Polyurethanes are extremely versatile materials with applications as diverse as low density flexible foams providing comfort, low density rigid foams for insulation purposes and compact integral skin materials for car bumpers.

After an expected lifetime of more than 10 years, these polyurethanes can be recycled in various ways, as described in the ISOPA Recycling Fact Sheets. Regardless of the recycling technology employed, two factors play a key role in determining the technical and commercial feasibility of recycling polyurethane materials:

a) Densification of low density, voluminous polyurethane foams, allowing for energy and cost-effective transportation from collection point to recycling operation.

b) Size reduction of polyurethane articles (mattresses, car-seats, insulation panels etc.) making them suitable for treatment in the chosen recovery process, which may vary from mechanical recycling to chemolysis or energy recovery.

A range of grinding techniques has been developed for various polyurethane materials. The required particle size may vary from particles less than 200 micron for reuse as a filler, to larger pieces for feeding into a chemolysis or incineration unit.

This ISOPA fact sheet summarises the most important methods known today for compacting and grinding polyurethanes.
A significant share of polyurethane materials are used in low density foams (typically 20 to 60 kg/m³). These low densities offer many advantages during the useful lifetime of these products (weight/energy/material savings, cost effectiveness). In those cases, however, where transport of waste polyurethane materials from a collection point to a recycling plant is required, the foams need to be compacted in order to make transportation energy and cost-efficient.

Two key methods for compacting polyurethane foams are being practiced:

- baling, for flexible foams and
- briquetting, for rigid foams.

**Briquetting**

Densification of rigid foams will cause cell gases to be released. Depending on the nature of these cell gases and the need for their recovery, it may be necessary to carry out the densification process in equipment designed to collect these gases, for subsequent appropriate post-treatment. Typical equipment used for this purpose consists of a shredder, followed by a high pressure extruder or a pellet mill.

Application of heat ensures that the gases are also removed from the polymer which forms the cellular matrix. The entire system is encapsulated and operated under negative pressure to prevent leakage. Where there is the possibility of inflammable gases or fine particles being released, the equipment and process conditions should be designed to eliminate the risk of fire or explosion.

**Baling**

Densification of polyurethane flexible foams is carried out using a baling process. A typical cycle is as follows:

- loading of press
- pre-pressing (until the final length and width of the bale are reached)
- final pressing (until the final height is reached)
- binding of the bale (manual or automatic)

Transport density reached with such equipment is in the range of 100 - 400 kg/m³ (10 to 2.5 m³/ton).
Technologies for size-reduction of polyurethanes have been developed and are summarized in the overview above.

**Precision knife cutting**

For powdering flexible or rigid foams to particle sizes less than 0.25 mm, special types of knife cutters can be used. These so-called precision knife cutters are characterised by a large number of static and rotating knives.

The special sieves used in this type of equipment are designed in such a way that additional powdering is achieved.

### Polyurethane Type

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Technology</th>
<th>Supplier (e.g.)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid foam</td>
<td>Precision knife cutting</td>
<td>Pallmann</td>
<td>Prototype</td>
</tr>
<tr>
<td>&lt;0.3 mm</td>
<td>Pellet mill</td>
<td>Kahl</td>
<td>Commercial</td>
</tr>
<tr>
<td>&lt;0.2 mm</td>
<td>Ball mill</td>
<td>Tecaro</td>
<td>Prototype</td>
</tr>
<tr>
<td>Flexible foam</td>
<td>Precision knife cutting</td>
<td>Pallmann Herbold Alpine Condux</td>
<td>Commercial</td>
</tr>
<tr>
<td>&lt;0.3 mm</td>
<td>Pellet mill</td>
<td>Kahl</td>
<td>Prototype</td>
</tr>
<tr>
<td>&lt;0.2 mm</td>
<td>Solid state shear extruder</td>
<td>Berstorff</td>
<td>Developmental</td>
</tr>
<tr>
<td>&lt;0.2 mm</td>
<td>Cryogenic grinding</td>
<td>Pallmann</td>
<td>Prototype</td>
</tr>
<tr>
<td>&lt;0.2 mm</td>
<td>High shear mixing</td>
<td>Silverson</td>
<td>Developmental</td>
</tr>
<tr>
<td>&lt;0.1 mm</td>
<td>Two roll mill</td>
<td>Hennecke</td>
<td>Commercial</td>
</tr>
<tr>
<td>&lt;0.1 mm</td>
<td>Two roll mill</td>
<td>Mobius Techn. Inc.</td>
<td>Commercial</td>
</tr>
<tr>
<td>RRIM</td>
<td>Impact disc mill</td>
<td>Pallmann</td>
<td>Prototype</td>
</tr>
</tbody>
</table>

