EXTRUSION

The high molecular weight grades of Lucite Diakon are normally recommended for extrusion and a range is available to provide combinations of properties suited to particular applications.

Where increased toughness is required a range of Lucite Diakon ST grades is available.

Acrylic materials produce melts which are generally higher in viscosity than many other thermoplastic materials under normal processing conditions. The melt viscosities of the individual grades of Lucite Diakon are shown in Figures 22 and 23, pages 25-26.

EXTRUDER

Barrel Design
Single screw vented barrel extruders with bi-metallic or nitrided barrels are recommended for extruding Lucite Diakon. (See Appendix III, Volatile Chemicals Evolved During Processing of Lucite Diakon Acrylic Polymers.)

Screw Design for Vented Extruders
In the extrusion process a great deal of the power input to the screw is converted into heat by the shearing action of the screw on the material. It follows that screw profile designs need to be carefully chosen to obtain maximum output per revolution coupled with adequate homogenisation without excessive adiabatic heat evolution.

The minimum length/diameter (L/D) ratio for a vented barrel extruder screw suitable for acrylic material is about 27:1 but higher L/D ratios of 33:1 are available and these are preferred since they give higher and extremely steady outputs. Screws are generally nitrided or chromium plated, or have 'flame-protected' flights.

If surging is to be avoided a long feed section is desirable in the screw since acrylic material is hard and must have sufficient time to plasticise before it is compressed. A compression ratio of between 2.2:1 and 3.0:1 is recommended for the first stage of the screw and a pump ratio (volume of first metering section to volume of second metering section) between 1:1.5 an d 1:2.0. A deep decompression zone in the second stage of the screw is recommended in order to accommodate melt swell.

Feed Throat
Feed throats are usually fitted with surrounding water temperature control to prevent bridging or premature melting of material. Where Lucite Diakon bead polymer is used it is essential always to operate with water cooling on the feed throat.

Breaker Plate
A breaker plate and filter pack are not absolutely necessary with virgin Lucite Diakon, but can help pigment dispersion in coloured material and where rework is being processed, acting as a safety precaution. Where used, the filter pack would consist of one fine mesh (aperture 75-150 micron) supported by a coarser mesh (250-300 micron) and a breaker plate. Manual or automatic filter changers are usually incorporated in extruders having barrel diameters 90 mm and above.

Vacuum Pump
In order to obtain the full benefit of the vented barrel a vacuum pump should be connected to the vent port so that all the volatiles can be removed from the melt as it passes through the decompression zone. A vacuum pump is absolutely necessary when operating at high screw speeds if a clear, glossy extrudate is required.

It is essential to have an efficient water cooled condenser between the vent port and the vacuum pump in order to collect the volatiles emitted and thus prevent the pump from becoming blocked.

All pipes between the vent port and the vacuum pump should be of at least 50 mm bore and ideally should be insulated to prevent premature condensation of the volatiles. Any sharp bends or restrictions in the pipework should be avoided since they could be readily blocked if premature condensation takes place.

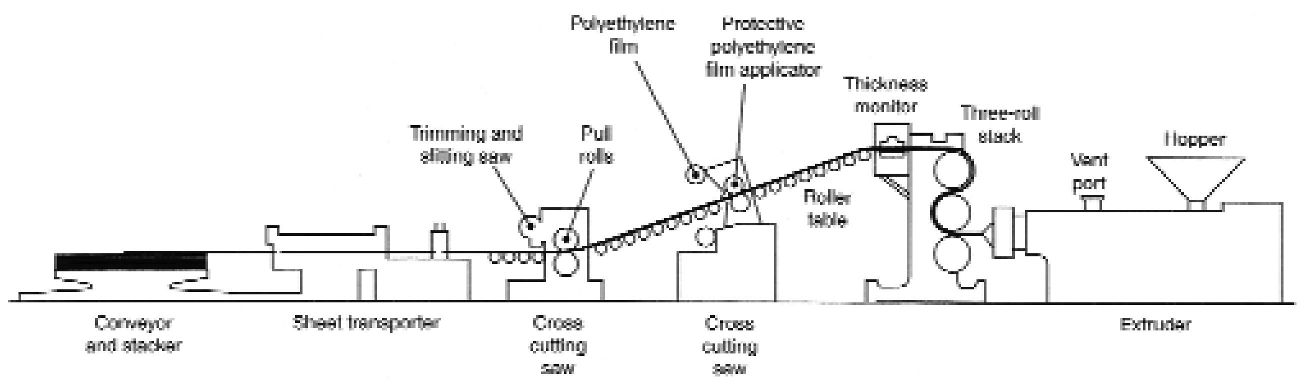


Figure 61 Sheet extrusion line layout

SHEET EXTRUSION

Extruder

An adequately powered vented barrel extruder with suitable screw design is essential since the removal of volatiles is necessary in order to obtain good surface finish at high throughputs.

