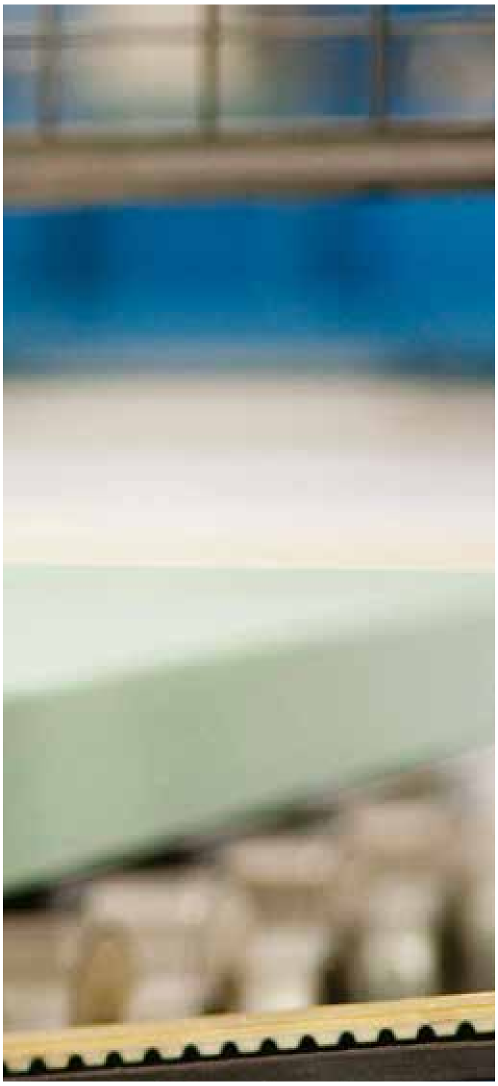
TECHNICAL BULLETIN

ArmaPET™ Struct

Armacell's structural foam cores provide a unique combination of material and processing properties, such as excellent fatigue resistance, process versatility, thermal and acoustic insulation or high curing temperatures.

www.armacell-core-foams.com



armacell®

ArmaPET™

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1. INTRODUCTION

Over the past decades, fibre-reinforced composites have proven their worth as weight-saving structures that deliver energy efficiency, durability, functionality and cost effectiveness over the long term. In transportation applications, for example, fibre-reinforced composite sandwich panels are utilised to lower weight. Less weight on a train, boat, bus or anything else that moves is directly correlated to higher energy efficiency.

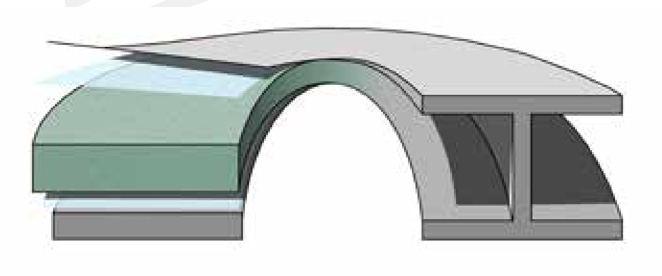
Armacell is the pioneer in the field of polyethylene terephthalate (PET) technology and initiated the breakthrough of PET foams as a structural core material in the composite industry. In the early days, ArmaPET Struct was made from virgin PET. Over the past decade, our global research and development team developed a patented process technology enabling the production of various PET foam products made entirely from recycled beverage bottles.

ArmaPET Struct brings the benefits of excellent fatigue properties, a higher curing temperature that enables shorter cycle times, a density variation of less than ±5 kg/m³ (0.3 lb/ft³), process compatibility with various production systems (e.g. infusion or prepreg), excellent thermoformability and 100% recyclability.

The trend of designing environmentally-friendly composite structures which are light, strong and recyclable has led industrial designers, specifiers and composite manufacturers to accelerate the substitution of conventional core materials such as Balsa, SAN, PUR or PVC with ArmaPET Struct in a wide range of composite sandwich applications as diverse as wind turbine blades, train floors and truck bodies, building envelopes, boat hulls and surfboards.

