The moulding of PTFE granular powders

Technical Service Note F1
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This Technical Service Note describes the compression moulding of unfilled Fluon® granular powders. Details of the processing techniques for the range of Fluon® filled powders are given in Technical Service Note F8, The Processing of Fluon® Filled PTFE Powders.

A comprehensive list of Technical Service Notes describing the processing and properties of Fluon® is given on page 35.

The moulding of granular polytetrafluoroethylene (PTFE) powders requires techniques fundamentally different from those commonly used with other thermoplastics. Above its crystalline melting point PTFE is in the form of a very high viscosity gel which does not flow readily enough to permit the use of injection moulding techniques. However, Fluon® granular powders can easily be moulded into a range of shapes by means of powder forming processes similar to those used for ceramics or powdered metals. Finished articles may then be obtained by machining or other techniques, or sometimes directly from the moulding process without further treatment. In the most common moulding process the powder is compacted in a suitable mould: the resulting moulding is then removed from the mould, heated to a temperature above the crystalline melting point to effect fusion of the individual particles, and cooled in a controlled manner to give the final moulded article. The compaction process is generally known as preforming and the heat treatment as sintering.
A range of Fluon® granular grades is available, each chemically identical, but having a different combination of end-use properties and powder handling characteristics. These grades are described in detail in a Fluon® Technical Information Sheet available on request. All Fluon® granular grades are identified by the letter G, followed by a three-figure number.

Fluon® granular powders with grade numbers in the 100 series have a small median particle size, which makes them suitable for a range of applications, such as high quality skived tape or sheet, requiring the best possible mechanical or electrical properties.

Fluon® granular powders in the 300 series have considerably larger particles, and are characterised by their higher bulk density and their excellent powder handling properties. While they may give finished parts with mechanical and electrical properties slightly inferior to those obtainable from the 100 series, they are suitable for a wide range of general moulding applications and also for fabrication by automatic and isostatic moulding techniques.

Fluon® granular grades in the 200 and 400 series are intended for fabrication by granular extrusion techniques. Their processing is described in Fluon® Technical Service Note F2.

Kegs of powder should be stored in cool dry conditions, preferably between 15 and 18°C (59 and 65°F). Excessively warm powder will have impaired powder flow and handling properties. Atmospheric moisture may condense on excessively cold powder if the keg is opened in a warm room and such condensation may cause cracked mouldings. Kegs of powder which have been exposed to extremes of temperature should be allowed to stand, unopened, until they have attained workshop temperature. The temperature of the PTFE powder should preferably not be allowed to pass through the room-temperature transition point (at about 19-20°C; 66-68°F) during the moulding operation, otherwise cracked mouldings may result.

Because of its excellent electrical insulating properties PTFE readily attracts dust, and great precautions are therefore taken during the manufacture of Fluon® to prevent contamination. It is strongly recommended that similar precautions be taken in workshops where the polymer is to be processed. Ideally a moulding shop should have tiled walls and floors, and other surfaces - such as bench tops - should be similarly easy to wash and clean. Entrance should be through an air lock system, and filtered air under slight pressure should be supplied to the shop. Operatives should be supplied with clean lint-free overalls and encouraged to maintain high standards of cleanliness.

Within its working temperature PTFE is a completely inert material, but when heated to its sintering temperature it gives rise to decomposition products which can be toxic and corrosive. These fumes start to be produced during processing: for example, when the material is heated to sinter it, or when brazed connections are being made to cable insulated with PTFE. The inhalation of these fumes is easily prevented by applying local exhaust ventilation as near to their source as possible.

Smoking should not be permitted in workshops where Fluon® is handled because smoking tobacco contaminated with PTFE will give rise to polymer fumes. It is therefore important to avoid contamination of clothing, especially the pockets, with PTFE and to maintain a reasonable standard of personal cleanliness by washing hands and removing any PTFE particles lodged under the fingernails.

More complete guidance is given in the Association of Plastic Manufacturers in Europe (APME) ‘Guide for the safe handling of fluoropolymers’. Users must consult the relevant material safety data sheets before processing Fluon® PTFE.
POWDER PROCESSING CHARACTERISTICS

The principal differences between grades in the 100 and 300 series are the result of differences in the physical size and shape of the powder particles. Table I illustrates these differences by comparing some typical properties of two standard grades, Fluon® G163 and Fluon® G307. From the table it can be seen that the major difference between these grades is in particle size.

Fluon® G163 is an example of products having very small irregular shaped particles: as a result they have a low bulk density (apparent powder density) and poor powder flow properties. However, when moulded at a pressure of only 16 MPa (2320 lbf/in²) then sintered and cooled as recommended, they give articles with the highest tensile strength, with the greatest freedom from voids and therefore excellent electrical properties, and with an excellent surface finish. The strength of the preformed parts before sintering (sometimes known as the green strength) is also extremely high and this can be an important factor with some moulding operations.

Fluon® G307 exemplifies products which have much larger, nearly spherical, particles which are agglomerates of smaller particles. The higher bulk density and excellent free-flowing nature of such powders make them very suitable for automatic moulding or isostatic moulding, and easier to handle in normal moulding operations. In a given mould, filled by volume, Fluon® G307 produces a larger part than does Fluon® G163. These good powder handling properties are achieved at the expense of a small reduction in tensile strength, surface finish, preform strength and electrical properties compared with products such as Fluon® G163. For G307 a moulding pressure of 32 MPa (4640 lbf/in²) is recommended although pressures as low as 20 MPa (2900 lbf/in²) may be acceptable for some applications.

Figures 1 and 2 show the variation with preforming pressure of the tensile properties of discs moulded from Fluon® G163 and G307. It can be seen that Fluon® G163 has reasonable tensile properties when moulded with a preforming pressure as low as 8 MPa (1150 lbf/in²), but the use of such low pressures is not generally recommended because of the pressure decay which normally occurs throughout a column of PTFE powder, and because of the greater sensitivity of the properties to small changes in preforming pressures at these low pressures.

During sintering the dimensions of PTFE moulded articles change significantly with a reduction in the dimensions perpendicular to the direction of preforming pressure application (shrinkage), and an increase in the dimensions parallel to the direction of pressing.

Shrinkage is dependent on preform size and shape, preforming pressure, other preforming conditions such as time and temperature, and sintering/cooling conditions. Of these variables, preforming pressure has the major effect on shrinkage.

