What's a *TEPEX*® Sandwich?

By Steve Mowry

TEPEX is the registered trademark of Bond-Laminates GmbH (www.bond-laminates.de/en). Since 2000 the industrial group CENTROTEC Sustainable AG (www.centrotec.com/index_e.php) has been a partner within Bond-Laminates. With the support of CENTROTEC, Bond-Laminates has established its industrial development and manufacturing facilities in Brilon, Germany. TEPEX sandwich is a combination of thin outer layers with a structural foam core. This family of materials is lightweight but very stiff/rigid. Alternating movements can also be absorbed due to the inherent properties of the sandwich composite structure. This makes the material particularly useful for loudspeaker woofer cone applications.

CONSTRUCTION

TEPEX sandwich is a material that consists of thin outer skins of TEPEX dynalite and a foam core (***Fig. 1***). This combination results in a very rigid but light material that can be formed three-dimensionally in a single operation. This is because the forming temperature for both the outer layers and the foam is the same. The forming temperature is approximately 190° C.

FIGURE 1: Illustration of molded sandwich composite construction, Focal "W" cone (www.utopia-be.com/Technology/Cone.htm).

A key component of Tepex sandwich is the Rohacell core (www.rohacell.com/en), which is a polymethacrylimide (PMI) hard foam that is used as a core material for sandwich composite constructions. It exhibits outstanding mechanical and thermal properties. In comparison to all other foams, it offers the best ratio of weight and mechanical properties as well as the highest heat resistance of any structural foam. Rohacell is the registered trademark of Rohm GmbH, a subsidiary of Degussa AG, Düsseldorf, Germany, with distributors throughout the world.

I discussed sandwich composites in "Metal Sandwich Composite Cones for Pro Drivers" in the May 2006 issue of *Voice Coil*. There is an I-beam two-dimensional analogy associated with sandwich composites with the resultant distribution of loads inherent in the skin/foam core configuration, where a composite is simply a specific combination of two or more materials that improves the properties of the individual components. Nature itself has demonstrated the principle that high-strength fibers are the most suitable lightweight material for absorbing forces. Wood, plant leaves, muscles, and bones are just a few examples of composite structures that occur naturally.

These fibers critically determine the mechanical characteristics of the composite, such as its strength and rigidity. The materials generally used are glass and carbon fibers. The matrix material, too, performs a crucial function, transferring the forces between the fibers. The utilization of thermoplastics such as TPU and PA12 offer clear advantages in terms of forming properties, shelf life, and ease of recycling over thermoset plastics.

TEPEX sandwich can readily be formed into straight cones. The fundamental stages involved are heating the semi-finished cone, forming and subsequently cooling the part in the mold, then removing and finishing the cone including trimming and attaching the surround. Process heating by means of infrared radiation is the preferred method; however, contact heating can also be used. The typical components are carbon, glass and/or aramid fibers, the binding resin, and Rohacell. The process and raw materials are much easier to control than paper cone manufacturing. Once removed from the mold, the properties are stable and environmentally robust. "Quality is designed-in."

There are several grades of TEPEX sandwich composites that are well suited to loudspeaker woofer and midbase transducer applications.

TEPEX sandwich 106-FG50—0.07mm 28% Glass Fiber Reinforced Nylon 12 (Polyamid) skins/2-10mm Rohacell LS foam core.

TEPEX sandwich 106-FG200—0.17mm 45% Glass Fiber Reinforced Nylon 12 (Polyamid) skins/2-10mm Rohacell LS foam core.

TEPEX sandwich 106-FG290—0.25mm 45% Glass Fiber Reinforced Nylon 12 (Polyamid) skins/2-10mm Rohacell LS foam core.

TEPEX sandwich 108-FG200—0.17mm 45% Glass Fiber Reinforced Thermoplastic Polyurethane skins/2–10mm

TABLE 1 Material properties of TEPEX skins

Material	28% Glass/PA12	45% Glass/PA12	45% Glass/TPU	45% Carbon/TPU	50% Carbon/PPS
Modulus	11.6 GPa	17.5 GPa	23 GPa	41 GPa	40 GPa
Density	1600kg/m^3	1800kg/m^3	1900kg/m^3	1500kg/m^3	1550kg/m^3
Poisson's #	0.3	0.3	0.3	0.3	0.3
Damping	0.010	0.010	0.010	0.010	0.010
Max Temp	105°C	105°C	90°C	90°C	220°C