*Multi-knife rotors are used in precision knife cutters*
Two-roll mill

The two-roll mill consists of at least one pair of rollers, rotating in opposite directions at different velocities. The resulting shear forces in the very narrow gap between the two rolls convert the polyurethane foam into a fine powder with typical particle sizes less than 0.1 mm.

Machinery integrating the two-roll mill into the flexible slabstock process was developed by Hennecke for the purpose of feeding the reground powder from production cuttings directly back into the manufacture of flexible slabstock foam.

Flakes are ground into powder by the two-roll mill, sieved and stored in a silo.

Then, the powder is transported via a feed screw and blended in a premixer with polyol. The premix is then transported to the mixing head, where it is reacted with isocyanate and then poured to make flexible slabstock foam. Hennecke claims successful usage of up to 30% regrind in the process.

Pellet-Mill

The pellet-mill consists of two or more metal rollers, which press the polyurethane foam through a metal plate with small holes (die). Depending on type of foam and processing conditions, the output of the mill consists either of fine polyurethane powder or of compact pellets.

These are suitable for transport or for feeding into an incineration unit. During the operation of the mill, the polyurethane material is subjected to heat in the process, dependent on rollers speed, die thickness, and diameter of the holes.

Impact disc mill

Grinding of RIM or RRIM materials is done typically in a two step process. Materials are first granulated in a knife mill to a particle size of ca. 3 mm and then in a second step powdered in an impact disc mill. This typically gives a powder containing a fraction of ca. 40% with a particle size of less than 200 micron. This material can be separated by sieving. The larger granules can be fed into the grinding operation again or used for other applications.
Cryogenic grinding

Because of the resilient / elastic nature of flexible polyurethane foams, the grinding of these materials to small particle sizes is difficult, in particular when the material is heated up during the grinding operation.

Extruder

A process for grinding various polyurethane foams (from rigids to flexibles) to fine powders was developed using solid state shear extrusion (Shutov, Berstorff). The method operates at moderate temperatures (20 - 100°C).

By cooling these materials to well below the embrittlement temperature, e.g., liquid nitrogen, the grinding process can be made much more efficient.

Particle sizes that can be obtained depend on the type of polyurethane foam; for rigid foam, particle sizes less than 0.032 mm were reported, for flexible foam a particle size less than 0.17 mm was obtained.

CAUTION

As with any organic powder, precautions must be taken to prevent powder explosions. Flexible foam powder, e.g., has been found to promote flame propagation at more than 100 g/m³.

Specific types of polyurethane foams may contain flammable blowing agents and/or flame retardants. Whilst the manufacturing, processing and normal use of such foams, in particular rigid polyurethane foams for construction, is well understood and controlled, the secondary processing of these materials for recycling purposes is currently less well understood.

The suitability of materials for the envisaged recycling process and necessary precautions required to prevent work-place exposure and emissions should at all times be checked.

RECOMMENDATIONS

The correct choice of equipment may depend on many factors and should be performed in close consultation with equipment manufacturers.

Depending on the article to be ground, precautions might be required to prevent damage to the equipment by, e.g., steel inserts.

Consult national and local regulations which may govern the recovery and disposal of materials. Observation of such regulations includes the recovery and disposal of CFC’s, if and when contained in these materials.

Recycling companies are kindly invited to submit to ISOPA their references in case they are active in practicing PU recycling and recovery.

The overview can only give the most important grinding/densification methods and lists only the suppliers known to the authors at present. No recommendation from ISOPA can be derived from this fact sheet. Furthermore, nothing contained herein shall be construed as a recommendation to use any product in conflict with existing patents and regulations covering any material or its use.