HIGH DENSITY POLYETHYLENE: HDPE

MATERIAL PROPERTIES.

Under conditions of comparatively low temperature and pressure, ethylene can be polymerized to give a plastic (HDPE) which has only a small number of short chain branches. This is achieved by using Ziegler-Natta catalysts with ethylene and small amounts of alpha olefines as monomers.

Polyethenes produced in this way have less chain branching giving higher levels of crystallinity and therefore higher densities than LDPE. Polyethenes with densities of 0.910 to 0.925 g/cm³ are called LDPE or Type 1, those with densities of 0.926 to 0.940 g/cm³ are called MDPE (sometimes LLDPE) or Type 2 while those with densities of 0.940 to 0.965 g/cm³ are called HDPE or Type 3.

For any polythene higher crystallinity and density will also give higher rigidity, tensile strength, hardness, melting point, heat distortion temperature, chemical resistance, viscosity and resistance to permeation. However increasing crystallinity results in lower clarity and impact strength.

LDPE has a melting point of 110 to 125 °C, MDPE 115 to 128 °C, HDPE 130 to 135 °C. By comparison PP melts between 165 and 175 °C. Cross-linked PE will not melt but will become rubbery at about 115 °C.

As with all polyolefins the weathering resistance of HDPE is poor but can be improved by the addition of carbon black or UV absorbing additives. Carbon black also helps to reinforce the material.

HDPE has good dynamic fatigue resistance but not as good as PP and exhibits no living hinge effect. Compared to PP homopolymer, HDPE has better resistance to low temperature impact and to oxidation. On the other hand PP has a higher Vicat softening point, better resistance to flexing, higher hardness, higher tensile and greater elongation. The surface gloss on products can be similar for either polymer.

HDPE Can be cut easily with a knife. It can also be easily scratched with a knife or fingernail while PP can not.

The shrinkage of HDPE is 1.5 - 4% (and even 5% in thick sections) due to its high level of crystallinity.

Permeability of HDPE for organic vapors is least for alcohols and then increases in order from acids to aldehydes and ketones, esters, ethers, hydrocarbons and halogenated hydrocarbons. HDPE may be cross-linked using high energy radiation or by the incorporation of peroxides and this decreases permeability to an extent.

Because of the stiffness of this material it is widely used as carrier, tote bags or counter bags. In such applications its high strength allows the use of very thin films providing an important cost saving.
HDPE is used in packaging applications in the form of thin, paper-like film, for example, for the wrapping of cheese.

Pipes, especially as gas and cold water supply pipe are major application for HDPE. This again is because of the rigidity of this material and its comparatively low cost.

Sheet for thermoforming is also made but in comparatively small quantities. A disadvantage of of HDPE is high specific heat and latent heat of fusion resulting in long heating and cooling times.

CHEMICAL PROPERTIES.

HDPE has no known solvent at room temperature but will dissolve in aliphatic and aromatic hydrocarbons above 60 C. Such materials will also cause swelling at room temperature. HDPE is swollen by white spirit and carbon tetrachloride but (unusually) fares better than PP in these materials. The resistance of HDPE to aromatic and chlorinated hydrocarbons is much better than that of LDPE.

HDPE is not attacked by concentrated salts, acids or alkalis at room temperature and resists some oxidising agents such as hypochlorites. Oxidising acids will attack it.

Theoretically HDPE is more resistant to oxidation than LDPE but in practice they are similar. Commercial grades of HDPE always contains antioxidant(s) which are important in processing and subsequent service. Small amounts of oxidation severely affect the electrical properties of HDPE.

HDPE is attacked by UV light and the use of carbon black or UV screens for outdoor exposure is essential.

HDPE is affected by environmental stress cracking (ESC) when it is subjected to external or internal stress in the presence of polar liquids or vapors. ESC can also be caused by detergents or silicone fluids as well as many other agents. PP is far less affected by ESC than HDPE.

When this material is heated in a flame it ignites easily then burns with a yellow-tipped, blue flame giving off only a little smoke. It forms burning drops and when the flame is extinguished gives off a smell like candle wax.

When heated in the absence of a flame HDPE will soften and melt to give a clear liquid, as the crystal structures are destroyed, at approximately 135 C. It is stable in the absence of air up to approximately 300 C when it decomposes to give low molecular weight hydrocarbons.