TABLE 2 Material properties of Rohacell cores

Material	Rohacell 71XT	Rohacell 71LS	Rohacell 51LS	Rohacell 31LS	Coated Paper
Modulus	105 MPa	90 MPa	68 MPa	35 MPa	6.0 GPa
Density	75kg/m^3	75kg/m^3	52kg/m^3	32kg/m^3	683kg/m^3
Poisson's #	0.4	0.4	0.4	0.4	0.33
Damping	0.10	0.10	0.10	0.10	0.020
Max Temp	230° C	170° C	170° C	170° C	N/A

Rohacell LS foam core.
TEPEX sandwich 108-FG290—0.25mm 45% Glass Fiber Reinforced Thermoplastic Polyurethane skins/2–10mm Rohacell LS foam core.
TEPEX sandwich 208-C190—0.25mm 45% 12k Carbon Fiber Reinforced Thermoplastic Polyurethane skins/2–10mm Rohacell LS foam core.
TEPEX custom high temp sandwich—0.25mm 50% 12k Carbon Fiber Reinforced Polyphenylene Sulfide skins/2-10mm Rohacell 71XT core.

Note that Rohacell LS refers to LoudSpeaker applications and XT refers to eXtended Temperature application. The safe operating temperature of TEPEX is directly related to the resin utilized. TPU applications have the friendliest low temperature processes. PA12 requires slightly higher process temperature, while PPS requires high temperature processes.

SIMULATION

The mechanical material properties of the skin materials are listed in ***Table 1***. The mechanical material properties of various Rohacell core materials and for a base line simulation, treated/coated paper are listed in ***Table 2***.

Figure 2 illustrates the cone geometry used in all simulations. Only the thicknesses and material properties change.

I will simulate all models with S. M. Audio Engineering's proprietary linear dynamic one-dimension composite axisymmetric shell finite element natural frequency analysis with lumped boundary conditions. The assembly boundaries are free to move only in the ±y-direction, the direction of operation. The voice coil, spider, surround, neck joint, et al. are replaced with two spring and two mass elements. The appropriate values for these are an input to this analysis and can be based on measured data or other simulations. The air load was ignored. This simplifies the FEA. Ironically, the typical "Composites Engineer" is not familiar with harmonic analysis techniques. Their analysis is focused on structural criteria.

First I will simulate a moving assembly containing a 1.3mm thick hard paper cone. The assembly models remain constant throughout this discussion except for the cones. A summary of the results is listed here and the mode shapes are illustrated in ***Figs. 3-6***.

MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	MODAL DAMPING
f_0	22	77	
f_1	973		0.02
f_2	1148		0.02
f_3	1297		0.02

The piston mode shape in ***Fig. 3*** is the same for all models. All points move in phase. The frequencies of the piston mode, f_0, vary due to the mass of the respective cone.

The first bending mode is reasonably well damped, but that is what is expected from paper.

A moving assembly containing a 0.25mm 45% Carbon-TPU/8.0mm Rohacell 31LS/0.25mm 45% Carbon-TPU TEPEX sandwich cone was simulated. A summary of the results is listed here, and the first three bending mode shapes are illustrated in ***Figs. 7-9***.

FIGURE 2: Cone geometry used in all simulations.

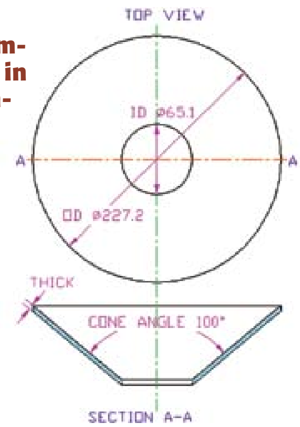


FIGURE 3: Piston mode shape at f_0 = 22Hz.

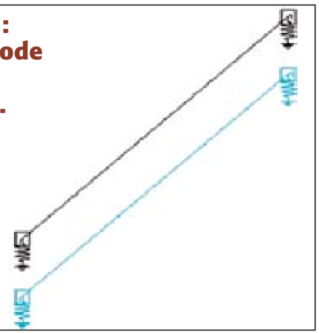


FIGURE 4: First bending mode shape at f_1 = 973Hz.

FIGURE 5: Second bending mode shape at f_2 = 1148Hz.

