TECHNICAL BULLETIN

Acoustic Behavior of Sandwich Panels

DIAB

BACKGROUND

Sandwich construction is being used more often in applications that require sound attenuation in addition to high strength, low weight, and thermal insulation. DIAB core materials can be used in these applications to provide sound attenuation as well as other necessary properties.

Attenuation of sound depends on the media of propagation and the frequency and is caused by absorption, spreading, and scattering.

Noise control

Designing a sandwich structure to maximize sound reduction involves identifying several variables.

These variables are:

1. Source of sound
2. Path of sound (i.e. airborne or structure borne)
3. Frequency of sound (i.e. high pitch or low pitch)
4. Panel size

Source of Sound

Is the sound coming from machinery attached to the structure or is it coming from the structure itself? Isolating the source of the sound is the first step in designing a quiet structure.

Any structure may produce noise when set into vibration. Generally the motion is an unwanted effect of some desired function, e.g., the vibration of a machine tool. Equipment attached to the structure such as motors and generators create vibrations, which can be transmitted to the structure causing it to act as a sounding board, generating noise through the vibrating panels.

This can be prevented by isolating the engines with resilient mounts. To suppress the sound created by the machinery itself, the compartments housing the machinery should be lined with sound insulating materials.

Path of Sound

Is the sound travelling through the air or through the structure?
When sound travelling through the air reaches an obstruction such as a wall or bulkhead, it is absorbed, reflected, or transmitted through the object. Using a sound insulation lining will increase the amount of sound that is absorbed and decrease the amount that is reflected or transmitted to the panel.

Building the panels with materials that decrease the propagation speed of the sound such as Divinycell H60 and woven roving, will reduce the sound that is transmitted through the panel.

Frequency of Sound

Does the offending sound have a high pitch or a low pitch?

At low frequencies (< 500 Hz), panels tend to vibrate and become resonant. The best way to avoid resonant panels is to make sure they are adequately stiff i.e. using thick, high-density core materials.

At intermediate and high frequencies (> 1,000 Hz), it is better for the panel to be less stiff so the sound loses energy as it travels through the panel. The best ways to attenuate high frequency sound is to use thin, low-density core material in laminates or to apply a viscoelastic material to the panel.

Panel Size

Generally, it is difficult to control the panel size in a sandwich structure to maximize acoustic properties. Each different panel size has a different resonant frequency. For this reason, it is important to know the frequency of the offending sound.

Larger panels tend to be more flexible and thus resonate more easily at lower frequencies. Smaller panels are generally stiffer and have higher resonant frequencies.

DESIGN EXAMPLES

An example of an application that requires sound attenuation is an engine room bulkhead or deck panel in a boat.

Typically these panels are built with plywood, balsa wood, or PVC foam with fiberglass skins on both sides.

The panel in this example is 12-feet by 8-feet. In order to achieve adequate structural properties, a typical laminate schedule would be as follows:

450 g/m^2 Chopped strand mat
800 g/m^2 Woven roving
450 g/m^2 Chopped strand mat
****
25 mm Divinycell H80, H60, ProBalsa or 19 mm Plywood
****
450 g/m^2 Chopped strand mat
800 g/m^2 Woven roving
450 g/m^2 Chopped strand mat

The sound transmission loss (sound level reduction) was calculated for each panel and plotted over a frequency range of 100 Hz – 6,300 Hz. Figure 1 below shows the results.

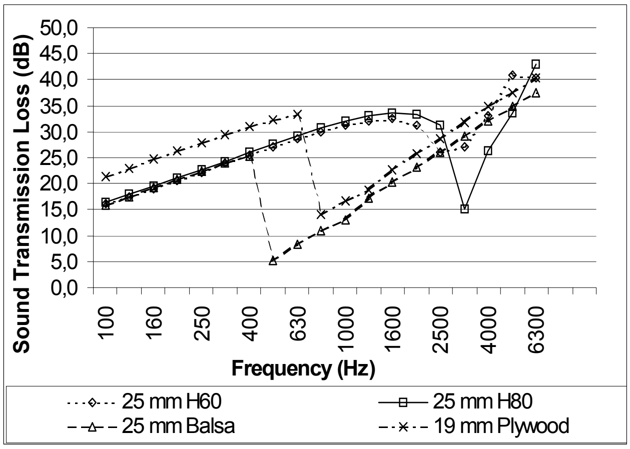


Figure 1: Sound transmission loss for sandwich panels

A concern in sound attenuation is critical frequency, shown by the dip in the graph. At this point, the sound transmission loss drops off and the panel is less effective at attenuating sound at and around this frequency.