COLORING.

The natural color of the material is an opaque, milky white and so a wide color range is possible. Transparent extrusions are not possible even in thin sections as HDPE crystallises very rapidly on cooling unlike PP or nylon.
HDPE is sold in both compounded colors and as natural material for coloring on the extrusion machine by techniques such as masterbatching and dry coloring.

When dry coloring do not use adhesion promoters such as paraffin. Control the mixing time precisely as too short a mixing time gives poor dispersion and inadequate adhesion while too long a mixing time may cause pigment compaction.

Do not exceed approximately 0.4% pigment. Higher color concentrations can be achieved with colored compounds.

MATERIALS HANDLING.

HDPE will absorb less than 0.01% water in 24 hours at room temperature. This means that drying is not normally necessary. If it is, dry in a hot air oven for 3 hours at 65 C.

HDPE is available in both granular and powder form. The powder form is cheaper but can give problems of materials handling and feeding.

The granular form is much easier to handle as it will flow under its own weight but can create problems if it is blended with masterbatch as separation can occur in the machine hopper.

FLOW CHARACTERISTICS.

Because the impact resistance of HDPE decreases and notch sensitivity increases as molecular weight falls the most commonly used grades of HDPE have high molecular weights i.e. low values of melt flow index (MFI). Using the traditional 2.16 Kg weight at 190 C, HDPE extrusion grades all have values below 0.3.

To enable these grades to be more readily distinguished, the MFI test is carried out with a 5 Kg weight giving values about 3 times greater than those found with the 2.16 Kg weight. Note that the MFI values at 5 Kg are higher than we would expect from the change in weight because of the viscoelastic properties of polymer melts.

For film MFI (5) values in the range 0.17 to 0.53 are used while for sheet and pipe typical values are about 0.4 and for cable sheathing about 0.85.

The viscosity for a typical pipe grade with MFI (5) = 0.43 is given by;

\[
\text{Viscosity} = \text{antilog} \left( 4.866 - 0.0030 \times \text{temperature (C)} - 0.538 \log (\text{shear rate (s}^{-1})) \right)
\]

SCREW AND BARREL DESIGN.

Because of its high viscosity at extrusion processing conditions, there can be a problem at high screw speeds with shear heating raising melt temperatures to unacceptably high values. Screws should be designed to cope with this problem. A relatively deep metering zone channel is used and the screw speed not raised too high.
With conventional screw designs there should be a relatively short compression zone and a compression ratio of 3:1.

For pipe extrusion screw lengths are in the range 25 to 30D while for film the range is 18 to 24D. Improved output is obtained with a decompression screw where the metering zone channel is deepened in the final 8D. The zone lengths are Feed 12D, 1st Metering 3D and 2nd Metering 8D. Zone depths in mm are given in the following table.

<table>
<thead>
<tr>
<th>SCREW (mm)</th>
<th>FEED ZONE</th>
<th>1st METERING</th>
<th>2nd METERING</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>9.3</td>
<td>3.6</td>
<td>6.0</td>
</tr>
<tr>
<td>90</td>
<td>11.4</td>
<td>4.7</td>
<td>7.5</td>
</tr>
<tr>
<td>115</td>
<td>13.1</td>
<td>5.6</td>
<td>8.6</td>
</tr>
<tr>
<td>150</td>
<td>15.6</td>
<td>6.8</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Barrier type screw designs have also been used successfully with HDPE. Typically a 115 mm barrier screw will have a 24:1 L/D ratio and be operated at up to 100 r.p.m.

If grooved feed inserts are used in the barrel they should be cooled and the grooves fine. For a 63 mm extruder, there are 8 grooves each of depth 2.5 mm and width 8 mm. The grooves extend 3.5 D beyond the feed throat opening. With a grooved feed section longer screws incorporating shear and mixing sections are recommended.

BARREL AND DIE TEMPERATURES.

Since melt temperature depends on screw design, screw speed as well as barrel and die settings the following table is a guide only.