2. SANDWICH THEORY

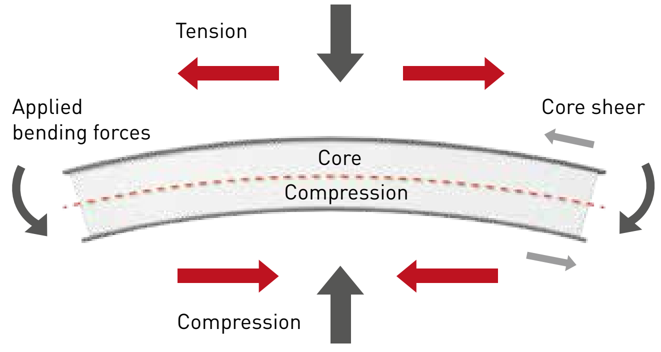
Sandwich composites are a special group of laminated composites widely used in engineering applications such as aircraft, aerospace, vehicles or buildings. A good way to visualize the structure of a 'sandwich core panel' is to use the analogy of an "I" beam. It consists of a thick and lightweight core with a strong and relatively thin skin.



Caption: "I" beam analogy for composites

The bending resistance for a rectangular cross-sectional beam or plate is proportional to the cube of the thickness. Increasing the thickness by adding a core increases resistance with only a negligible increase in weight. The maximum normal stresses occur at the bottom and top surface so it makes sense to use thin high strength/rigidity skins with a thick lightweight core material in the middle.

The advantages in weight and bending stiffness make sandwich composites attractive in many applications such as wind energy, marine, transportation, building and construction and many more.



Caption: Stress in sandwich panels

BENEFIT OF USING COMPOSITES AND SANDWICH STRUCTURES:

- // High strength-to-weight ratio
- // Very high stiffness-to-weight ratio
- // Freedom of design
- // Long service life, low maintenance
- // Easy to repair

Solid material	Core thickness / t	Core thickness / 3t
t	2t	4t
Stiffness		
1.0	7.0	37.0
Flexural Strength		
1.0	3,5	9.2

Caption: Strength-to-weight ratio

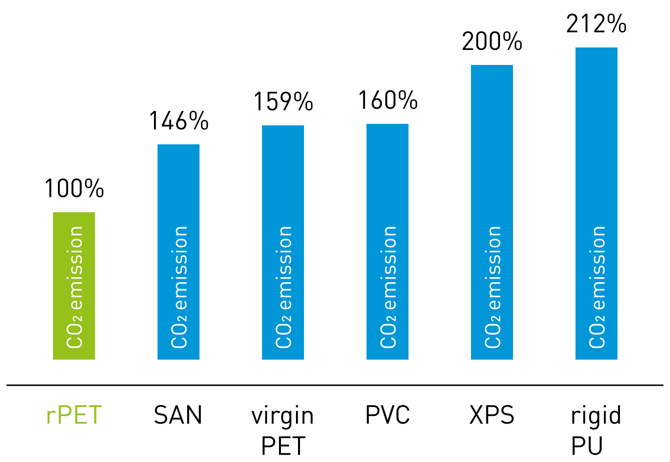
3. ECO CYCLE

In the post-consumer life-cycle of a plastic bottle Armacell's reprocessing technology creates a virtuous eco-circle.
Plastic bottles that have been collected for recycling, sorted and crushed into flakes are taken to Armacell's plant in Thimister-Clermont, Belgium, in Brampton, Canada, or Suzhou, China.

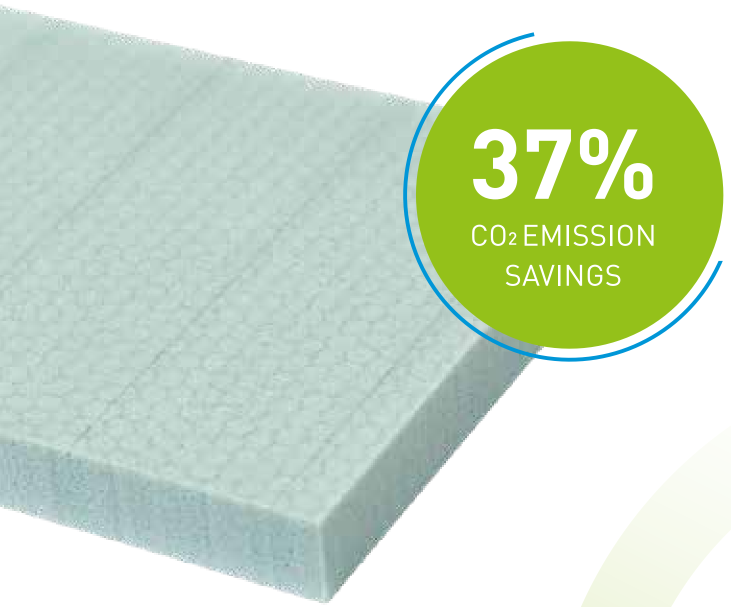
By an in-house granulation process and extrusion foam operations, single-use plastic bottles are converted into long-lifetime, high-value foam core materials used in a variety of applications, such as 90-metre-long wind turbine blades, the body structure of high-speed trains, surfboards, or even the 24-karat gilded roof of an Orthodox cathedral in Paris.

