Trim The Weight, Not The Comfort

Molded flexible foam with Honeywell Solstice™ Liquid Blowing Agent cuts weight up to 20% in seats, carpet underlayment, other acoustic parts, integral skin and more — all without sacrificing comfort, durability and acoustics. You’ll have the flexibility to meet desired designs while trimming weight to more easily meet MPG and environmental goals. Plus, it’s nonflammable and U.S. EPA SNAP-listed.

Learn more at honeywell-blowingagents.com or 1-800-631-8138.
Rohacell Triple F: Innovative high temperature foam for sandwich components

Sandwich designs are used in a wide variety of applications in multiple industries and for many years there has been a growing interest in the automotive industry. However, innovative solutions are needed to fulfill expectations related to costs and volumes. The manufacturing processes and the materials used, such as resin systems and core materials, must all be suitable for high-volume production. Now, with the development of Rohacell Triple F, a competitive solution is available for volumes of up to 50,000 complex 3D sandwich components per annum.

1 Introduction

Performance, safety and comfort – these are the guiding principles of today’s automobile production industry. Today it is hard to imagine driving vehicles without integrated navigation systems, on-board computers and powerful, efficient engines. But installation of these luxury features and safety technologies increases the overall weight of the vehicle. A current example, the VW Golf, illustrates that modern cars are much heavier than several years ago (in 1974: 750 kg; today: 1,200 kg). This is difficult to align with the current directives of the EU Commission, which state that the CO₂ emissions of a vehicle must be below 95 g/km. Non-compliance with the directives results in manufacturers facing hefty fines.

The general aim now is to increase safety even more, yet reduce the weight, and subsequently, CO₂ emissions. To resolve this problem, it is necessary to completely reconsider the materials that have been used in the past. The result is that car makers are increasingly turning to lightweight construction solutions, using materials such as aluminum, carbon fiber-reinforced polymers and high grade steel.

2 Sandwich components

One of the most promising approaches in lightweight construction is the sandwich design (fig. 1). This design concept consists of a lightweight, but mechanically resilient, core material that is sandwiched between two relatively thin cover layers. The cover layers are usually strong, rigid materials, such as fiber-reinforced polymers. The fibers used are often glass or carbon fibers, typically embedded in a duroplastic resin matrix. The core material can consist of honeycomb structures or rigid foams.

The task of the core material is to keep the cover layers apart and distribute forces evenly throughout the structure. When there is a good bond between the cover layers and the core material, forces can be transferred by the core material. For example, flexural forces can – to a certain extent – be converted into tensile forces, which the fiber layers can absorb better. Sandwich structures also provide extraordinary results in regards to component rigidity. As the core material becomes thicker, this increases the rigidity of the component disproportionally with no significant

- Fig. 1: Structure of a sandwich component

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Weight</th>
<th>Flexural rigidity</th>
<th>Flexural strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>t = 2</td>
<td>-1</td>
<td>-12</td>
<td>-6</td>
</tr>
<tr>
<td>t = 4</td>
<td>-1</td>
<td>-48</td>
<td>-12</td>
</tr>
</tbody>
</table>

Tab. 1: Theoretical maximum possible effect of using core materials on flexural rigidity and flexural strength
increase in weight. Table 1 compares the maximum theoretical flexural rigidity and flexural strength of a monolithic fiber structure with two sandwich structures of different thicknesses. All three examples have the same cover layer thickness, but it can be seen that as the component thickness increases, the flexural rigidity and flexural strength of the sandwich structures increase disproportionally. In many cases, this provides an opportunity to reduce the thickness of the cover layers and make the overall weight of the component lighter by using a core rather than a monolithic solution.

Other positive side effects of using foams as core materials are improved thermal and acoustic insulation, better absorption of impact, and damping vibrations. However, the disadvantages of sandwich components are the high production costs, especially for complex components, and the problem of recycling, which has not yet been adequately resolved.

High demands are placed on the core materials of sandwich structures. In addition to compression forces, they must also be able to absorb tensile and shear loads. To ensure a functioning bond, the surface must adhere well to the cover layers and the weight should be as low as possible. Apart from the described requirements of the application, the requirements of downstream processing must also be considered.

Besides from polymer foams, honeycomb structures made of aluminum, for example, can also be used. At a given density, they exhibit higher compression strengths and are non-flammable. However, because of the open structure there are limitations regarding downstream processing, especially when liquid resin systems are used. The higher compression strengths exist only in the preferred direction of the honeycomb structure, which limits the use to essentially two-dimensional components. With three-dimensional components, polymer foams have considerable advantages because of their isotropy in terms of shaping and load distribution.