An average of the sound transmission loss over a frequency range of 125 Hz – 4,000 Hz is called the Sound Transmission Coefficient (STC). Figure 2 shows a comparison of the STC of each panel.

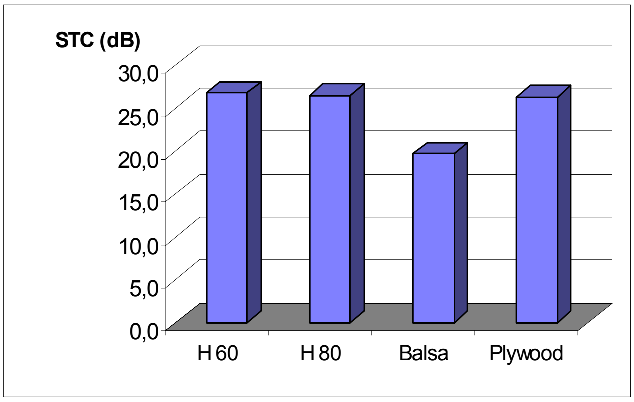


Figure 2: Comparison of STC of sandwich panels

As the graph shows, the H60 panel has the highest STC followed by the plywood panel and the H80 panel with the balsa panel having the lowest STC.

One of the reasons for building with sandwich construction is the weight savings achieved by using a lightweight core material. Figure 3 shows a comparison of the effectiveness of the sound attenuation of the panels with regard to weight per area.

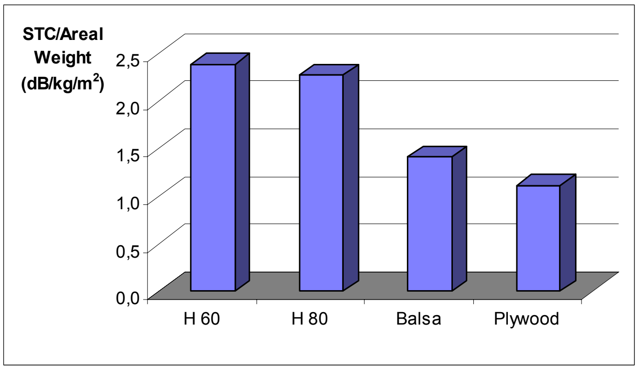


Figure 3: STC divided by weight per area of sandwich panels

An ideal core material for sound attenuation will have high mass, low shear stiffness, and high compression stiffness. However, don’t be misled. Divinycell H60 has a relatively low mass, but the ratio of mass to shear stiffness is the highest for Divinycell H grade foams, making H60 the best choice of Divinycell PVC foams for sound attenuation.

DESIGN EXAMPLES

Background theory

Sound is a fluctuation in pressure that is propagated as waves in an elastic medium. The wave type and speed depends on the medium in which the sound is traveling. Fluids, such as air and water, can only support longitudinal waves while solids can support longitudinal and transverse or shear waves. In finite solids, a combination of these waves exists, the bending wave.

Frequency, (*f*), the number of times a wave oscillates per second, determines the pitch of sound. High pitch sounds have a high frequency and low pitch sounds have a low frequency. The unit for frequency is the cycle per second, which is called hertz (Hz). The range of human hearing is typically 20-20,000 Hz.

Sound pressure is measured in units called decibels, dB, which is a term used to give the relative magnitude of two powers by comparing the one under consideration to a standard. The sound pressure level in decibels is defined as twenty times the logarithm to the base 10 of the ratio of sound pressure to the reference sound pressure. Decibels do not add numerically as linear figures do; i.e., 60 dB + 60 dB = 63 dB.

Sound Propagation

Sound propagates through solids at different speeds and in different wave types depending on the frequency of the sound. Bending waves are dominant at very low and high frequencies. Shear waves are the primary means of propagation at intermediate frequencies.