Table 1. Typical properties of Fluon® granular grades G163 and G307. (Not to be used for specification purposes)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>G163</th>
<th>G307</th>
</tr>
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<tbody>
<tr>
<td>Median particle size</td>
<td>µm</td>
<td>25</td>
<td>675</td>
</tr>
<tr>
<td>Bulk density</td>
<td>g/l</td>
<td>375</td>
<td>725</td>
</tr>
<tr>
<td>Compression ratio</td>
<td></td>
<td>4.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Powder flow</td>
<td></td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Preform strength</td>
<td></td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Surface finish</td>
<td></td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Recommended preforming pressure*</td>
<td>MPa</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>lbf/in²</td>
<td>2320</td>
<td>4640</td>
</tr>
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*See figs 1, 2 and 3
Figure 1. Effect of performing pressure on tensile strength (N.B. Typical values - not to be used for specification purposes)
Figure 2. Effect of performing pressure on elongation (N.B. Typical values - not to be used for specification purposes)
Figure 3 shows the variation in the diametral shrinkage (based on the mould case dimensions) of discs of Fluon® G163 and Fluon® G307 made with a range of preforming pressures and all sintered under the same conditions. Diametral shrinkage decreases as pressure increases, the effect of changes in pressure being smallest at higher pressures. It follows that the shrinkage of a set of moulded pieces made at the same nominal pressure will be less sensitive to any slight variations in pressure the higher this pressure is. There is, however, an upper limit to the permissible preforming pressure, because very high pressures cause so much internal stress in the preforms that they are liable to crack during sintering. This limit will vary with preform geometry but 50 MPa (7250 lbf/in²) should not normally be exceeded except when small parts are moulded automatically.

MOULD DESIGN

A typical mould used for Fluon® is shown in Plate 1. The body of the mould is made of a heat-treated high chrome steel, which is corrosion-resistant, and permits a high maximum working pressure with a comparatively thin wall. The end plates and mandrel may be of the same material; alternatively end plates of carbon steel may be used, chrome-plated for wear resistance and to prevent rusting. This type of mould gives excellent service in every way - freedom from rust contamination, freedom from distortion during preforming and hence easy ejection of preforms. It resists damage from rough handling, which in turn prevents scoring of preforms. However, the relatively high cost will often rule out this construction when a large number of moulds, mandrels and end plates is required to provide a comprehensive range of preform sizes. A more common construction, which is sufficiently serviceable, consists of chrome-plated carbon steel for the body and mandrel, with nylon or similar hard, non-metallic material for the end plates. The surfaces of the mould and mandrel in contact with the preform should have a good finish (0.1-0.2 µm: 5-10 µ inches Rₐ) to assist preform ejection. The clearance between sliding parts should be between 0.075 and 0.125 mm (0.003 and 0.005 inch) depending on diameter. This loose fit permits ready release of trapped air during the preforming cycle at the expense of the formation of a small amount of flash.

To avoid distortion of the moulds during preforming the wall thickness must be adequate for the range of preforming pressures to be used. Wall thickness may be calculated using Lamé's Thick Cylinder formula:

\[ t = \frac{D}{2} \left( \sqrt{\frac{f + p}{f - p}} - 1 \right) \]

where
- \( t \) = wall thickness
- \( D \) = internal diameter
- \( f \) = tensile yield stress of mould material
- \( p \) = internal pressure

Since PTFE powder does not behave as an incompressible fluid, the conditions during preforming are not hydrostatic. Work with PTFE by the UKAEA has shown that the internal radial pressure is about 70% of the applied axial pressure. Using this factor, assuming a working axial pressure of 50 MPa (7250 lbf/in²), and applying a safety factor of two, the required wall thicknesses for High Chrome Steel and Carbon Steel have been calculated for a range of mould diameters, as shown in Figure 4 (p.13). When designing moulds it is worth considering the possibility that they may at some time also have to be used with filled grades of PTFE, in which case they should be designed to withstand preforming pressures up to 90 MPa (13000 lbf/in²) or even higher.

When making a mould for an item of any given diameter, allowance must be made for the diametral shrinkage of the PTFE which occurs during sintering. Thus, the mould should be made slightly oversize, using the data given in Figure 3 as a guide. The exact diameter of the finished moulding will depend on the type of powder used, and on the preforming and sintering conditions. It is not usual to work to close tolerances in conventional compression moulding of PTFE blocks and tubes, but for a given mould and type of PTFE powder it should often be possible, by careful control of processing conditions, to maintain the diameter within about 1 to 2 mm of the desired value. With small mouldings closer tolerances than this may be possible, while very large blocks may require a greater machining allowance because of the difficulty of achieving perfectly parallel sides.

Plate 1. Components of a typical mould for Fluon® PTFE

§ United Kingdom Atomic Energy Authority
The length of mould required is calculated using the compression ratio value for the powder grade used (see Table 1). Compression ratio is defined as the ratio of the height of the powder in a mould to the height of the finished, sintered, block. Compression ratio values take into consideration the fact that an increase in height occurs during sintering. However, this ratio is usually not sufficiently precise to calculate the exact volume of powder required so the amount is better calculated on a weight basis, assuming that the final specific gravity of the sintered part will lie between 2.16 and 2.18.

**Example**

It is required to mould a solid cylinder, using Fluon® G163, to dimensions of 100 mm diameter, 100 mm length. Using a moulding pressure of 16 MPa (2320 lbf/in²) an allowance must be made for a diametral shrinkage of approximately 5%.

Hence the mould diameter required is: \[
\frac{100}{0.95} \text{ mm} = 105 \text{ mm}.
\]

The weight of powder required is \(\pi \times (5)^2 \times 10 \times 2.17 = 1704\) g. The compression ratio for G163 is 4.4 (Table 1). Therefore the mould height required is approximately 4.4 x 100 mm.

For convenient handling the mould may be made in sections which fit accurately together: this is especially necessary when long preforms are required. With this type of construction only the lowest section need be made to withstand the full moulding pressure, and the upper sections may be progressively lighter. This is because much of the initial compaction is achieved at low pressures. The typical relationship between powder height and preforming pressure is shown in Figure 5.

**Figure 3. Typical effect of preforming pressure on shrinkage during sintering**
Figure 4. Suggested wall thickness for cylindrical moulds to be used at performing pressures up to 50 MPa (7250 lbf/in²)
**PREFORMING TECHNIQUES**

The preforming process is basically simple and straightforward, but careful attention to several detailed aspects is needed if good quality preforms are to be produced consistently.

**Presses**

In selecting a press to use for moulding PTFE, consideration must be given to the following characteristics:

1. the total thrust which the press is capable of delivering
2. the daylight of the press, i.e. the space between the upper and lower platens
3. the length of stroke of the ram
4. the degree of control which can be exercised over platen movement.