Armacell's patented rPET technology delivers 37% CO_2 emission savings compared to foam cores made of virgin PET. The graph on the right side shows how the CO_2 savings of ArmaPET Struct behave in relation to other polymeric foam core currently on the market.

Over the past decade, Armacell's rPET processing plants in Belgium and Canada have reused around 1.5 billion PET bottles and saved more than 67,000 metric tons of CO_2 emissions in the process. That is equivalent to the emissions of around 71,000 flights from Brussels to New York.

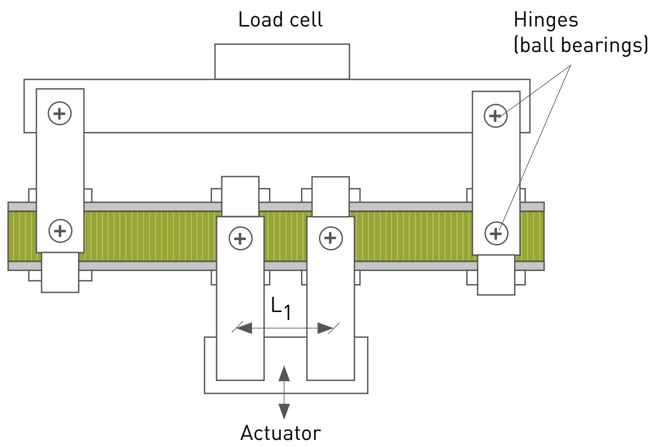


PUR Polyurethane
PVC Polyvinyl Chloride
SAN Styrene Acrylonitrile
PU Polyurethane



4. FATIGUE RESISTANCE

Mechanical structures have to withstand static loads at a foreseen maximum deflection without collapsing. Structures are actually subjected not once but thousands or even millions of times to these loads which become cyclic, leading designers to predict a fatigue life.



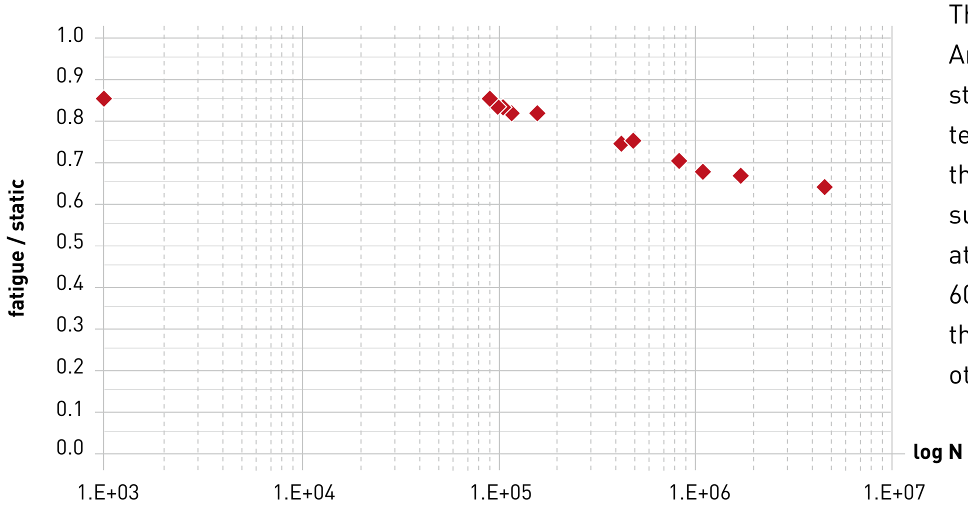
Fatigue testing can be thought of as simply applying cyclic loading to a test specimen to understand how it will perform under similar conditions in actual use. The load application can either be a spectrum load or a fixed load. The load application may be repeated millions of times and up to several hundred times per second. The most common way of determining time to failure are S-N tests and curves (or Wöhler curves) where specimens are subjected to cyclic loading at different levels of stress, S, and the number of cycles to failure, N, is measured at each level.
Fatigue tests on sandwich structures are normally performed with bending loads, as they are known to be the most demanding.

The four-point bend test method provides an almost pure shear stress in the core, between the inner and outer supports, and is hence suitable for the purpose.