Bending Waves

At very low and very high frequencies, bending waves are the primary means of sound propagation in sandwich panels. Bending waves are a great concern as the movements they cause in the plate can generate sound waves in air. At low frequencies, the core in sandwich panels acts as an ideal spacer, maintaining the distance between the skins. The bending wave speed at low frequencies can be calculated as follows:

$$c_B = \sqrt{2\pi f}\,\sqrt[4]{\frac{B_t}{m}} \quad m/s$$

where $m = m_{core} + 2m_{face}$, kg/m^2

$$B_t = \frac{1}{2}E_f h_f \left(h_f + h_c\right)^2$$

E_f = modulus of elasticity for face material, N/m^2
h_f = thickness of face, m
h_c = thickness of core, m

At very high frequencies, the skins begin to act independently about their individual neutral axes. The propagation speed through the sandwich panel will correspond to the propagation speed in one face with half of the core mass added to the face mass. For high frequencies, the bending wave speed can be calculated as follows:

$$c_{Bf} = \sqrt{2\pi f}\,\sqrt[4]{\frac{B_f}{m_f + \frac{1}{2}m_c}} \quad m/s$$

where
B_f = stiffness of an individual face, Nm
m_f = surface mass of an individual face, kg/m^2
m_c = surface mass of core, kg/m^2

Shear Waves

At intermediate frequencies, shear waves are the primary means of sound propagation in sandwich panels. This means that the sound propagation speed is controlled by the core shear stiffness. Wave propagation speed increases as core shear stiffness increases. The propagation speed for shear waves can be calculated as follows:

$$c_s = \sqrt{\frac{Gh}{m}} \quad m/s$$

where
G = shear modulus of core, N/m^2
h = thickness of sandwich, m
$m = m_{core} + 2m_{face}$, kg/m^2

DESIGN EXAMPLES

Effective Wave Propagation Speed

The actual wave in a sandwich panel will be a combination of bending and shear waves, with a gradual transition from wave type to wave type as frequency increases.

Sound Transmission Loss

Sound reduction can be achieved either by sound transmission loss or by sound absorption. Sound absorption is mainly a surface phenomenon but also depends on the size and shape of the panel. When used in sandwich construction, core materials generally do not contribute much to sound absorption since they have skins on both sides. However, they do contribute significantly to sound transmission loss, as it is a combination of forced and resonant transmission mechanisms.

Mass Law

The mass law gives the maximum theoretically obtainable sound transmission loss. It assumes that the airborne sound transmission loss of a plate is dependent solely of the surface mass of the plate and the frequency. This assumption only holds true if there are no natural frequencies in the frequency range of interest and that the critical frequency is above the frequency range of interest. The mass law can be expressed as follows:

$$R_0 = 20\log m + 20\log f - 42 \quad dB$$

where

R_0 = Sound transmission loss for normal incidence, dB

m = surface mass, kg/m^2

The mass law states that the sound transmission loss increases by six decibels every time the mass or the frequency is doubled.

Forced and Resonant Transmission

Sound transmission loss is made up of forced and resonant transmission loss. The sound transmission loss will depend on the transmission type that has the lowest loss. Forced transmission is caused when forced bending waves are excited by an incident sound wave. Resonant transmission is caused when natural frequencies in a structure are excited and sound is radiated.

Generally, the forced response will determine the sound transmission below the critical frequency and the resonant transmission loss will be the main factor above the critical frequency. The approximate sound transmission loss can be calculated as follows:

$$R \cong R_0 - 10\log(2\sigma_d) + 20\log\left(1-\left(\frac{f}{f_c}\right)^2\right) \quad dB \qquad f < f_c$$

$$R \cong R_0 + 10\log\eta + 10\log\frac{f}{f_c} - 2 \quad dB \qquad f \geq f_c$$

where n = loss factor, 3 to 6 x 10^{-2} for PVC foam

$$\sigma_d \cong \frac{1}{2}\left(0.2 + \ln\left(2\pi\frac{f}{c}\sqrt{S}\right)\right)$$

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{m}{B}} \quad Hz$$

S = panel area, m^2

c = speed of sound, 344 m/s in air

Total Transmission Loss

Total sound transmission loss for a sandwich panel can be calculated by combining the mass law, forced and resonant transmission, and the dilatational response. The total transmission loss can be calculated as follows:

$$R = R_0 - 10\log\left[\frac{2\sigma_d}{\left(1-\left(\frac{f_{11}}{f}\right)^2\right)^2\cdot\left(1-\left(\frac{f}{f_c}\right)^2\right)^2 + n_{eq}^{\;2}} + \frac{\pi\sigma^2 f_c}{2nf}\right] +$$

$$+10\log\left[\left(1-\left(\frac{f}{f_{dil}}\right)^2\right)^2 + n_{eq}^2\right] \quad dB$$

where

$$f_{11} = \frac{\pi}{2}\sqrt{\frac{B}{m}}\cdot\left[\left(\frac{1}{l_x}\right)^2 + \left(\frac{1}{l_y}\right)^2\right] \quad Hz$$