A press should be provided with controls which allow for a steady and even application and removal of pressure. Poor or faulty equipment with uneven or jerky platen movement will usually cause cracked mouldings. A much more consistent product can be obtained by installing a system of automatic control, using a variable output pump and built-in timers to control approach speeds and dwell times.

**Figure 5. Typical effect of preforming pressure on compaction of Fluon® G163 and G307.**

Mould diameter 100 mm. Initial height of powder 280 mm. All measurements made on unsintered preforms.
As the initial height of the column of powder in the mould is greatly reduced during preforming, a press used for the moulding of Fluon® should have a large daylight and a long stroke. This factor is of relatively little importance when sheet is being moulded but becomes increasingly important when tall blocks are being produced. For the production of exceptionally bulky or long mouldings, pre-pressing with an air-cylinder to reduce powder height is advisable.

**Mould-filling**

PTFE powder must be added to the mould as uniformly as possible, to ensure even pressure distribution and removal of air during the pressing stage. With a free-flowing grade such as Fluon® G307 the powder may simply be poured into the mould cavity, care being taken to distribute it evenly across the mould area: tapping or vibration of the mould case will often help to settle the powder evenly. Powders such as Fluon® G163 have a tendency to form loose agglomerates, and it may be necessary to place a coarse sieve, eg. 8-mesh, 2 mm (BS 410), over the mould during filling, to break up any such lumps. Alternatively, a simple rotary disagglomerating device may be used: this is particularly helpful when Fluon® G163 has to be spread evenly over a relatively large area, as, for example, when pressing sheet. This device can be made cheaply, and construction details are available on request.

The moulding of sheet is in principle the same as the moulding of a solid cylinder, but greater care has to be taken to fill the mould evenly and to ensure that the powder is level. Because the powder depth is usually relatively small, any unevenness in the powder distribution will cause uneven pressing, resulting in a sheet with areas of variable density or thickness. Levelling may be achieved in two ways: either the mould may be filled to just above the top, and the surplus powder removed carefully with a straight edge, or it may be filled to below the top, and the powder distributed evenly with a thin wire. The wire must be taut, and it should be suspended from a frame resting on the top of the mould rim, so that it can be moved over the whole sheet area, exactly parallel to the plane of the sheet.

It is generally advisable to add the whole PTFE powder charge to the mould before any compaction is attempted, as joins between successively-pressed charges are potential points of weakness which may lead to preform cracking. However, an important exception to this rule is Fluon® G163, which has such a high preform strength that pre compaction of successive charges is possible with little risk of cracking. This technique of incremental pressing has the advantage that much longer mouldings can be made in a given mould than would be expected from a powder with a compression ratio 4.4:1. By repeated filling and pre compaction it is theoretically possible to obtain a preform almost as long as the mould case, though in practice more than three or four successive fillings are rarely likely to be worthwhile. The compaction pressure used between successive charges should be kept below 1 MPa (145 lbf/in²) to avoid the formation of weak joints between successive charges.

**Pressing**

The objective is to compact the powder in such a way that as much of the entrapped air as possible is expelled from the mould, which requires that compaction take place slowly, to give the air time to escape. Because the powder undergoes some elastic deformation during pressing, it is also essential that the pressure is applied and released slowly to avoid preform cracking caused by sudden stress changes. The optimum pressing cycle will depend on the size and shape of moulding, and should be determined by experiment. For small mouldings a relatively fast rate of press closure, eg. 150 mm/minute (6 inches/minute), is often possible though this should be reduced when compaction is almost complete, to prevent too rapid a rise of pressure. On the other hand, with long or large diameter mouldings the trapped air will take longer to diffuse out, and much slower compaction rates are necessary, from about 50 mm/minute (2 inches/minute) initially to as little as 5 mm/minute (0.2 inches/minute) at the end of compaction. Once the required preforming pressure has been reached the powder is held at this pressure for a time depending on the weight of the moulding. As a guide, a dwell of approximately 2 to 3 minutes per kg of PTFE is normally satisfactory, though for very large mouldings a proportionately shorter dwell than this is adequate, perhaps as low as 1/2 minute per kg.

The PTFE is, for convenience, normally compacted from the top only, by means of a cylindrical distance piece between the upper press platen and the top pressing piece of the mould. This distance piece must be long enough to stand clear of the mould case when compaction is complete; it must also be strong enough to withstand the maximum thrust applied to the moulding and its ends must be machined at right angles to its length. However, such single-ended application of the final moulding pressure is not recommended, except for very short mouldings, because of the pressure decay which occurs along the whole length of the moulding, as a result of friction between the PTFE and the wall of the mould case.

Such pressure decay will not only cause a variation in shrinkage along the moulding but may also lead to porosity in the lower part of the moulding. For this reason it is common practice to compact the powder, and then to give a short initial pressing, with a mould arrangement such as that shown in Figure 6 where the spacers below the mould case prevent the lower end plate from moving flush with the mould case during compaction. The pressure is then reduced until it is such that the spacers can be removed so that when pressure is re-applied it acts on the lower end plate as well as the upper one (Figure 7). This double-ended pressing ensures a preform of much more uniform properties. The spacer method is ideal for use with large moulds as it prevents unnecessary lifting of the heavy assembly.
Figure 6. Initial compaction: single-ended

Even when double-ended pressing is used, there is a limit to the length of preform which can be made without unacceptable porosity or excessive shrinkage at its mid point, because there is still pressure decay from the ends to the mid-point. As a rough rule-of-thumb, the maximum satisfactory length for a solid cylindrical preform is about eight times its diameter, and for a tubular preform about sixteen times its wall thickness. If the surface finish of the mould wall is rougher than that recommended (see Mould Design, page 11), friction will be greater, and the maximum preform length correspondingly shorter. Use of a higher preforming pressure than that recommended for a specific grade may sometimes allow somewhat longer mouldings to be made without porosity or ‘hour-glassing’ at the mid point, but there is a limit imposed by the tendency of over-pressing to cause cracking.

When pressing is complete the pressure should be reduced slowly - say 10 to 20 seconds for parts of about 1 to 2 kg, and longer for large mouldings. This controlled pressure release allows elastic recovery of the PTFE to take place slowly - an immediate height increase of about 2 to 3% may be expected.

Ejection
The final stage in the moulding process is the ejection of the preformed part from the mould.

Preform ejection from the mould should be carried out in one smooth continuous stroke. It is not usually necessary to time the rate of ejection: about 10 mm/second (0.4 inch/second) may be taken as a starting point, for most mouldings, but very large preforms may require much slower ejection. Where a central mandrel has been used during the moulding process it should be left in the preform until the latter has been ejected from the mould: the mandrel is then pressed out of the preform. Ejection may be done in the press used for the preforming operation, with an arrangement as shown in Figure 8 or alternatively, and better, in a press designed for ejection, such as that shown in Figure 9.