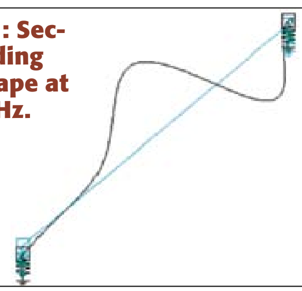


FIGURE 6: Third bending mode shape at f_3 = 1297Hz.

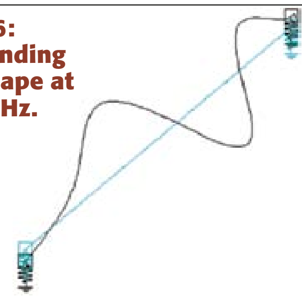


FIGURE 7: First bending mode shape at f_1 = 2093Hz.

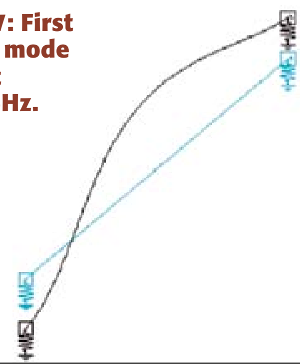


FIGURE 8: Second bending mode shape at f_2 = 3354Hz.

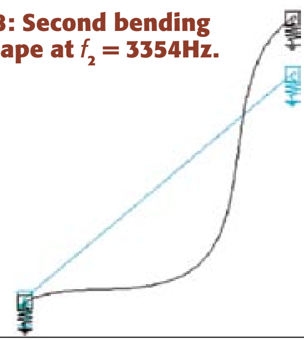
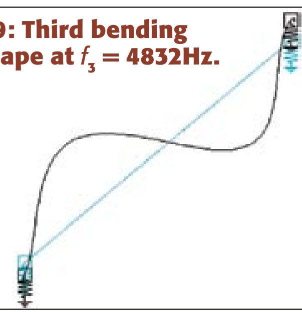


FIGURE 9: Third bending mode shape at f_3 = 4832Hz.



MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	COMPOSITE MODAL DAMPING
f_0	21	83	
f_1	2093		0.02
f_2	3354		0.03
f_3	4832		0.03

The cone model illustrated in ***Figs. 8-10*** is similar to the cones used in B&W's 250mm woofers in the 800D loudspeakers (www.netcomposites.com/news.asp?2865). It is no wonder that this topology and materials are the best all-around performing of all the simulations.

A moving assembly containing a 0.25mm 50% Carbon-PPS/2.0mm Rohacell 71XT/0.25mm 50% Carbon-PPS was simulated. A summary of the results is listed here, and the bending mode shapes are illustrated in ***Figs. 10-12***. This is a high temperature cone, good to 220° C with reasonable mass and stiffness along with good damping. This appears to be a good candidate for professional low-frequency transducer applications.

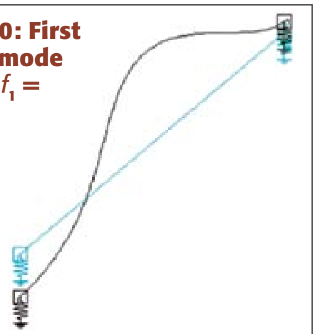


FIGURE 10: First bending mode shape at f_1 = 1722Hz.

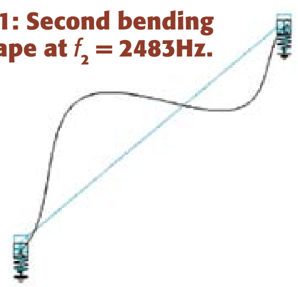


FIGURE 11: Second bending mode shape at f_2 = 2483Hz.

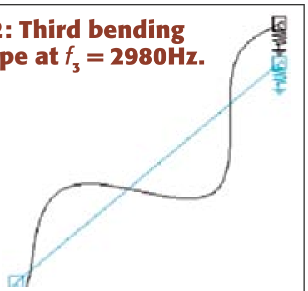


FIGURE 12: Third bending mode shape at f_3 = 2980Hz.

MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	COMPOSITE MODAL DAMPING
f_0	22	79	
f_1	1722		0.02
f_2	2483		0.02
f_3	2980		0.02

A moving assembly containing 0.07mm 28% Glass-PA12/4.0mm Rohacell 71LS/0.07mm 28% Glass-PA12 TEPEX sandwich was simulated. A summary of the results is listed here, and the first three bending mode shapes are illustrated in ***Figs. 13-15***. This is an ultra-light cone but with less stiffness than paper.

MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	COMPOSITE MODAL DAMPING
f_0	25	60	
f_1	690		0.04
f_2	1210		0.06
f_3	1364		0.05

The cone illustrated in ***Figs. 13-15*** seems to utilize skins that are just too thin and with too little glass fiber. In this case, the cone tends to the characteristics of Rohacell; the core properties dominate. The next simulation increases both the thickness of the skins but also simulates the increase in glass fiber content from 28-45%. The results indicate a cone with low mass and higher stiffness. This is similar to the Focal "W" cone (***Photo 2***).

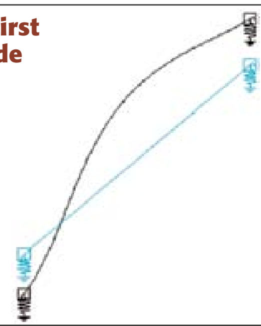


FIGURE 13: First bending mode shape at f_1 = 690Hz.

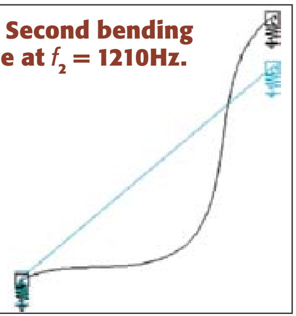


FIGURE 14: Second bending mode shape at f_2 = 1210Hz.

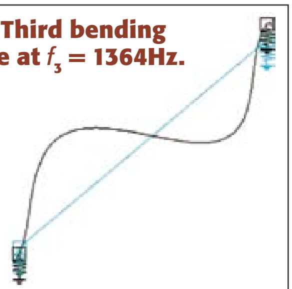


FIGURE 15: Third bending mode shape at f_3 = 1364Hz.

A moving assembly containing a 0.17mm 45% Glass-PA12/4.0mm Rohacell 31LS/0.17mm 45% Glass-PA12 TEPEX sandwich was simulated. The results are listed here, and the bending mode shapes are illustrated *in* ***Figs. 7-9***.

MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	COMPOSITE MODAL DAMPING
f_0	23	70	
f_1	1098		0.02
f_2	1819		0.03
f_3	2131		0.02

A moving assembly containing a 0.17mm 45% Glass-TPU/2.0mm Roha-cell 51LS/0.17mm 45% Glass-TPU TEPEX sandwich was simulated. The results are listed below, and the bending mode shapes are illustrated in ***Figs. 19-21***.

MODE	FREQUENCY (Hz)	GENERALIZED Mmd (g)	COMPOSITE MODAL DAMPING
f_0	23	70	
f_1	1156		0.02
f_2	1708		0.02
f_3	2016		0.02

OBSERVATIONS

The paper cone initially bends somewhat locally at the outside diameter (***Fig. 4***) and works inward as frequencies are increased (***Figs. 5*** and ***6***). The sandwich composite cones tend to distribute the bending load throughout the cone and bends more as a system at all modes. When the core thickness was in the range of 4–8mm, there was a simplifying of the mode shapes. When the core was less than 4mm thick, f_2 resembled f_3 in cones with a core of 4–8mm, illustrating improved damping. Furthermore, the modes (bending frequencies) were spaced farther apart than with the single laminate hard paper cone, and even farther apart as the core thickness was increased.

The transmission loss through the TEPEX sandwich cone is greater than with paper. This is due to the thickness and low-density, high air cell content, Rohacell core of the structure. This applies to sound pressure inside the enclosure.

This type of composite sandwich cone offers a high degree of inherent design flexibility to the loudspeaker engineer/designer. By changing skin thickness and/or material and/or core thickness and/or grade of Rohacell, a fairly wide range of cone characteristics can be realized.

The cost of TEPEX sandwich type composite cones depends on quantity and material selection; however, clearly this type of composite cone will be more costly than the best paper cone. Carefully designed molded TEPEX sandwich composite cones offer an exciting high-performance alternative to single laminate paper, plastic, or metal cones. Development of new cones such as these is best done in Asia to help minimize cost and thus offer the technologies to a broader end-user base.

Photos 1 and ***2*** show two examples of implementation of the types of cones that were presented here, and they are among the most highly respected loudspeaker manufacturers within the industry.