Die

Correct die design is of prime importance. The die must be:

Robust enough to withstand high internal pressures;
Capable of easy adjustment to give uniform flow across the width;
Free of any hold-up areas so that material and colour changes can rapidly be carried out;
Free from any blemishes, particularly on the die lips, which could cause die lines.

Various dies have been developed to obtain uniform flow across the width; the best of these is the truncated fishtail manifold die sometimes known as the ‘coathanger’ die as shown in Figure 62.

The finish of the die lips is of great importance because any imperfection, particularly on the exit edge, will immediately be transferred to the moving sheet as it leaves the die causing die lines. Die lips are usually made of tool steel and are carefully machined and polished before being hard chromium finished for protection. The exit edge is normally radiused very slightly, about 0.25 mm.

If a wide range of sheet thickness is to be produced, it will be advisable to have three sets of lips with different parallels in order to maintain uniform pressure inside the die body.
Recommended die parallels are given in Table 9.

Sheet thickness (mm)	Die parallel (mm)
Up to 2.5	60
2.5 to 5.0	100
5.0 to 10.0	150

Table 9 Recommended die parallels

Three-Roll Polishing Stack

Various methods have been devised to handle and cool the extruded acrylic sheet as it leaves the die but the method generally used is that based on a three-roll polishing stack. The three-roll stack and ancillary equipment form a versatile unit capable of handling most thermoplastic sheets and can produce either a plain or embossed finish. The best system for acrylic sheet extrusion is the one based on a separate motor for each roll.

Whilst the sheet is travelling round the rolls it is cooled uniformly, polished to remove any fine die lines caused by imperfections in the die lips and calendered to improve the thickness tolerance across the width. Sheet produced with a three-roll stack should have an excellent surface finish, and if conditions are carefully controlled, will possess low residual stress and hence exhibit low shrinkage on reheating before shaping. Thickness tolerances of ±3%, and even less, are possible.

Patterned or embossed sheet can readily be produced by fitting an embossing roll in the central position. The operation is then identical to that used for producing plain sheet.