The precise thrust needed to eject a preform from a given mould will depend on the internal surface finish of the mould, the wall thickness and the preforming pressure used. It will always be considerably less than the thrust used for preforming but must be adequate to carry out ejection without stopping.

The reason for taking these precautions during ejection is that during preforming the preform is subjected to a radial compressive stress which, because of the friction between the PTFE and the mould wall, and the relatively slow elastic recovery of PTFE, does not fall to zero when the applied pressure is removed. This residual stress causes the preform to expand slightly as it emerges from the mould. Stop-start ejection can cause uneven expansion, which is liable to induce circumferential cracks in the preform and these may be difficult to detect until after sintering. This type of cracking is likely to occur, even with careful ejection, if the mould distorts significantly under pressure, but use of a mould with adequate wall thickness will avoid this problem. A smooth surface finish on the mould wall also helps to avoid cracking of the preform by reducing the friction between preform and mould.

After ejection there is still some residual stress in the

Figure 7. Pressing: double-ended

Mould extension removed
Thrust applied through distance piece
Top pressing piece
Mould case
Compacted PTFE powder
Bottom pressing piece
Split ring spacers
Press platen
Press platen
Figure 8. Alternative arrangements for preform removal
preformed article, which is released during the sintering cycle. With very large preforms (eg. those with a minimum dimension greater than about 150 mm; 6 inches) it is advisable to allow a relaxation period of 12 to 24 hours at ambient temperature before sintering, to reduce the risk of cracking occurring as the preform is heated.

**AUTOMATIC PREFORMING**

Many small articles may be directly moulded to size on the various types of automatic presses available, at production rates much higher than those which can be achieved with traditional moulding techniques. Free-flowing grades of powder such as Fluon® G307 are required for this process. The preforming pressure should be slightly higher than that used for the conventional preforming process; the exact pressure required, and the optimum press cycle, usually have to be found by experiment for the particular moulding and the type of press concerned.

Initial mould dimensions should be calculated from shrinkage data such as that given in Table 1 and Figure 3 but because shrinkage depends on so many factors it will often be necessary to modify the mould size by experiment until the required preform dimensions are obtained. It is therefore advisable to make the mould parts with initial dimensions such that modifications can be made by machining. Minor adjustments to the size of finished articles can be effected by small changes in moulding pressure and pressing and sintering cycles.

**ISOSTATIC PREFORMING**

Isostatic preforming is a method of pressing PTFE powders which enables complex preforms to be made close to the required dimensions, thus requiring the minimum of machining.

The sintered components have a high degree of uniformity in physical properties. These inherent characteristics are attributable to powder compaction by means of a pressurised fluid, the powder being separated from the fluid by an impermeable membrane sufficiently flexible to transmit the pressure.

It is a process which complements the other methods of preforming, being of benefit where one or more of its advantages are significant. For example, it gives more uniform properties and requires less costly moulds, making it attractive for the manufacture, especially in small quantities, of items such as large tubes, thin walled shells and rods or tubes with high length/diameter ratios. The possibilities of making complex mouldings and of reducing material/labour costs are attractive for the manufacture of many components - e.g. articles with a closed end such as beakers and bottles.

It is less suitable than conventional preforming techniques for the production of relatively small, simple, symmetrical shapes, and less suitable than extrusion for the large quantity production of long rods or tubes.

Free flowing, low compression ratio powders such as Fluon® G307 are required for this process. This type of powder facilitates complete and uniform mould filling (even with intricate shapes) and ensures that the flexible membrane does not have to deform too severely in order to transmit the full pressure.

A detailed description of the isostatic preforming of PTFE, including practical aspects such as mould design, is given in Fluon® Technical Service Note F14, Isostatic Compaction of PTFE Powders.

The main technique used nowadays for sintering PTFE
Figure 9. A typical preform ejection press (shown in use for downward ejection)
Section 4. Sintering

is free-sintering, in which the preform is sintered after removal from the mould. An alternative method is pressure-cooling, in which the mould containing the preform is placed in an oven during sintering, removed while still hot, and returned to the press where pressure is applied during cooling. In the past the use of pressure cooling was often necessary to obtain acceptable properties from the PTFE moulding, but with modern PTFE powders free-sintering is nearly always satisfactory. However, pressure-cooling can still offer some advantages in special circumstances, for example in holding the shape of particular mouldings which might be liable to distort if free-sintered, or in making long mouldings in which the centre portion might be underpressed because of pressure decay during preforming. The pressure-cooling technique is more expensive to operate than is free-sintering, as both mould and press are occupied for much longer. Also, cooling under pressure creates considerable stresses in the PTFE moulding, so annealing after sintering is often necessary if dimensionally-stable parts are required.

When thin-section preforms are free-sintered, some means of preventing distortion may be necessary. For example, to produce a really flat sheet it may be necessary to place a light load, such as a rigid metal plate, on top of the sheet during the whole of the sintering process. Thin-walled tubes, sintered on end, are liable to bend unless a metal mandrel is placed inside to give support to the PTFE when in the gel state; the diameter of this mandrel should be such that the moulding does not grip it tightly when it shrinks on cooling after being sintered.

SINTERING EQUIPMENT

The commonest way of sintering PTFE preforms is by a batch process in an electrically-heated oven. To ensure reasonable economy in operation, the oven should be well insulated to reduce heat losses. It is advisable for the oven to have a chimney venting to atmosphere outside the building to minimise the chance of toxic products formed during sintering entering the working area. It is also possible to arrange for the heated chamber to be exhausted to atmosphere as the oven door is opened. Sintering is normally carried out at temperatures between 360°C (680°F) and 380°C (716°F).

It is essential that the temperature within the oven should be uniform and this is normally achieved with a system circulating air within the oven. Trays should be perforated to help air circulation. Temperature differences between the hottest and coolest parts of the oven should not exceed 5°C (9°F).

It is desirable for the oven to be fitted with a programmable time/temperature controller; this will enable a sintering cycle to be set when the preforms are placed in the oven so that no further attention will be necessary until the mouldings are removed. Apart from the controlling thermocouple one or more separate indicating thermocouples should be employed. The whole system should be regularly calibrated.

For reasons of safety an automatic temperature cut-out adjustable between 380 and 410°C should be installed. If, for any reason, the temperature cut-out fails and the oven temperature rises out of control, the heat should be switched off but the oven doors should not be opened until the oven has cooled.