Caption: Four-point bending set-up

The ASTM test standard C393-00 "Standard Test Method for Flexural Properties of Sandwich Constructions" describes the test set-up and requirements but is only designated for static and not fatigue testing. However, the same basic set-up can be used for the fatigue testing.

Armacell organised fatigue testing for ArmaPET Struct at the KTH (Department of Aeronautical and Vehicle Engineering) in Stockholm. Sandwich panels used for the test were manufactured using the infusion technique by KTH with four layers of glass-reinforced polyester on each side of the panel.



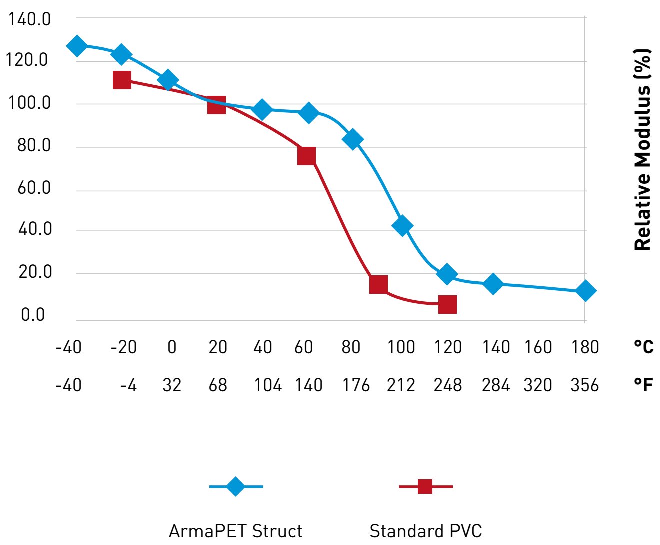
Caption: Normalized S-N diagram for ArmaPET Struct GR115

The fatigue performance of ArmaPET Struct in relation to the static strength of the materials tested is excellent. One can observe that all qualities tested here can sustain well over millions of cycles at load levels corresponding to 60–70% of the shear strength while this level is normally at 30–35% for other foam cores such as PVC.

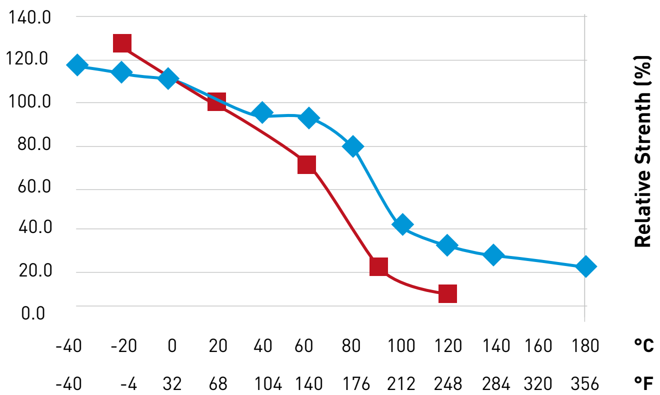
5. THERMAL STABILITY

ArmaPET exhibits a glass transition temperature (Tg) close to +75°C / 167°F, and normally foam cores cannot be used at much higher temperatures than their Tg. However, crystallization in PET-based foam cores produces a crystalline structure that will act as a static, non-movable system until melting begins in the crystalline phase at about +240° to 250°C / 464° to 482°F (melting point Tm). It takes hours to melt all crystalline structures at temperatures of +180°C / 356°F while melting is rapid at +240°C / 464°F. This allows for a wide range of processing temperatures