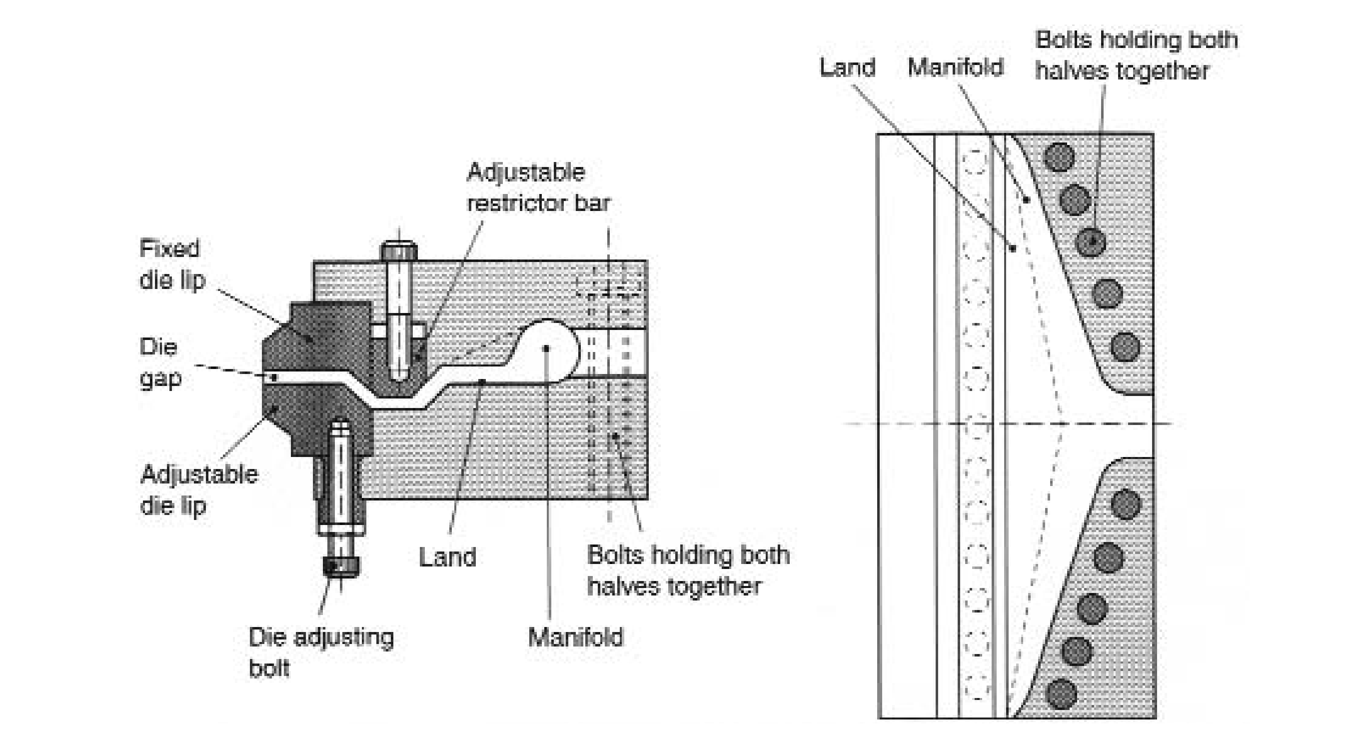


Figure 62 Truncated fishtail manifold sheet die

The temperature of embossing rolls must be accurately controlled and is normally slightly lower than that required for the production of plain sheet.

The actual roll temperatures depend to some extent on the pattern and are generally within the range 90-125°C for three-roll operation. To avoid corrosion and difficulty in cleaning, it is advisable to have embossing roll patterns protected by a final flash-chroming.

Surface Protection

In some cases it is desirable to protect the surface of the sheet with polyethylene film. The film should be approximately 0.05 mm thick and applied to the sheet while it is still warm by a separate set of lightly pressurised rubber-coated rolls positioned after the thickness monitor and just before the roller table. The film must be surface treated by electronic discharge techniques up to 900 W/m^2 on the side which is pressed to the sheet in order to give good adhesion.

CO-EXTRUSION

With co-extrusion, the advantages of Lucite Diakon acrylic materials; improved UV resistance and outdoor weathering, colourability, surface gloss and surface hardness; are obtained by simultaneously extruding a thin layer of Lucite Diakon onto the normal thickness plastic substrate; for example PVC or ABS. The co-extrusion, commonly referred to as capping, may be carried out on sheet, profile and tube.

Selection of the appropriate standard grade of Lucite Diakon or impact modified grade of Lucite Diakon ST depends upon the substrate and the capping properties required. Lucite Diakon ST grades may also be used to improve the detergent craze resistance for vanity sinks, work tops and shower cubicles used in caravans, mobile homes and hotel bathrooms. To prevent shear degradation during co-extrusion and promote maximum adhesion it is important to match the rheology of the Lucite Diakon grade to that of the substrate material.

ABS based substrates have similar thermal and rheological properties to those grades of Lucite Diakon with medium to high temperature resistance and melt viscosity. Lucite Diakon CLH952 has been successfully used but advice should be sought on the selection of a suitable Lucite Diakon ST grade depending on the required end use performance.

Rigid PVC is shear sensitive with lower thermal properties and therefore the lower softening point easier flow grades of Lucite Diakon are recommended; for example Lucite Diakon CLG902 or the Lucite Diakon STG6 series.

PRODUCTION OF EXTRUDED SHEET

Die gap

Before commencing extrusion, the die gap should be set to a thickness depending upon the thickness of the sheet to be produced. A guide is given in Table 10 but it is stressed that this is only a guide since it depends upon extrusion temperatures, throughput and melt viscosity of extrudates.

Sheet thickness (mm)	Die parallel (mm)
2.0	1.7
2.5	2.3
3.0	2.9
4.0	4.0
5.0	5.5
6.0	7.0

Table 10 Die gap guide

Temperature Conditions

The temperature conditions for the extrusion of sheet from the various grades of Lucite Diakon are given in Table 11.

	MH254 CMH454	LH752 CLH952	ST35G8
Extruder Barrel			
Feed throat	cooled	cooled	cooled
Feed*	200-220	200-210	205-225
Meter	220-250	220-240	220-250
Decompression	220-240	210-230	220-230
Meter	220-240	220-235	225-235
Adaptor	220-240	220-235	225-235
Die	225-245	220-240	220-235
Polishing Rolls			
Top	110-120	110-120	110-120
Middle	100-110	100-110	100-110
Bottom	90-100	90-100	90-100

Table 11 Typical temperatures (°C) for Lucite Diakon sheet extrusion

*When using compound versions of Lucite Diakon such as CMH454 and CLH952, it may be necessary to raise the temperatures a further 5-10°C on the feeding zone in order to achieve melt stability. On larger extruders of 120 mm and above further increases in feed zone temperatures may be necessary to achieve melt stability.

Moisture

As acrylic materials are hygroscopic they should not be left exposed to the atmosphere for any length of time.

Experience has shown that on non-vented extruders a moisture level of less than 0.04% is necessary to achieve acceptable extrudate. Acrylic can be dried down to these levels but this can be difficult and time consuming and for this reason vented extruders are recommended for the majority of acrylic extrusion processes.

