mineral-based, fillers/extenders increase the overall "bulk" of the plastic.
Flame retardants	They are used to prevent ignition or spread of flame in plastic material. Plastics see substantial use in critical construction, electrical and transport applications, which have to meet fire safety standards either by mandatory regulations or voluntary standards. Flame retardants are added to plastics to meet these requirements

Impact modifiers	These ingredients enable plastic products to absorb shocks and resist impact without cracking. Required percentage of elastomeric material is added during the compounding process which are primarily used in automotive applications
Plasticisers	Plasticisers are used to make plastics softer and more flexible in nature
Nucleating Agents	To increase the stiffness of the compounded material, nucleating agent is added. It also helps to balance the stiffness & impact strength of the final resin.
Inorganic Ingredients	Oxide : Silica, Titanium oxide, Magnesium oxide, Antimony oxide Hydroxide : Aluminium, Magnesium & Calcium hydroxide Carbonate : Calcium carbonate, Dolomite Sulfate : Basic magnesium sulfate Silicate : Talcum, Clay, Mica, Glass fiber, Glass balloon, Glass beads, Calcium silicate, Montmorillonite, Bentonite Carbon : Carbon black, Graphite, Carbon fiber
Organic Ingredients	Wood powder, Jute, Kenaf fiber, Hemp fiber, Nylon Fiber / Aromatic polyamide fiber

Compounding Process Advantages

Benefits of Compound

- Improvement in physical and thermal properties of polymer like increase in stiffness, toughness, heat distortion temperature, etc.
- Compounding process increase the volumetric output and have the ability of down gauging.
- Compound used as readymade resin for final application as per desired performance.
- Compound is a high quality resin with improved dispersion and reduce waste in final use.
- It helps to reduce material cost by using some amount of fillers.

Benefits of Masterbatches

- When compared to raw pigments, masterbatches allow for higher accuracy of controlling the opacity or transparency of final, colored products.
- Predetermined ratios of additive ingredients are included in masterbatches, which means there is a minimal chance of variance during the manufacturing process.
- Masterbatches give users better color consistency when working with large orders.
- Unlike masterbatches, pigments can become airborne during processing, which allows them to contaminate adjacent manufacturing lines.
- Melting processes are improved because binding agents in masterbatches are matched with polymers being used.
- Pelletisation helps in better handling of masterbatches as compared to additives in powder form.

Compounding Resin Selection

One of the best aspects of compounding process is its versatility. This process can be carried out with polyolefins and engineering / specialty plastics (Nylon, PC, PBT, PVC, PET, ABS, etc.) as base resins. Each material has applications and functions for which it works best.

Polyolefins are widely used in compounding and masterbatches industry for automotive, appliance, thermoware and construction applications because of good processability and high impact strength offered by impact copolymer. Addition of various filler makes polyolefin dimensionally stable and becomes a good alternative of engineering plastics for compounder. The major advantage of polyolefin is good thermal stability that helps to make various compound with desired performance.

In case of PP & PE, higher melt flow materials are being used for compounding process, as it helps to mix properly with ingredients. Resins having MFI in the range of 10 - 70 g/10 min are more preferable for compounding and masterbatch processing.

Effect of Resin Variables on Compounding Process

Sl.No.	Resin Properties	Indicator	Product Property
1	**Molecular Weight** impacts the strength of polymer		
1.1	Molecular Weight ↑	MFI ↓	Stiffness ↓
1.2	Molecular Weight ↓	MFI ↑	Stiffness ↑
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 ↓	Stiffness ↑ Clarity ↓
3.2	Isotacticity ↓	Xylene solubility ↑	Stiffness ↓ Clarity ↑

Table 1 – Correlation between Resin and Product Property

Polysure PP & PE Grade Offerings for Compounding Sector

Polysure PP

Polysure PP CM12RR, CM12RE, CM25NR, CM40NR, CM65NR are Polypropylene Impact Copolymers, produced by latest LyondellBasell Spheripol II Technology & are primarily suitable for compounding applications. These grades combine exceptional processability, high toughness and excellent filler dispersion.

Sector	Grade	MFI*	Typical Applications	Special Characteristics
Polysure PP	CM12RR	12	Automotive Components, Luggage, Appliances, Compounding	Good Stiffness - Impact balance & Easy Processing
	CM12RE	12	Luggage, Automotive Components, Compounding	No Break Grade with Superior Toughness
	CM25NR	25	Rigid Packaging, Automotive Components, Compounding	Low Warpage & Low Cycle Time
	CM40NR	40	Appliances, Housewares, Compounding	Reactor Grade, Good Stiffness - Impact balance
	CM65NR	65	Compounding, Appliances, Housewares	Reactor Grade, Low Warpage & Low Cycle Time