There is additional information available on the development of this 250mm woofer's sandwich composite cone in B&W's 800D development whitepaper, www.bwspeakers.com/downloadFile\technicalFeature\800_Development_Paper.pdf, pages 8, 9, 24, and 25. Frankly, the entire paper is a must read and includes discussions on several other exciting technologies and cutting-edge loudspeaker engineering. M3

Steve Mowry, president of SM Audio Engineering, has a BS, Business Administration, from Bryant College, and a BS and MS, Electrical Engineering, from URI with highest distinction. Steve has worked in R&D at BOSE, TC Sounds, EASTTECH, and P.Audio. Steve is currently an independent consultant/lecturer in project management/transducer and system design. His website is www.s-m-audio.com.

FIGURE 16: First bending mode shape at f_1 = 1098Hz.

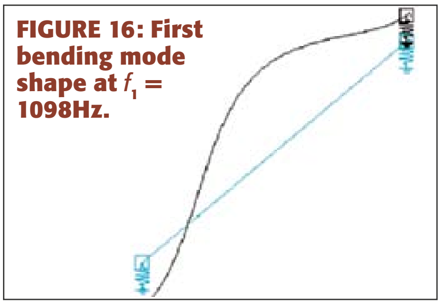


FIGURE 17: Second bending mode shape at f_2 = 1819Hz.

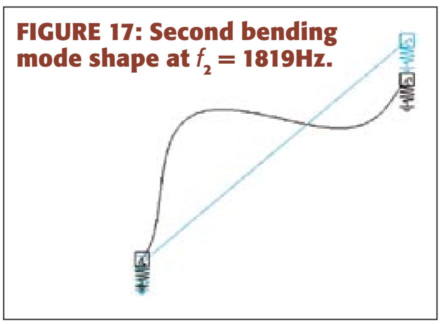


FIGURE 18: Third bending mode shape at f_3 = 2131Hz.

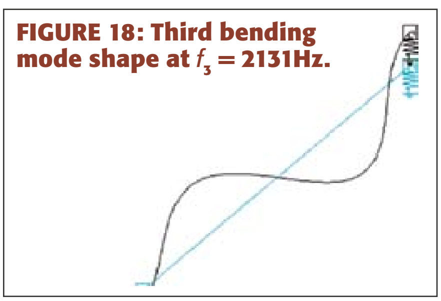


FIGURE 19: First bending mode shape at f_1 = 1156Hz.

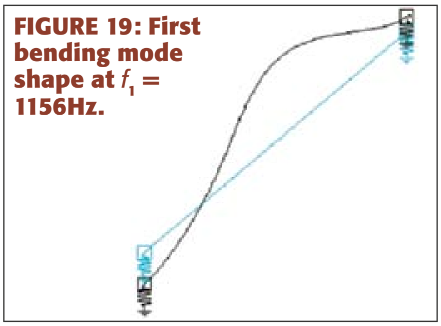


FIGURE 20: Second bending mode shape at f_2 = 1708Hz.

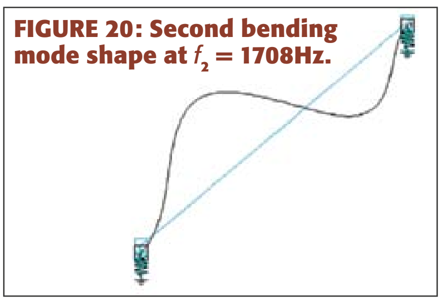


FIGURE 21: Third bending mode shape at f_3 = 2016Hz.

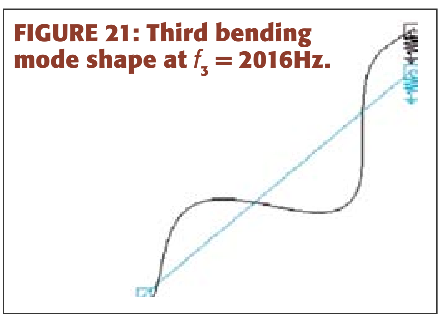


PHOTO 1: B&W 250mm woofer with TEPEX sandwich type Carbon Fiber-TPU/8mm Rohacell 31LS/Carbon Fiber-TPU composite cone.

PHOTO 2: Focal 325mm woofer with sandwich type glass fiber-polymer resin/Rohacell/glass fiber-polymer resin composite "W" cone.