Rework

Rework material can be used satisfactorily. The levels will depend on the nature of the application as a slight deterioration in the colour of the rework may take place during this operation. Material to be reworked should be processed as quickly as possible under clean conditions to minimise moisture absorption and dirt contamination. The grid size on the grinder should be 3-6 mm.

Shutting Down the Extruder

As standard Lucite Diakon is a relatively thermally stable material no special precautions are necessary when shutting down the extruder. The barrel of the extruder should be emptied, the screw speed reduced to a minimum and the motor stopped. However, after running Lucite Diakon ST grades it is recommended that the extruder is purged with a high molecular weight grade of standard Lucite Diakon to avoid possible die build up and discolouration of material on subsequent start-up.

Sheet Shrinkage

Extruded acrylic sheet can have the problem of high shrinkage when heated prior to shaping unless particular care is paid to extrusion conditions. If the sheet is clamped during heating and shaping, as in vacuum forming, some shrinkage can be tolerated, but if it is heated freely in ovens in a manner similar to cast sheet then a low shrinkage is desirable.

Extrusion conditions which increase shrinkage are:

Low linear speed through three-roll stack;
Excessive melt build-up in nips of three-roll stack;
Excessive tension between three-roll stack and pull rolls;
Die temperatures too low;
Excessive draw-down between the lips and three-roll stack arising from incorrect relationship of die and nip gap settings.

With 3 mm thick sheet, experience has shown that the longer the time the sheet takes to go around the rolls of the three-roll stack the higher the shrinkage. Figure 63 shows the effect of line speed on shrinkage of 3 mm extruded acrylic sheet produced on a three-roll stack with 250 mm diameter rolls.

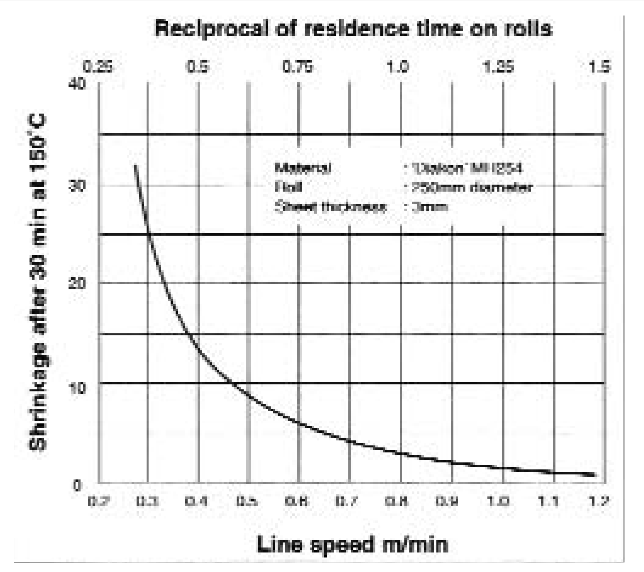


Figure 63 Effect of linear speed on shrinkage of acrylic sheet

Output Capabilities

As shown in Figure 63 when operating with a three-roll polishing stack the line sheet speed is critical if excessive shrinkage is to be avoided. Because of this there is a limit to the maximum sheet width which it is advisable to produce on a given extruder. Taking 3 mm thick sheet, a minimum line speed of 0.75 metre/minute and rolls of 250 mm diameter as standard, the maximum recommended widths for 30:1 L/D ratio extruders are given in Table 12.

Extruder size (mm)	Output (Kg/h)	Maximum recommended sheet width (mm)
60	80	500
90	300	1400
120	500	2000
150	800	2200

Table 12 Maximum recommended widths of 3 mm extruded Lucite Diakon sheet

LIGHTING DIFFUSER PROFILE EXTRUSION

Lighting diffuser profiles can be produced by two methods depending upon the complexity of the design. For relatively simple shapes, containing no corners with a radius smaller than 3 mm, the post-forming method from a tube die is probably the most satisfactory. Where sharp corners are required and there are projections to the periphery or an embossed base, a profile die must be used.

Post-Forming from Tube Dies

Post-forming from a tube die offers several advantages over the use of profile dies. Tube dies can be made accurately at low cost, their symmetry facilitating uniform flow and, with the usual die centering arrangements, control of wall thickness is relatively simple. A wide variety of profiles can be produced from standard tube dies by the use of internal and external metal forming plates. These plates, which can either be steel or brass approximately 6 mm thick, have the forming surfaces radiused and polished to reduce friction. Internal and external perforated copper air cooling tube rings are used to promote uniform cooling of the profiles.

A suggested design for a 100 mm die is shown in Figure 64. The circumference of the die should allow a minimum of 15% draw-down, ie the circumference of the die should be at least 15% greater than the periphery of the required section. In practice, draw-downs of 20-25% are sometimes used but this introduces excessive orientation. The die may be fitted with interchangeables to produce reeded or plain surface as required.