When small mouldings are made at high output rates, as is common with automatic preforming equipment, a conveyor oven, as opposed to the more usual batch operation, may be used to give continuous sintering. The optimum temperature profile and throughput rate must be found by experiment for the particular preforms being sintered.

TIMES AND TEMPERATURES

Sintering a PTFE moulding involves heating it at a temperature well above its crystalline melting-point of about 340°C (645°F) until the individual PTFE particles coalesce and lose their identity. The melting-point falls to the traditionally quoted 327°C (621°F) only after PTFE has been melted for the first time. The time required to complete the sintering process depends on:

Maximum temperature reached
Rate of heating
Rate of cooling
Thickness of PTFE through which heat has to pass
**Maximum temperature**

In general, the higher the maximum sintering temperature, the quicker can sintering be completed, but an upper limit is imposed by the tendency of PTFE to degrade slightly at very high temperatures. For granular Fluon® grades (and for most filled grades) a maximum sintering temperature of 370°C (700°F) is recommended. Small mouldings can be sintered at up to 380°C. However, for thicker section pieces and for grades containing fillers which are less thermally stable than PTFE it is advisable to reduce the peak temperature to 360°C.

Some sintering will take place at all temperatures above the melting-point, so that the effective sintering time is always longer than the dwell period at maximum temperature.

**Rate of heating**

The rate of temperature rise, particularly with large mouldings, is limited by the need to minimise stresses set up in the moulding as it expands on heating, particularly when close to the melting-point, as a volume change of about 25% occurs during the change from solid to gel state.

For very thin section mouldings (e.g. sheet), it is often possible to use very fast heating rates such as may occur, for example, in a conveyor oven, or even to place the moulding in an oven already heated to 380°C (716°F). For thicker sections it becomes necessary to reduce the rate of heating and to incorporate a dwell period at 310°C (590°F) so that the entire moulding reaches the same temperature before it passes into the gel state.

**Rate of cooling**

For very thin mouldings, the rate of cooling is governed mainly by the crystallinity required in the finished product, slow cooling giving maximum crystallinity, and quench cooling minimum crystallinity. The effect of crystallinity on the properties of PTFE mouldings is summarised in Table 2.

For thicker mouldings fast cooling is inadvisable because of the risk of introducing high stresses which may cause cracking or severe distortion. In general, the rate of cooling back to room temperature should be relatively slow with a dwell period at 300°C (572°F) necessary to minimise residual stress in the moulding. If completely stress-free mouldings are required a further dwell of up to 6 hours at 250°C (482°F), should be included in the cycle. Alternatively, annealing may be done as a separate operation, with a dwell period at 250°C (482°F), followed by cooling at a rate not greater than 30°C/hour (54°F/hour).

**General form of sintering cycle**

A typical sintering cycle, incorporating a dwell period at maximum temperature and various rates of heating and cooling, is shown in generalised form in Figure 10.

**Effect of section thickness**

The length of each of the seven time intervals shown in Figure 10 is governed by the section thickness of the moulding, which is defined as the minimum dimension, e.g. the wall thickness of a tube (provided that the bore is large enough to allow free passage of air during sintering), the diameter of a solid rod, or the thickness of a sheet or disc.

Figures 11 and 12 show sets of graphs which relate the length of each time interval to the section thickness for solid and tubular mouldings respectively. The complete cycle for any thickness is obtained by adding together the times for each of the seven intervals.

No attempt has been made to present cycles for mouldings less than 20 mm (0.8 inch) thick, as such a wide range of possibilities exists. Mouldings in the thickness range of 20 - 50 mm (0.8 to 2.0 inches) are relatively non-critical as regards sintering cycle, so the graphs are shown as dotted lines to indicate that other cycles may give equally good results. However, as sintering time and temperature can have a marked effect on the end properties of PTFE mouldings, any cycle, once chosen, must be closely adhered to if mouldings of consistent quality are to be produced.

The use of Figures 10, 11 and 12 for some typical mouldings is demonstrated in Table 3.

**Type of polymer**

Cycles based on Figures 10 and 11 are suitable for all Fluon® granular moulding grades. Peak temperature may need reducing for certain filled grades.

**Pressure-cooling**

Where pressure-cooling is used, a longer dwell at maximum temperature will usually be necessary. This is partly because the mould case also has to be heated, and partly because the rapid cooling, which occurs when the mould and moulding are transferred from oven to press, reduces the time during which the moulding is in the gel state.

With small mouldings it may be possible to place the mould containing the preform in an oven already heated to 380°C (716°F).

After the dwell at sintering temperature (the optimum time must be found by experiment) the mould is transferred to a press, and the moulding is allowed to cool under pressure. Air- or water-cooling may be used to reduce the cooling time.
Table 2. Effect of crystallinity on certain properties of PTFE

<table>
<thead>
<tr>
<th>Low crystallinity (quenched or fast-cooled)</th>
<th>High crystallinity (slow cooled ≤ 30° C/h; 54° F/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower shrinkage</td>
<td>Less distortion</td>
</tr>
<tr>
<td>Great transparency</td>
<td>Lower residual stress</td>
</tr>
<tr>
<td>Better flex life</td>
<td>Better dimensional stability</td>
</tr>
<tr>
<td>Higher tensile strength and elongation to break</td>
<td>Lower permeability</td>
</tr>
<tr>
<td></td>
<td>Higher specific gravity</td>
</tr>
<tr>
<td></td>
<td>Lower creep</td>
</tr>
</tbody>
</table>

Table 3. Typical PTFE sintering cycles derived from Figures 10 and 11

<table>
<thead>
<tr>
<th>Examples</th>
<th>Rod</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter 100 mm</td>
<td>Outside diameter 550 mm</td>
</tr>
<tr>
<td></td>
<td>Height &gt;100 mm (Section thickness 100 mm)</td>
<td>Height &gt;200 mm (Section thickness 200 mm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interval number</th>
<th>Temperature range</th>
<th>Rod</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Room temp. to 310</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>dwell at 310</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>310 to 370</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>dwell at 370</td>
<td>5.5</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>370 to 300</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>dwell at 300</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>300 to 100</td>
<td>4.5</td>
<td>19</td>
</tr>
</tbody>
</table>

Total cycle 25 hours 123 hours

Figure 10. General form of a PTFE sintering cycle
Figure 11. Sintering cycle time intervals related to section thickness for solid mouldings
Figure 12. Sintering cycle time intervals related to section thickness for tubular mouldings
Section 5. Quality assessment

Simple physical tests such as the determination of ultimate tensile strength and elongation, and the measurement of relative density (specific gravity), can provide an assessment of product quality. The values obtained for tensile properties are very dependent on the method of specimen preparation, and on the test procedure, so this test is really most useful as a measure of product consistency. There are, however, many specifications issued by national standards organisations and other bodies, which incorporate standardised test procedures and limits for various specific types of PTFE product. Please contact AG Fluoropolymers for details. The most important international standards are ISO 12086-1 and –2:1995 for raw materials and ISO 13000-1 and –2:1997 for semi-finished products.