DESIGN EXAMPLES

l_x and l_y = panel edge lengths, m

$$n_{eq} = \sqrt{n^2 + 0.1n}$$

$$\sigma = \frac{Pc}{\pi^2 S f_c^{3/2}} \sqrt{f} \qquad f \ll f_c$$

$$\sigma = 0.45\sqrt{\frac{P f_c}{c}} \qquad f = f_c$$

$$\sigma = 1 \qquad f \gg f_c$$

P = perimeter of panel, m

$$f_{dil} = \frac{1}{2\pi}\sqrt{\frac{\frac{4}{3}E_c}{t_c\left(2m_f + \frac{m_c}{3}\right)}} \quad Hz$$

t_c = core thickness, m
m_f = surface mass of face, kg/m^2
m_c = surface mass of core, kg/m^2

Figure 4 shows the sound transmission loss over a wide frequency range for different Divinycell sandwich panels.

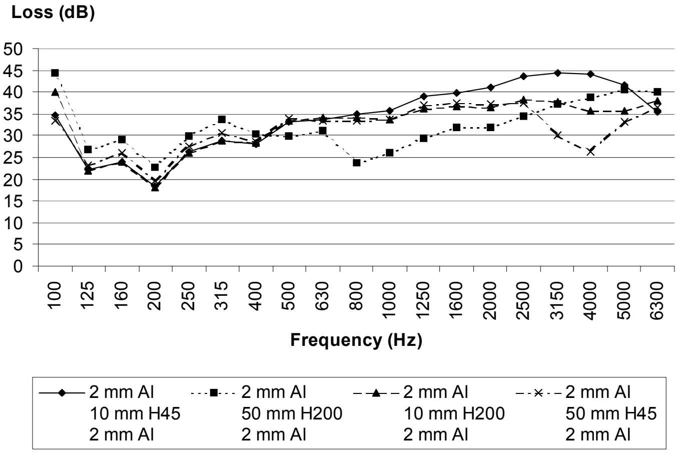


Figure 4: Sound Transmission Loss vs. Frequency for Divinycell Sandwich Panels

CONCLUSIONS

In order to design quiet sandwich structures designers must know the source of the offending sound, the path of that sound, and the frequency of that sound. Machinery must be isolated from the structure with resilient mounts. Then panels must be designed to maximize sound transmission loss while still being structural adequate. Designers can be sure that a structure built with DIAB core material will be a quiet structure.

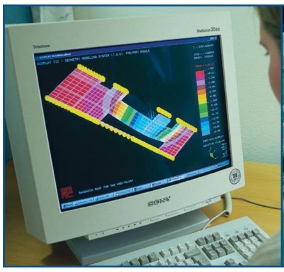
DIAB TECHNICAL SERVICES

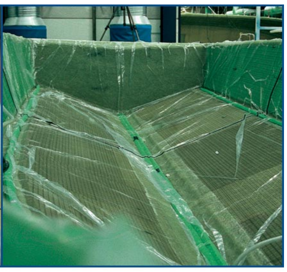
A Complete Service from Design to Finished Product

DIAB Technical Services was established to partner and help our customers maximize the benefits provided by the DIAB sandwich concept. Technical Services personnel are strategically located around the world to provide advice and support wherever a project is located. They bring to a project a unique set of skills and experience regarding the engineering and construction of sandwich structures.

Our engineers have unrivalled experience of both analytical design and finite element modelling of sandwich composite structures.

As a result we are able to offer the most cost-effective solution. Numerical tools are very useful for optimizing the structural design of components that have complex shapes and load cases. Analytical methods provide a quicker and lower cost solution for straightforward problems. Our strength is to choose the most appropriate design procedure for each specific case and when necessary validate our findings with in-house testing.


Finite element analyis of a sandwich component.


A DIAB Technical Services supervised trial infusion.


Carrying out an hydraulic crush test for a customer.


On site customer training by DIAB Technical Services.

When it comes to the construction of sandwich composites we are able to draw on a broad skill base that covers everything from hand lay-up to resin infusion and from limited to series production.

Taking infusion as example, we have been involved in numerous projects over many years in a wide range of industries, producing both small and ultra large components (100 foot plus). Our comprehensive services can include:

Providing assistance with the selection of the optimum combination of fiber and core to ensure a trouble-free introduction. Recommending the most appropriate machining methodology to optimize core kit fitting and resin flow. Designing an infusion strategy that includes detailed proposals regarding equipment and materials.

Finally, we can provide both theoretical and practical training of personnel and then directly assist a customer's team with prototyping and infusion trials.

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