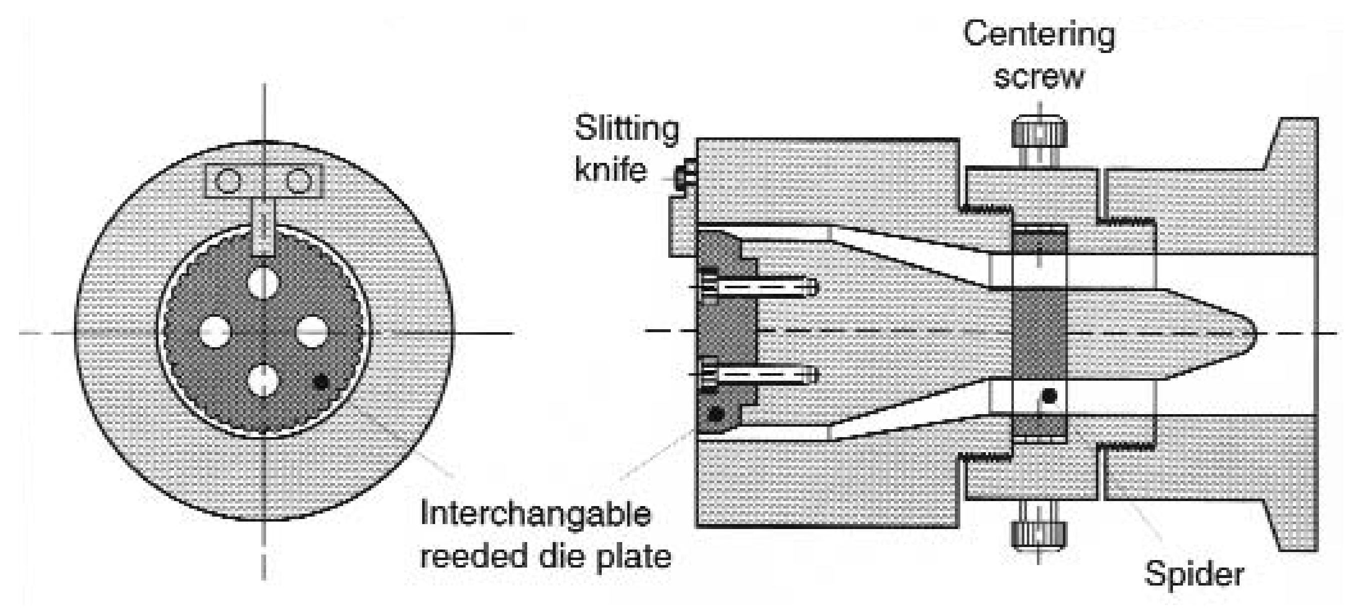


Figure 64 Die for 100 mm diameter tube with slitting knife

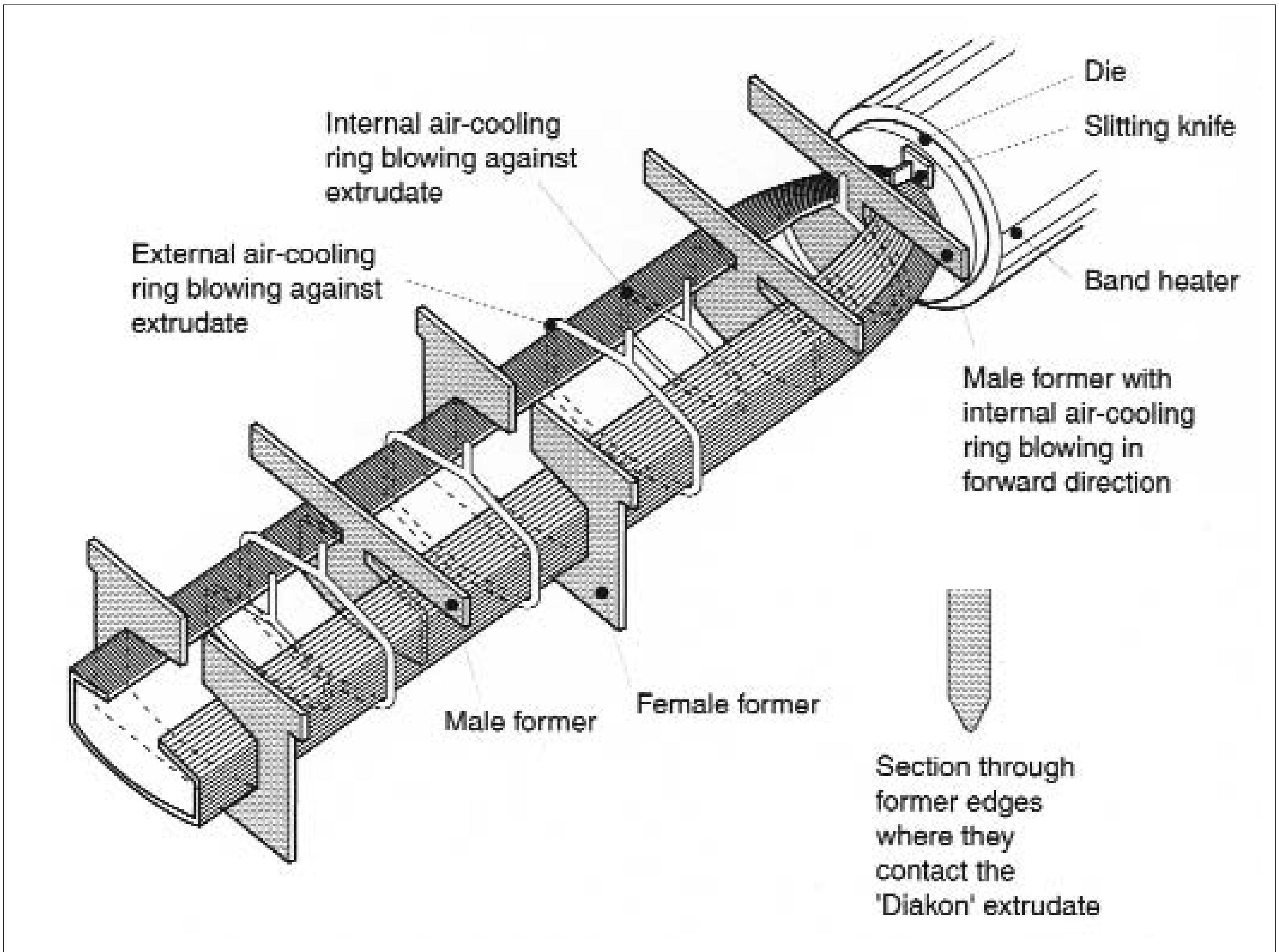


Figure 65 Die and forming box arrangement

Operation
When extrusion starts, the emerging tube is slit by the knife mounted on the die face. The slit tube is fed through the cooling box containing only the external formers. Once the extrudate is held by the haul-off system the internal formers can be inserted, the positions of the formers adjusted and cooling regulated until the desired shape is obtained. The extrudate is cooled by a gentle flow of air from the cooling rings. To avoid uneven cooling or too rapid cooling the air should be directed on to the former, rather than the extrudate.

A suitable arrangement of the die and forming box is shown in Figure 65.

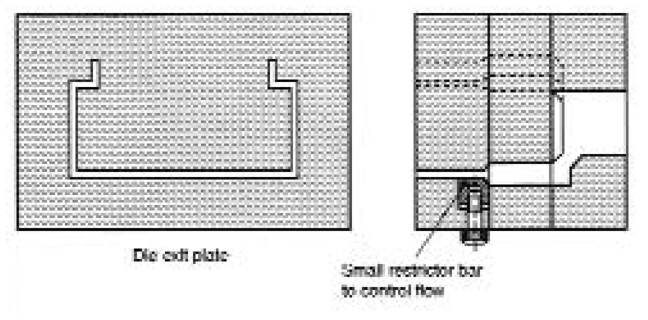


Figure 66 Profile die for acrylic lighting diffuser.

Typical conditions for producing profiles by this method for Lucite Diakon grades are given in Table 13.

	Units	MG102 CMG302	MH254 CMH454	LH752 CLH952	ST35G8
Extruder Barrel					
Feed throat	°C	cooled	cooled	cooled	cooled
Feed	°C	190	200	190	200
Metering	°C	205	205	205	210
Decompression	°C	200	200	200	205
Metering	°C	200	205	200	205
Adaptor	°C	200	200	195	205
Die body	°C	180-200	190-210	190-200	190-205

Table 13 Typical conditions for Lucite Diakon tube and profile extrusion

Profile Dies
No specific recommendations can be given for the design of profile dies since every shape presents its own peculiarities. Frictional drag on the material during its passage through the die must be taken into consideration and so must the tendency for preferential flow in the thicker sections. It follows that the shape of the die orifice often differs considerably from that of the extrudate obtained from it.

With complicated profile dies it may be necessary to incorporate small adjustable restrictor bars in the die to control the melt flow through certain areas. A suggested design for a profile die is shown in Figure 66.

Care is necessary to avoid distortion of the section and the use of a cooling formers is recommended.