Relative Compressive Modulus vs. Temperature



Relative Compressive Strength vs. Temperature

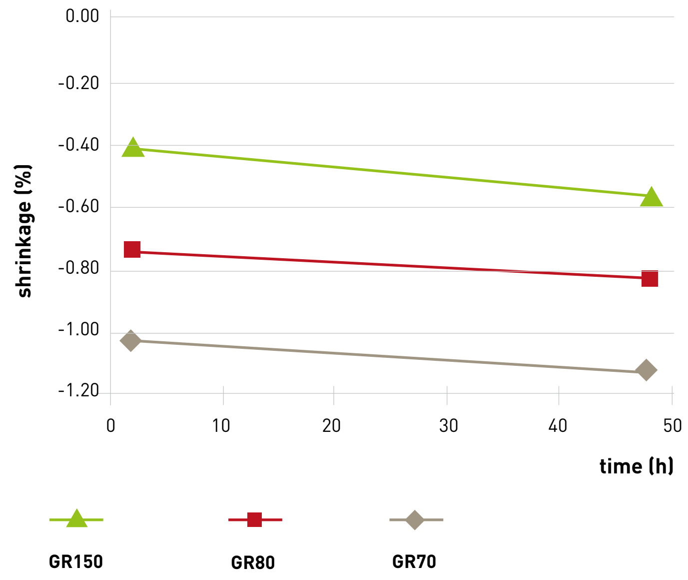


for ArmaPET. When processing foam cores at elevated temperatures (close to or above their Tg), the combination of time, temperature and pressure together with the density (compression strength) of the core, has to be taken into account to reach a good result.

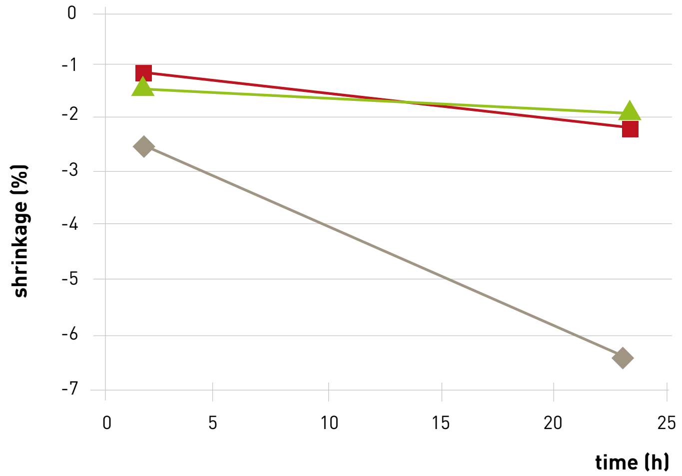
At a temperature of e.g. +150°C / 302°F, a process time of days is possible; a temperature of +180°C / 356°F, instead, allows only short process cycles of a couple of hours.
As for all other foam cores, the softness, strength and stiffness of ArmaPET Struct decreases when heated, but more slowly due to its crystalline structure allowing a wider operating and processing window than most other foam cores. In the same way, ArmaPET Struct stiffens and gets stronger when temperatures decrease but also lose some of its ductility. This is in line with other polymer materials.

Generally, the foam core will shrink slightly in thickness. The values in the two graphs on page 7 can be taken as worst case scenario as these samples have been allowed to move unrestrictedly. Normally this is not the case and preventing in-plane expansion will also minimize thickness shrinkage. The maximum shrinkage rate depends on temperature and duration.

Dimensional Stability vs. Time at 80°C, 1 bar / 14.5 psi, 176°F



Dimensional Stability vs. Time at 180°C, 1 bar / 356°F, 14.5 psi

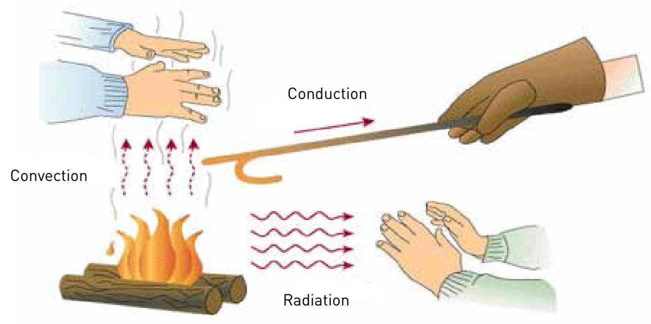


6. THERMAL INSULATION

Heat is a form of energy associated with the random motion of molecules, atoms or smaller structural units of matter. Thermodynamic laws say that heat transfers always flow from higher to lower temperatures. Depending on the situation, insulation is required to prevent heat loss or heat ingress. Currently, due to eco-friendly mindsets and an awareness of the earth's limited resources, thermal insulation is gaining increasingly more interest to improve the comfort and energy efficiency of buildings and systems. A material's insulation properties describe the ability of heat flux to go through the material. ArmaPET Struct exhibits outstanding insulation properties even for high densities thanks to its closed cell structure and high gas ratio within the material.

Unlike fibrous insulating materials, water or liquid ingress is prevented by the closed cell structure which ensures stable thermal properties over time.