Due to their high strength/rigidity-to-weight ratio, very low specific weight, design freedom and high energy absorption, sandwich components are already used in a wide range of applications. Specifically in aircraft construction, sandwich technology is one of the most important approaches for reducing weight. Sandwich components are also used in the rotor blades of wind turbines, in marine vessels and also in sports equipment, including skis, surfboards and bicycles (fig. 2). Normally, these are small series where the number of similar parts seldom exceeds a few hundred per year.

In most cases, the foams used in sandwich components are available as semi-finished sheets and blocks. To create the final geometries, the foams must be shaped on CNC milling machines or with a thermoforming process. With CNC milling, it is possible to produce very complex three-dimensional components. However, because of the high proportion of cutting losses and the long processing times, this type of shaping is not efficient enough to manufacture large numbers of pieces in serial production.

On the other hand, thermoforming can be used only to produce simple three-dimensional shapes. In this process, the core material and the respective cover layers are heated and pressed into the desired shape under pressure.

### 3 Processing

Foam cores can be processed in a variety of ways. In the simplest case, the sandwich structure is created with manual lay-up; in other words, the cover layers are applied to the core material almost exclusively manually with a very low degree of automation. Accordingly, the number of parts that can be produced in this manner is low. To produce larger volumes faster and more efficient processes are needed, such as pressing or RTM (resin transfer molding). The latter is shown in figure 3. The fibers and core material are shaped and bonded by the injection and hardening of liquid resin. The higher the pressure and temperature, the shorter the cycle times.

Temperatures for this process are generally above 130 °C and it is therefore important to use core materials that can withstand high temperatures and pressures. One suitable material is polymethacrylimide foam.
4 Polymethacrylimide (PMI)

As described above, rigid foams for sandwich applications are often produced as blocks. The polymethacrylimide-based structural foam from Evonik Resource Efficiency GmbH is manufactured according to this method. It has been commercially available since the 1970s under the Rohacell brand. PMI is created by radical copolymerization of methacrylonitrile (MAN) and methacrylic acid (MAA) (fig. 4).

The synthesis of the statistical polymer takes place in glass chambers kept at a specific temperature in a water bath. In addition to the monomers, blowing agents and additives are added to tailor the desired properties in the finished foam block. Because of the low space-time yield, this process has cost disadvantages compared to other polymerization methods, but this is the only way to obtain a homogeneous polymer block that guarantees the high level of properties for which PMI is known. This applies also to the monomers that are used. Because of the lack of the methyl group in the polymer backbone, the frequently discussed substitution of methacrylates with corresponding acrylic compounds would have considerable disadvantages for the performance of the produced foams with negligible reductions in manufacturing costs.

When the monomers have been polymerized, the polymer block is subjected to a defined temperature program in a tempering oven. The high temperatures cause imidization between neighboring MAN and MAA units. As the copolymerization is not a strictly alternating copolymerization, various secondary structures are formed in addition to the actual target structure (fig. 5). However, the type and quantity of secondary structures can be controlled specifically through skilled formulation to optimize the product properties.

After imidization, the tempered polymeric product is converted to a high performance foam at 170–250 °C. At this temperature, the viscosity of the polymer is reduced, the blowing agents diffuse from the matrix and, after nucleation, form closed cells. Densities of 30 kg/m³ and less can be achieved (fig. 6).

The desired density and required pore size are adjusted via the temperature and the type and quantity of blowing agent. This allows the properties of the foam to be controlled and adapted to suit the respective technical applications and processes.

Rohacell foam manufactured by this process has very high mechanical strength and low weight compared to other commercially available polymer foams. Due to the high temperature stability of up to 220 °C, Rohacell can be used in high-temperature processes. Thermoplastic cover layers can also be used.

5 In-mold foaming of PMI

The foam blocks produced by this method are a suitable basis for the production of flat parts. As described above, they can also be used to produce three-dimensional parts for limited numbers of pieces through milling and/or thermoforming. To satisfy demand for geometrically complex and three-dimensional foam cores produced in larger quantities, new approaches had to be explored.

With the development of Rohacell Triple F, it is now possible to provide PMI-based complex, three-dimensional structural cores in larger numbers. Granules are produced from the well-established PMI raw material. The PMI particles are pre-foamed to the required density in a newly developed process. Foaming time is reduced considerably by using radiation instead of circulating air. The pre-foamed particles are then filled into a mold. When the closed mold is heated, the particle
foam expands and completely fills the cavities. When foaming is complete, the molded part is cooled and the three-dimensional foam core can be removed and processed immediately (Fig. 7). There is no need for post-treatment steps that are required for other materials, such as degassing, flame treatment, sand blasting, or removing blowing agents or release agents.