With elaborate profiles, embossing with a light diffusing pattern may be required on the outer surface of the base of the profile. This can readily be done by means of a two-roll system. In order to move past the embossing mechanism, some patterns and shapes may require slight outward displacement of the sides of the profile, while the material is still hot and pliable near the die. The sides are then immediately returned to the desired final position by means of sizing plates.

Two-colour profiles for lighting fittings can also be produced by using a specially designed die coupled to two extruders. With this technique, opal and clear materials are commonly used. Normally a smaller extruder produces completely opal sides as the larger machine produces the clear base. Alternatively the smaller machine can simply lay an opal film on to the clear sides. Die design is complicated for two-colour extrusion and it is advisable that a die be obtained from an experienced manufacturer of this type of equipment.

TUBE EXTRUSION

In common with other thermoplastics the sizing methods used for tube production may also be successfully used with Lucite Diakon. The two most common methods use either internal air pressure with external sizing plates or an externally applied vacuum through a sizing bush fully immersed in water.

Internal Air Pressure

This technique can be used for tube sizes up to 75 mm diameter. The air pressure, which should be accurately controlled, is quite low (100-150 mm of water). To maintain the internal air pressure an end plug or a floating plug is commonly used. The external diameter is maintained by sizing plates and cooling in hot water (70°C) for tube sizes up to 30 mm or gentle air cooling for larger diameters up to 75 mm where excessive buoyancy in water could lead to uneven cooling. Slow cooling is essential to eliminate residual stresses which otherwise could lead to failure in service. Line speeds using this technique tend to be slower than for the water-cooled vacuum system.

To allow for the melt swell of material as it leaves the die it is normal for the diameter of the die to be approximately 5% less than the diameter of the sizing system.

Water Cooled Vacuum System

This is a widely used method for tube extrusion up to 150 mm diameter and utilises a perforated brass sizing bush submerged in hot water at 70°C to which a variable vacuum may be applied. In order to effect a satisfactory seal at the entrance to the vacuum bath a die diameter 20-25% greater than the sizing die diameter has been found necessary. The diameter of the sizing die should equal the diameter of the required tube size plus an allowance for shrinkage on cooling. A typical shrinkage allowance for a wall thickness of 5 mm would be 1.7% and for a 1 mm wall 1.2%.

Typical line speeds for tubes produced by this technique would be 1-2 metres/minute.

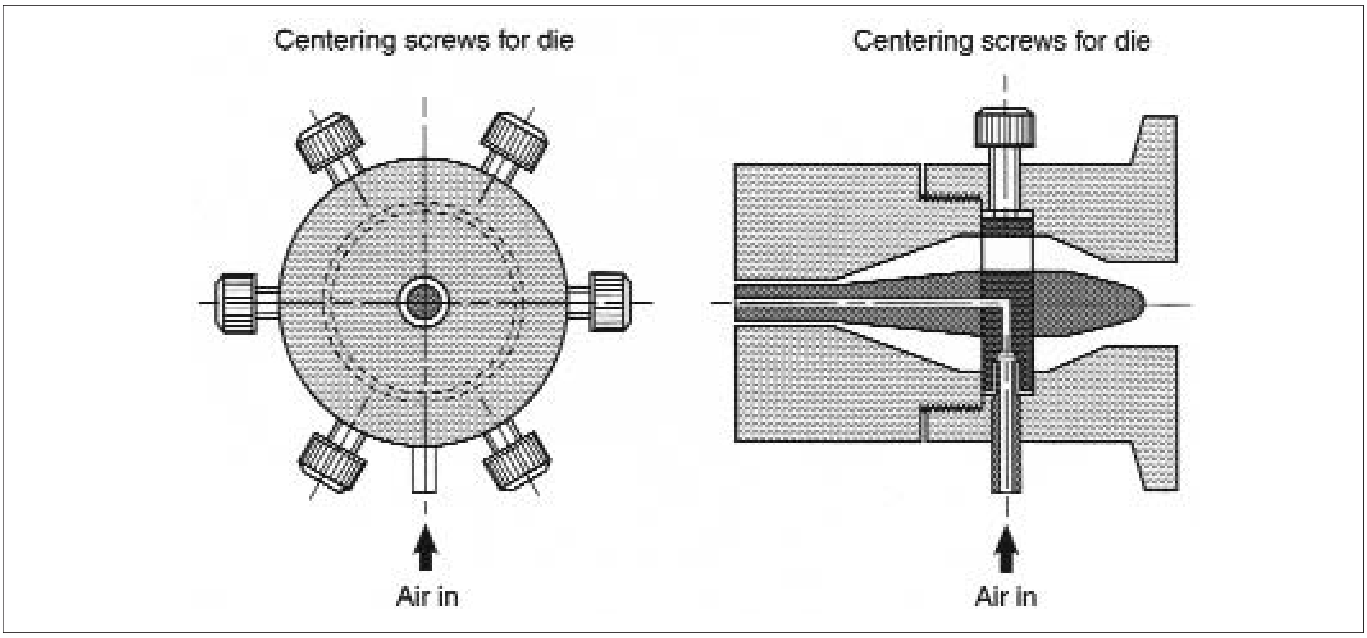
Suggested processing temperatures for tube are similar to those given for lighting diffusers in Table 13.