A rapid check for gross defects in moulded articles may be made by treating a sample with a penetrant dye such as ‘Ardrox’ 996P2†. Porosity or fine cracks may then be detected by visual examination. This simple test procedure is non-destructive and may alone be an adequate test for parts intended for non-critical end uses.

† Supplied in the UK by Chemetall plc, 65 Denbigh Road, Bletchley, Milton Keynes, MK1 1PB (UK)
Tel. +44 (0) 1908 649333 Fax +44 (0) 1908 361872
www.aerospace.chemetall.com
in mid-Europe by Chemetall GmbH, Frankfurt a.M. Tel. +49 (0) 697165-0
and in the USA by Chemetall Oakite, 50 Valley Road, N.J. 07922, Berkeley Heights
Tel. +1 908 508 2214 Fax +1 908 464 7914 Toll-free 800 526 4473
www.oakite.com
Section 6. Diagnosis of faults in mouldings

Table 4 lists some of the faults which may occur during moulding with possible causes and suggested ways of avoiding them.

Table 4. Common moulding faults and their avoidance

<table>
<thead>
<tr>
<th>Fault</th>
<th>Possible cause</th>
<th>Suggested corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Preform is cracked in planes perpendicular to direction of pressing.</td>
<td>(i) Incorrect ejection procedure.</td>
<td>Adopt recommended procedure using slow, continuous ejection.</td>
</tr>
<tr>
<td></td>
<td>(ii) Mould wall is too thin for preforming pressure used, causing temporary or permanent 'barrelling' of mould during preforming, which overstresses preform on ejection.</td>
<td>Check wall thickness against that recommended, and determine if there is any permanent distortion of the mould. Check that pressure gauge is not reading low.</td>
</tr>
<tr>
<td></td>
<td>(iii) Mould wall has localised damage (e.g. a metal burr) which causes high stress concentration in the preform as it is ejected over the damaged area.</td>
<td>Check condition of mould wall surface, and machine or grind if necessary.</td>
</tr>
<tr>
<td></td>
<td>(iv) Powder excessively cold.</td>
<td>Condition powder as recommended.</td>
</tr>
<tr>
<td></td>
<td>(v) Entrapped air.</td>
<td>Decrease press closing rate. Check end plate clearances.</td>
</tr>
<tr>
<td>(2) Preform is scored longitudinally.</td>
<td>Indentation in edge of mould at end through which ejection took place.</td>
<td>Repair indentations. Deep scores may lead to preform cracking.</td>
</tr>
<tr>
<td>(3) Preform is weak and friable.</td>
<td>Underpressing.</td>
<td>Check that press gauge is reading correctly. Check that end plates do not tilt excessively. Check that press platens are substantially parallel. Check that pressure transmitting piece is not bent.</td>
</tr>
<tr>
<td>(4) Preform weak and friable at one end only</td>
<td>Underpressing caused by pressure decay.</td>
<td>Check that correct double-ended pressing technique is used.</td>
</tr>
<tr>
<td>(5) Sintered article shows cracks as in (1) above.</td>
<td>(i) Cracks may have been present in preform but not noticed.</td>
<td>Check similar preform by applying felt tipped marker pen to surface and removing surplus ink with rag moistened with suitable solvent. Minute cracks show up in this way. Correct as in (1) above.</td>
</tr>
<tr>
<td></td>
<td>(ii) Rates of heating and cooling too rapid during sintering.</td>
<td>Check oven temperature cycle. Use cycle as recommended.</td>
</tr>
<tr>
<td>Fault</td>
<td>Possible cause</td>
<td>Suggested corrective action</td>
</tr>
<tr>
<td>-------</td>
<td>----------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>(6) Hollow tape billet exhibits cracks on internal wall.</td>
<td>Air circulation through central hole restricted during sintering, causing incorrect rate of heating at internal surface.</td>
<td>Check that free air circulation through central hole is possible when billet is loaded into oven: Reduce rate of heating during sintering cycle. Increase size of central hole.</td>
</tr>
</tbody>
</table>
| (7) Sintered article cracked in an irregular manner. Cracks may be discrete or may link up at random angles. Cracks may penetrate deeply into article. | (i) Excessively high preforming pressure used.  
(ii) Insufficient relaxation time allowed before sintering.  
(iii) Excessively long sintering time used. | Adjust pressure to within recommended range.  
Allow increased relaxation time especially for very large preforms.  
Reduce times to those recommended. |
| (8) Sintered article bent. | (i) Uneven pressure application.  
(ii) Uneven sintering oven temperature; possibility of cold spots. | Check items under (3) above.  
Check oven for ingress of cold air. Reduce air flow if forced extraction system used. Check all oven heater elements. |
| (9) Sintered article shows smaller diameter at centre than ends and/or centre section of moulding is porous to penetrant dye. | Excessive pressure decay during preforming. | Increase preforming dwell time at pressure.  
Improve surface finish of mould.  
Increase moulding pressure slightly.  
Check that mould end plate clearance is sufficient.  
Reduce length of preform.  
Try pressure-cooling if no other solution satisfactory. |
| (10) Sintered article shows signs of melt flow after sintering. Internally article may show discolouration and evolution of gas. Metal plates in contact with article may show excessive corrosion. | Too high sintering temperature, leading to thermal degradation. | Check sintering cycle maximum indicated temperature. Check actual oven air temperature with thermocouples in several positions.  
Use chart recorder if possible to check for temperature fluctuations.  
Ensure oven cutout operates at 400-410°C (752-770°F). |
| (11) Regions of sintered articles have ‘chalky’ appearance and poor physical properties. | Local undersintering caused by ingress of cold air, or gross overloading of oven, restricting air flow. If effect is uniform at centre of moulded section, sintering cycle may be too short. | Check correct sinter cycle used.  
Check loaded oven air temperatures as suggested in (10).  
Check oven as in (8) (ii).  
Resinter article. |
| (12) Interior of sintered article has very dark appearance. | Too high sintering temperature, too long sintering time. | Sinter to recommended cycles.  
Slight colour change from surface to interior may be unavoidable with very thick sections. Physical properties will be affected only when discolouration is severe (usually accompanied by internal cracking). |
<table>
<thead>
<tr>
<th>Fault</th>
<th>Possible cause</th>
<th>Suggested corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td>(13) Sintered articles show distortion. Machined articles give poor dimensional reproducibility.</td>
<td>Too fast cooling rate leading to residual stress in moulding.</td>
<td>Use slower cooling rate during sinter cycle. Use stress relieving technique, either incorporated in sinter cycle or as separate operation after sintering.</td>
</tr>
<tr>
<td>(14) Gross blotches and spots of varying transparency visible in thin sections such as skived tape.</td>
<td>Oversintering.</td>
<td>Use recommended cycles. Effect may show only in the interior of large billets.</td>
</tr>
<tr>
<td>(15) Machined surfaces and thin sections such as skived tape have voids visible to the unaided eye.</td>
<td>Powder damp when moulded.</td>
<td>Check storage conditions. Ensure kegs are not opened until powder temperature is substantially the same as ambient temperature in press shop.</td>
</tr>
</tbody>
</table>
MOULDINGS WITH CHANGES OF CROSS-SECTION
(STEPPED MOULDINGS)