**MFI in g/10 as per ASTM D1238*

Table 2 – Characteristics of Polysure PP Grades

Typical Properties of Polysure PP

Sl. No	Property	Test Method	Unit	CM 12RR	CM 12RE	CM 25NR	CM 40NR	CM 65NR
1	Melt Flow Index (230°C & 2.16 kg)	ASTM D1238	g/10 min	12	12	25	40	65
2	Tensile Strength at Yield, Type I Specimen	ASTM D638 (50 mm / min)	MPa	22	21	27	28	26
3	Tensile Elongation at Yield, Type I Specimen		%	7	7	7	5	5
4	Flexural Modulus (1% Secant)	ASTM D790A	MPa	1000	950	1500	1500	1350
5	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	120	No Break	85	65	60
6	Notch Izod Impact Strength (-20°C)		J/m	-	100	-	-	-
7	Vicat Softening Point (10N)	ASTM D1525	°C	145	142	151	150	150
8	Heat Deflection Temperature (0.455 MPa)	ASTM D648	°C	90	85	100	96	95

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

Table 3 – Properties of Polysure PP Grades

Polysure LLDPE

Polysure LLDPE M2024L, M5026L are Linear Low density polymers produced by latest Univation Swing Plant & primarily suitable for masterbatches and compounding. LL M2024L & M5026L combines exceptional processability with excellent filler dispersion.

Product	Grade	MFI*	Typical Applications	Special Characteristics
Polysure LLDPE	M2024L	20	Masterbatches	Good Filler Dispersibility
	M5026L	50	Masterbatches	Excellent Filler Dispersion & Processability

**MFI in g/10 as per ASTM D1238*

Table 4 – Characteristics of Polysure LLDPE Grades

Typical Properties of Polysure LLDPE

Sl. No	Property	Test Method	Unit	M2024L	M5026L
1	Melt Flow Index (190°C & 2.16 kg)	ASTM D1238	g/10 min	20	50
2	Density (23°C)	ASTM D1505	g/cc	0.924	0.926
3	Tensile Strength at Yield, Type IV Specimen	ASTM D638 (50 mm / min)	MPa	12	10
4	Tensile Strength at Break, Type IV Specimen		MPa	8	8
5	Tensile Elongation at Break, Type IV Specimen		%	300	150
6	Notch Izod Impact Strength (23°C)	ASTM D256A	J/m	500	450
7	Flexural Modulus (1% Secant)	ASTM D790A	MPa	400	350
8	Vicat Softening Point (10N)	ASTM D1525	°C	94	90

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

Table 5 – Properties of Polysure LLDPE Grades

Processing Guidelines

Parameters for LLDPE

- Barrel Temperature: 180 – 220°C
- Die Head Temperature: 180 – 220°C

Parameters for PP

- Barrel Temperature: 190 – 230°C
- Die Head Temperature: 190 – 210°C

Storage & Handling

Bags should be stored in dry & dust free environment at temperature below 50°C. 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.

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.

Applications of PP & PE Compounds

Polypropylene and Polyethylene compounds are used in many applications. The automotive industry is one of the key area, where demand for PP compounds is drastically increasing. There are many other segments, where compounds are also widely used.

Automotive Applications

- Dashboard, Bumpers
- Seating Components
- Instrument Panel
- Steering, Pulley
- Fans & Shrouds
- Electrical Panel
- Interior Trims

Household Appliance

- Refrigerator / Washing Machine Enclosure
- Electrical Body Parts
- Juicer Machine

Electrical & Electronic Parts

- Electrical Wire Cover & Support
- Electrical Board
- Air Conditioner
- CFL Holder

Masterbatches Sector

- Additive Masterbatches
- Color Masterbatches
- Filler Masterbatches

Troubleshooting Guide for Compounding Process

Compounding Process is a compact & integrated technique, which involves multiples steps. Many a times, we face processing & performance related difficulty during manufacturing of compounded material. Although these issues vary from machine to machine, we have recommended the probable cause and remedy for few generic issue of compounding process.

PROBLEM	POSSIBLE CAUSES	TYPICAL SOLUTIONS
SCREW ROTATES & NO MATERIAL EXITS THE DIE	▪ Feed throat is plugged or bridged ▪ Feed throat cooling is not working properly ▪ Feed zone temp. is too high	▪ Clean the feed throat ▪ Increase water flow rate of feed throat ▪ Reduce feed zone temperature
EXTRUDER SCREW DOESN'T TURN	▪ Barrel temperature low ▪ Foreign object in the feed throat ▪ Torque limit exceeded	▪ Increase barrel temperature ▪ Remove foreign object from feed throat ▪ Decrease output to reduce torque
MELT FLOWS OUT OF THE BARREL VENT	▪ Back Pressure too high ▪ Wrong screw design ▪ Incorrect temperature profile ▪ High vacuum pressure of vent	▪ Change breaker plate/screen ▪ Modify screw design ▪ Adjust temperature ▪ Reduce the vent vacuum
LEAKING OF POLYMER AT BREAKER PLATE OR DIE	▪ Breaker plate not positioned properly ▪ Damaged breaker plate ▪ Back pressure too high ▪ Bolts on die not tightened	▪ Reposition the breaker plate ▪ Replace breaker plate ▪ Change screen packs ▪ Tighten the die bolts
POOR OR INSUFFICIENT POLYMER MIXING	▪ Temperature too low ▪ Back pressure too low ▪ Improper screw design	▪ Raise barrel temperatures ▪ Add finer screen pack ▪ Change screw design to provide required dispersive mixing

Table 6 – Troubleshooting solutions for Compounding Process

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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