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>Sheet</th>
<th>Film</th>
<th>Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFI (5)</td>
<td>0.6</td>
<td>0.17</td>
<td>0.53</td>
</tr>
<tr>
<td>Zone 1 temperature</td>
<td>185</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Zone 2 temperature</td>
<td>195</td>
<td>230</td>
<td>200</td>
</tr>
<tr>
<td>Zone 3 temperature</td>
<td>210</td>
<td>250</td>
<td>220</td>
</tr>
<tr>
<td>Die temperature</td>
<td>210</td>
<td>250</td>
<td>220</td>
</tr>
</tbody>
</table>

DIE DESIGN AND CONSTRUCTION.

For smaller pipes spider type dies are generally used. For large pipes, a spiral mandrel is used or the conventional mandrel is held in place by a breaker plate type support. The land length should be 14 to 25 times the pipe diameter, the greater the output velocity the greater the necessary land length.

Blown film dies are of the spider type with a smear restriction downstream of the spider supports or of the spiral mandrel type. Typically, the die gap is between 0.75 and 1.40 mm and the die diameter between 75 and 200 mm.

Sheet dies of the type used for HIPS are satisfactory. Sheet thickness of up to 12 mm is possible. The die should have an adjustable land after the manifold and choker bar sections. Land lengths of 65 mm have proved satisfactory.
DOWNSTREAM EQUIPMENT.

Both pressure and vacuum sizing are used for pipe production. For pressure sizing, there is a slight expansion after the die i.e. the die gap OD equals the pipe ID. For vacuum sizing the expansion is greater with a 25% increase in diameter common.

In blown film, in order to achieve reasonable impact values a relatively large blow up ratio between 3 and 6 is employed. The bubble has a long neck (between 6 and 9 times the die diameter) and a characteristic wine glass shape. To achieve greater stability with this shape of bubble an internal stabilizer can be used together with an outer 'iris diaphragm'. In these cases the bubble often contracts to a diameter less than that of the die opening before eventually expanding to the final film diameter.

Sheet is extruded onto a polishing roll stack consisting of 3 to 5 polished, chrome plated rolls of at least 200 mm diameter. The gap between polishing rolls is often about half of the die gap or slightly more for the higher melt index resins. The table below shows roll temperatures in centigrade. The temperatures refer to the circulating fluid set points. Surface temperatures will be less until the extrudate is being cooled.

<table>
<thead>
<tr>
<th>ROLL</th>
<th>Top</th>
<th>Middle</th>
<th>Bottom</th>
<th>Fourth</th>
<th>Fifth</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPERATURE</td>
<td>99</td>
<td>110</td>
<td>107</td>
<td>88</td>
<td>66</td>
</tr>
</tbody>
</table>

EXTRUDER PLASTICIZING CAPACITY.

Line capacity depends on both the extruder, the die and the cooling section. The table below shows some typical outputs in Kg/hour.

<table>
<thead>
<tr>
<th>EXTRUDER SIZE</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt; 0.1 mm)</td>
<td>Blown Film</td>
</tr>
<tr>
<td>(6 mm)</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>63</td>
<td>170</td>
</tr>
<tr>
<td>90</td>
<td>300</td>
</tr>
<tr>
<td>115</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

STARTING UP.

There are no special problems with HDPE. Follow the procedures laid down for LDPE taking special care not to melt the polymer in the feed section before extrusion starts by keeping temperatures low until just before the screw is started.

SHUTTING DOWN.

Three are no special problems though for die and extruder cleaning it is helpful to purge with LDPE. To prevent oxidation, leave polymer in the extrusion equipment and reduce temperatures as fast as possible when it is intended to start again at a later date without cleaning the equipment in the intervening period.

REPROCESSING.
When this material is reclaimed it is suggested that up to 20% may be blended into the virgin Material.

FINISHING.

This material may not be joined to itself using solvents as there is no solvent at room temperature. Because of its inert, 'non-stick' surface it also cannot be very successfully bonded using adhesives, limited success with contact or hot melt adhesives.

If the surface is made polar, for example by using a flame or an electrical discharge, then this material may be bonded to metals using epoxides or nitrile-phenolic adhesives.

Corona discharge treatment is necessary before printing on HDPE.

HDPE is commonly welded using techniques such as hot plate or hot shoe.

Machining of this plastic is difficult because of its soft, resilient nature. Do not apply too much pressure when machining as the material will distort.