Plate 2 shows a flanged moulding which might be machined from a solid block, but which can be made more cheaply if moulded directly. To avoid cracking in the region where the parts of different diameter meet it is necessary to prevent powder flow during preforming across this region where the cross-section changes. It is also necessary to maintain equal preforming pressures on the two parts, each of which has a different cross-sectional area. With those automatic presses which have separately controllable rams for pressing from above and below, it is relatively easy to make this type of moulding, as the independent rams can be set for different thrusts, strokes and approach speeds. However, with conventional platen presses a modified moulding technique is needed as only a single ram is normally available.

In the past various techniques have been used but these have generally required complicated moulds or difficult operating procedures. An alternative method of making mouldings containing changes of cross-section has been developed. This uses a flexible pad or cushion to transmit the pressure from the press equally to each part, as described below.

The flexible insert or pad should be soft and resilient enough to act in a similar way to a fluid, transmitting pressure equally to each mould part and deforming to accommodate relative movement of the parts. Many rubbers and plastics having a Shore ‘A’ hardness of about 30 - 50 are likely to make suitable inserts, but those which can be cast into shape are particularly suitable.

The flexible insert can have a number of different shapes. One-piece shapes, see (a) and (b) in Figure 13 are easily damaged in use and may require frequent
re-casting or renewal. Two-piece shapes such as (c) and (d) are preferable because the part which enters the central hole in the outer pressing piece and is therefore most susceptible to damage, can be separately renewed.

Preparation of a moulding
The following operations are necessary to prepare a moulding comprising two parts of different diameter, using the flexible insert technique:

i) Take the weighed quantity of powder needed for the base, distribute it uniformly in the bottom of the mould, then compact it gently with the compacting tool, using hand pressure. (Compaction at this stage ensures that the powder will not be locally depressed by the outer pressing piece)

The thickness of the base and of the upper part of the moulding is controlled by the weight of powder used for each of these parts.

ii) Insert the outer pressing piece into the mould.

The internal edges of the outer pressing piece, which form the change in cross section of the moulding, should be radiused to prevent excessive local stress.

![Figure 13. Flexible inserts](image-url)
iii) Take the weighed quantity of powder needed for the upper part of the moulding and pour it into the cavity in the outer pressing piece.

iv) Insert the mould components which comprise an inner pressing piece, the flexible pad or pads and the top pressing piece.

Place the assembled mould between the platens of a hydraulic press with a suitable distance piece between the upper platen and the top pressing piece.

v) Compact the powder in exactly the same way as when making preforms by conventional moulding techniques, i.e. slowly apply the recommended preforming pressure, hold for a time and then slowly release.

The recommended pressure is obtained from **Table 1**, page 8, and should be calculated over the total base area of the mould.
(vi) From the mould case withdraw the complete assembly of pressing pieces which contain the preform. Take away the top and bottom pressing pieces and the flexible pads. Ensure that the preform is not stuck to the outer pressing piece by cutting away any ‘flash’.

Engage the jaws of the screw ejector with the groove provided in the outer pressing piece. Eject the preform slowly by means of the ejector screw which pushes against the inner pressing piece.

Controlled ejection of the preform, using a simple screw ejector, is particularly necessary with the flexible insert technique because ‘flash’ from the flexible pad can be forced between the inner and outer pressing pieces and considerable initial force may be needed to start ejection.

**POROUS MOULDINGS**

PTFE mouldings may be used as filters in corrosive environments, and in such instances need to have a porous structure. This can be achieved in several ways.

**Underpressing of normal moulding powders**

This is probably the most versatile method, as by varying the type of PTFE powder and the pressing technique, a wide range of pore sizes and degrees of porosity can be obtained. The exact results will depend on several factors, including the geometry of the preform, but a general guide to the effect of preforming pressure on porosity is given in Figure 14 for Fluon® G163 and G307. It can be seen that porosities (calculated from weights and volumes of the complete mouldings after sintering) of up to 30% are achievable, with G307 requiring about three times as great a preforming pressure as G163 for the same degree of porosity. Pore sizes are difficult to estimate but, as a guide, the maximum pore size achievable is likely to be of the order 10 - 20 µm for G163, and 200 - 300 µm for G307.

**Using pre-sintered powder**

Because its particles are relatively large and hard Fluon® G201 (a presintered powder designed for ram extrusion) can be used in two ways to produce articles with porosities in the region of 50% with very large-pored structures.

Using the conventional technique Fluon® G201 can be preformed at 30 MPa (4350 lbf/in²) and sintered in the normal manner. This will result in a very porous structure; however, large sectioned pieces may suffer from distortion or cracking on sintering.

A more suitable method is to fill a container uniformly with Fluon® G201 powder and then seal it so that the expansion of the PTFE is restricted. The assembly is then placed in an oven at 380°C (716°F) for sufficient time for the G201 particles to fuse together (a suggested guide for the sintering temperature is 1 hour for the mould plus a further 1 hour for every 25 mm of PTFE section). After the sintering time has elapsed the assembly is removed from the oven and allowed to cool to room temperature before the porous PTFE article is removed from the mould.

The advantages of this method are:
1. No pressing of the powder is required.
2. The finished article takes up the shape of the mould thus eliminating or reducing machining.
3. Because only very low pressures are generated by the expansion of the PTFE during the sintering operation, low cost, thin walled moulds can be used.

**UNETCHED MOULDINGS SUITABLE FOR BONDING**

A method has been developed to make it possible to bond Fluon® PTFE onto a substrate using adhesives but without the necessity of first chemically etching the PTFE.