With the innovative Rohacell Triple F technology it is possible to produce a three-dimensional structural foam where almost 100% of the material is used. Other costs can be saved by minimizing manual work and through shorter cycle times per component. Instead of a few hundred milled parts per year, it is now possible to produce up to 50,000 complex three-dimensional sandwich components per year quickly and efficiently. Another advantage over milled foam cores is that design elements, such as screw threads, can be foamed directly into the core as inserts. Figure 8 shows a demonstrator that illustrates some of the different design options that are possible with Rohacell Triple F. They include two different metal inserts and a variation of different complex geometries.

Because of its temperature and pressure resistance, the Rohacell Triple F foam core is ideally suited for quick processes, including high pressure RTM and wet impregnation. It allows the short cycle times needed for mass production. All common resin types and thermoplastic polymers can be used as a matrix for the cover layers. The density depends upon the stresses acting on the component and can be adjusted from 75 kg/m³ to more than 200 kg/m³. Function integration of inserts during in-mold foaming saves further post-processing steps. However, as with most particle foams, mechanical performance is lower than that of block material. This can be easily compensated with a slight increase in density.

Using Rohacell Triple F as a core material, Audi AG, in collaboration with Benteler SGL and LiteCon GmbH, developed ultra-RTM technology. Through this collaboration, the new material saw use in the first serial applications. Since 2015, the technology has been used in CFRP sandwich components for load-bearing structures in the bodywork. In 2016, the technology received the JEC Innovation Award and the CFK-Valley Innovation Award.

### 6 Comparison between Rohacell Triple F and PU foams

In addition to Rohacell Triple F, PU rigid foams are suitable for use as a core material. They are produced by simple tool technology. However, they require post-process-

---

**Fig. 6:** REM image of a Rohacell Rima structural foam

---

**Fig. 7:** Production of a Rohacell Triple F foam core: The polymer particles are pre-foamed and then bonded to form a complex foam core using an in-mold foaming method

---

**Tab. 2:** Overview of the physical properties of Rohacell Triple F (1-5-X A05 at 23 °C)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Rohacell 75 Triple F</th>
<th>Rohacell 110 Triple F</th>
<th>Rohacell 150 Triple F</th>
<th>Rohacell 200 Triple F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal density in kg/m³</td>
<td>ISO 845</td>
<td>75</td>
<td>110</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Tensile strength in MPa</td>
<td>ISO 527-2</td>
<td>1.3</td>
<td>1.9</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Tensile modulus in MPa</td>
<td>ISO 527-2</td>
<td>90</td>
<td>143</td>
<td>199</td>
<td>262</td>
</tr>
<tr>
<td>Elongation at break in %</td>
<td>ISO 527-2</td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Compressive strength (3 %) in MPa</td>
<td>ISO 844</td>
<td>1.0</td>
<td>1.7</td>
<td>2.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Compressive modulus in MPa</td>
<td>ISO 844</td>
<td>64</td>
<td>117</td>
<td>172</td>
<td>299</td>
</tr>
<tr>
<td>Thermal expansion ×10⁶/K</td>
<td>ISO 844</td>
<td>47</td>
<td>44</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>Glass transition temperature in °C</td>
<td></td>
<td>211</td>
<td>205</td>
<td>193</td>
<td>189</td>
</tr>
</tbody>
</table>
ing. To remove residues of blowing and release agents, they must be cured and flame treated, while Rohacell Triple F is basically ready to use.

Because of the lower mechanical properties of PU systems, density has to be increased considerably to achieve specific characteristics. A rule of thumb is a factor of 2. The differences between the compression strengths of Rohacell Triple F and PU foam at room temperature are shown in figure 9. The difference becomes even more pronounced at higher temperatures (fig. 10). This is important in processes associated with high pressures and high temperatures.

**7 Summary and outlook**

The first Rohacell Triple F cores are already being used in various structural applications in the automotive industry, such as B pillars and cross beams.

There is obviously great potential for Rohacell Triple F for the design of sandwich components in mass production. With the help of Rohacell Triple F it is now possible to develop lightweight, temperature and pressure-resistant foam cores with high mechanical properties (tab. 2). With the time saving process, these can be foamed to form complex components with the inclusion of various inserts and can be delivered directly to customers, ready to use.

Because of the high temperature and pressure resistance, Rohacell Triple F foam cores can be processed into sandwich structures in quick hardening processes, such as RTM or wet impregnation. In collaboration with well-known Tier 1 companies and OEMs, methods were quickly developed to achieve the very short cycle time needed for mass production.

---

**Fig. 9:** Comparison of the compression properties of Rohacell Triple F and PU foam at 23 °C

**Fig. 10:** Comparison of the compression properties of Rohacell Triple F and PU foam at 130 °C