Die Design

A typical die design for acrylic tube is shown in Figure 67. The die should be fully streamlined and should be chrome plated to minimise any tendency to sticking. Alternatively a hard tool steel,highly polished, may be used.

The high melt viscosity of acrylic can lead to memory lines from the arms of the torpedo carrier. To reduce this tendency die land lengths up to 20 times the wall thickness and compression ratios (areas between arms of torpedo carrier to die annulus) up to 15:1 are recommended.

Figure 67 Die for acrylic tube



FABRICATION OF SHEET EXTRUDED FROM LUCITE DIAKON

Sheet extruded from Lucite Diakon can be shaped by vacuum forming and other conventional shaping techniques.

Shaping temperatures in the range 150-190°C are normally used. With vacuum forming it is advisable to heat the sheet on both sides simultaneously. For conventional shaping the sheet can be heated in circulating air or infra-red ovens. Sheet extruded from MH254 is shaped at the higher end of the temperature range.

In common with other types of extruded sheet Lucite Diakon extruded sheet will shrink on heating. The degree of shrinkage depends upon the processing conditions, thickness and equipment used. If the sheet is pre-heated in the unclamped state in an oven before transferring to a clamping jig for shaping, allowance must be made for shrinkage but if the sheet is clamped in a framework before pre-heating, as in vacuum forming, no shrinkage allowance is generally necessary.

Extruded acrylic sheet readily absorbs moisture from the atmosphere. If pre-heated too rapidly before shaping, absorbed moisture can produce small bubbles within the sheet resembling those formed when the material is overheated. In vacuum forming, heating rates are generally rapid and consequently it is essential with this process to use sheet with a low moisture content. Care should therefore be taken to minimise moisture uptake before shaping, either by using the sheet immediately after extrusion or by storing under conditions which will reduce moisture absorption. Packing the sheet in polyethylene film will slow down the rate of moisture absorption but will not act as a permanent moisture proof barrier.

If surface bubbling occurs when the sheet is heated and before it is soft enough to give the required definition, the moisture content is too high or the heat too intense. The moisture content can be reduced by pre-drying the sheets in an air circulating oven at 70-80°C, and this can conveniently be done overnight. For effective drying the sheets should be separated to allow the hot air to circulate between them.

EXTRUSION FAULT REMEDIES

Fault	Probable cause	Remedy
Bubbled extrudate	1 Wet material 2 Blocked vent 3 Output too high for extruder 4 Overheating	Dry material in oven/use vented extruder Clean vent and pipework Reduce screw speed Reduce operating temperatures
Surface streaks	1 Wet material 2 Blocked vent 3 Output too high 4 Contamination in die 5 Entrapped air	Dry material in oven/use vented extruder Clean vent and pipework Reduce screw speed Clean die or purge Change extrusion conditions or screw design
Die lines	1 Imperfections on die lips	Polish or replace die lips
Rough surface	1 Too low die temperature 2 Too low polishing roll temperatures 3 Too low melt temperature 4 Poor roll finish	Increase die temperature Increase polishing roll temperature Increase melt temperature Polish rolls
Surface craters	1 Ineffective polishing	Increase roll temperature and pressure
Poor colour of extrudate	1 Hold-up in extruder 2 Contamination	Ensure no dead spots, particularly in vent region Ensure material and machine are clean
Variation of shape	1 Temperature fluctuation in extruder or die 2 Uneven flow through die 3 Irregular extruder output 4 Irregular haul off 5 Partially blocked screw	Check temperature control Modify die design Reduce output rate Adjust feed zone temperature Check voltage supply Check haul off for slip or speed variation Purge through with rework
Fold marks ('chevron' marks)	1 Uneven flow through die	Modify die design or adjust flow through die with restrictor bar
Unpolished areas ('lakes')	1 Uneven flow through die	Adjust flow through die with restrictor bar
Excessive orientation	1 Linear sheet speed too slow 2 Polishing pressure too high 3 Line tension too high 4 Draw-down too high 5 Roll temperature too low	Increase output of complete line Reduce polishing pressure Reduce tension between polishing rolls and pull rolls Reduce draw-down Increase roll temperature
Poor embossing	1 Melt too viscous 2 Rolls too cold 3 Insufficient polishing pressure 4 Excessive tension	Increase melt temperature Increase roll temperatures Increase pressure on rolls Reduce tension between polishing rolls and pull rolls.