The principle applies to moulded components, including sheet, and consists of incorporating a porous PTFE layer into the surface of the component during fabrication so that the porous surface is receptive to adhesives.

The first step is to manufacture the porous PTFE layer and this is achieved in the following manner.

A tape ring mould is uniformly filled with Fluon® G201 and closed with the normal close-fitting metal end piece. The whole assembly is placed in an oven and sintered as in the previous section. When the cooling is complete the porous moulding is removed from the mould and skived into tape using the normal skiving operation (as a suggested guide, tape of about 0.5 mm [0.020 inch] thickness should be prepared).

The porous tape can then be used to form the bondable surface of a PTFE component by placing a layer of it in the bottom of a mould before filling it with the required grade of Fluon® moulding powder (e.g. G163 or G307). The normal procedure for preforming and sintering is then carried out, resulting in a sintered component with a grainy surface receptive to adhesives.

A suitable adhesive (e.g. epoxy resin) is then spread
thinly over the degreased porous surface which can then be brought into contact with the suitably prepared substrate. More detailed information on bonding PTFE is given in Fluon® Technical Service Note F9, Finishing Processes for Polytetrafluoroethylene.

COINING

The coining process for Fluon® is similar in principle to the impact moulding of other thermoplastics such as acrylic sheet. The coining of Fluon® is carried out on a moulding which has already been sintered. The item, usually in the gel state, is transferred to the coining die where it is pressed at pressures of 15 - 40 MPa (2175 - 5800 lbf/in²) and cooled under pressure.

The guiding principle is to lose as little heat as possible in transferring the moulding in the gel state from the oven to the die, and to apply pressure as quickly as possible while the temperature is still retained. It is simplest to coin immediately after sintering but this method is not always suitable unless a rotational oven is used. The alternative is to have a separate heating oven alongside the coining press, precautions (e.g. local exhaust ventilation) must be taken to prevent operators from being exposed to PTFE fumes. If the design of the moulding incorporates thick and thin portions, care must be taken to ensure that the thin portions are at the same temperature as the rest of the moulding otherwise differential contraction and ‘frozen-in’ stress may result.

Coining can be used not only to make fine adjustments to dimensions and shape but also to change the shape radically from the original preform. Plate 3 illustrates an original moulding and a valve base coined from it.

In all instances the design must allow for lateral shrinkage. This shrinkage will depend on various factors including the size of the moulding, the polymer selected, and the pressure and temperature chosen, so trials and adjustments may be necessary before the required tolerance is achieved.

For the fabrication of large components which maintain their temperature, coining may be carried out at temperatures of 310 - 320°C (590 - 608°F). This avoids the effect of the dimensional changes which take place when the gel cools down through the transition temperature, and consequently reduces the risk of ‘frozen in’ stress.

It is a feature of parts which are shaped by coining that, on re-heating, they tend to return to their original shape. The greater the deformation the lower the maximum temperature at which the shape can be used. No trouble should be experienced with a service temperature of 150°C (302°F), but above this the useful working temperature depends on the amount of stress which has been introduced.

HEAT SHAPING

Figure 14. Typical effect of preforming pressure on porosity of Fluon® sintered mouldings. (Mould diameter 100 mm, and height 280 mm, volume filled with PTFE powder)
Using conventional heat shaping equipment, shapes may be formed from skived Fluon® sheet in the thickness range 0.25 - 0.75 mm (0.01 - 0.03 inch).

Two techniques are possible using a typical machine with the PTFE sheet heated in position:

1. Drape forming using pressure and a male mould,
2. Drawing down under vacuum into a female mould.

The first method is preferable because it accommodates more readily the 25% volume expansion of the PTFE as it changes to the gel condition above 327°C (621°F). This volume expansion is largely reversible on cooling.

When heat shaping PTFE sheet the depth of any indentation in the sheet should not be greater than the width of that indentation. As the depth of draw is increased for a given width, so the sheet will conform increasingly badly to the mould; ultimately porous areas will appear in the sheet as a result of severe overstraining.

Similar overstraining will occur and porous areas result if, because of stretching, the thickness of sheet is reduced by more than half.

Good conformation to mould shape will be obtained provided radii of curvature are not less than 2.5 mm (0.1 inch). Frequent changes of direction of curvature in the mould should be avoided.

Shapes made from sheet 0.375 mm (0.015 inch) thick and above should have reasonable form stability when reheated at temperatures up to 150 - 200°C (302 - 392°F).

Plate 3. A sintered moulding and a valve base coined from the moulding
The following is a comprehensive list of Technical Service Notes on Fluon®. These are available from the AG Fluoropolymers sales office.

F1    The Moulding of PTFE granular powders
F2    The Extrusion of PTFE granular powders
F3/4/5 The Processing of PTFE coagulated dispersion powders
F6    Impregnation with PTFE aqueous dispersions
F8    Processing of filled PTFE powders
F9    Finishing processes for polytetrafluoroethylene
F11   Colouring of polytetrafluoroethylene
F12/13 Physical properties of unfilled and filled polytetrafluoroethylene
F14   Isostatic compaction of PTFE powders
F15   Cast Film from Fluon® PTFE dispersion GP1
FTI500 Fluon® - A Guide to Applications, Properties & Processing
FTI800 Potential Material & Equipment Suppliers

Further Information

Information contained in this publication (and otherwise supplied to users) is based on our general experience and is given in good faith, but we are unable to accept responsibility in respect of factors which are outside our knowledge or control. All conditions, warranties and liabilities of any kind relating to such information, expressed or implied, whether arising under statute, tort or otherwise are excluded to the fullest extent permissible in law. The user is reminded that his legal responsibility may extend beyond compliance with the information provided. Freedom under patents, copyright and registered designs cannot be assumed.

Fluon® grades are general industrial grades. It is the responsibility of the purchaser to check that the specification is appropriate for any individual application. Particular care is required for special applications such as pharmaceutical, medical devices or food. Not all grades are suitable for making finished materials and articles for use in contact with foodstuffs. It is advisable to contact the AG Fluoropolymers sales office for the latest position. Users of Fluon® are advised to consult the relevant Health and Safety literature which is available from the AG Fluoropolymers sales office.

Users of any other materials mentioned in this publication are advised to obtain Health and Safety information from the suppliers.

Note

The data on processing performance given in this publication have been observed using the stated Fluon® grades and machine conditions. These data are representative but cannot cover all cases. Processors are therefore advised to satisfy themselves of the suitability of any particular equipment or production methods for intended applications.

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