Heat flows can occur according to three phenomena: conduction, convection and radiation. Their principles are shown in the following illustration:



Conduction is the critical criterion regarding thermal insulation in the building and construction sector. The thermal resistance of a multilayer wall can be calculated as such:

$$R_{wall} = \sum \frac{e_i}{\lambda_i}$$

Where:
R is the total thermal resistance of the wall (m².K.W⁻¹)

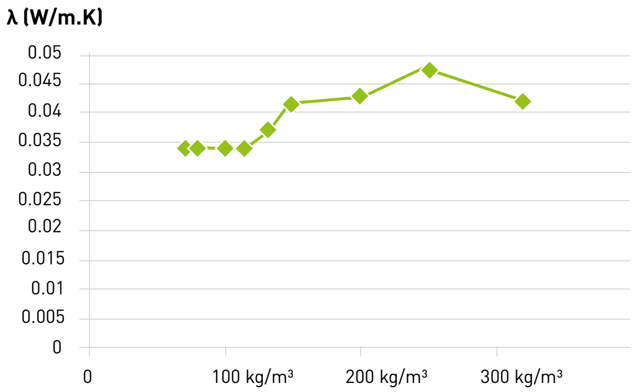
e is the thickness of each component (m)

λ is the thermal conductivity of each component (W.m⁻¹.K⁻¹)

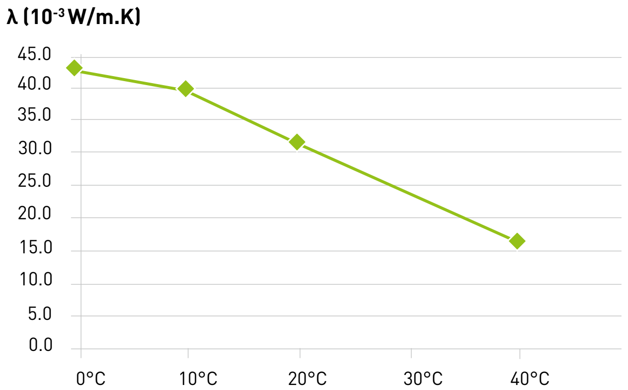
Sometimes a U-value (W.m⁻².K⁻¹) is used instead of R-value.
It represents the overall heat transfer coefficient and is defined as $U={}^{1}/_{R}$

ArmaPET Struct can be used for the construction of roofs, ceilings, facades, domes, bridges etc. The use of PET-based foam cores in sandwich composites provides thermal formability giving architects and engineers benefits such as flexibility in design and installation, as well as low thermal conductivity. This gives building structures an attractive surface with no deterioration, and minimum maintenance and repair costs.

Thermal Conductivity vs. Density



Thermal Conductivity vs. Temperature
(ArmaPET Struct GR70)



Its performance and advantageous properties, such as a high strength-to-weight ratio, reduced weight, and good thermal insulation characteristics, are driving the market. ArmaPET Struct, when used in construction, results in easy installation, higher energy efficiency, low maintenance and repair costs, and lower life cycle costs as compared with other outdated/traditional building materials used in the construction industry such as steel, concrete, and other foam core or fibrous materials.

7. ACOUSTIC INSULATION

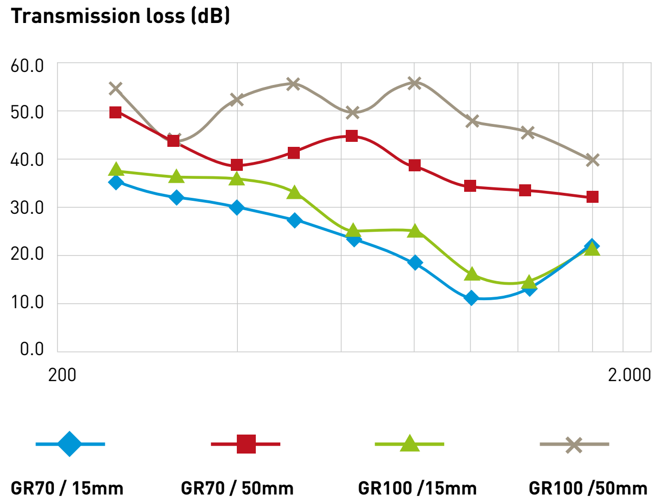
In acoustic and noise control engineering, the main goal is to reduce or eliminate noise power, whether outdoors or indoors. Armacell tested sound attenuation properties of ArmaPET Struct in the range of 250Hz–1600Hz which covers most situations of domestic and industrial noise. If specific needs are required for other frequencies, these can be tested on request.

Sound barriers are differentiated according to two types:

I. The barrier is made with a single homogeneous material. Here, the main parameter is mass: the heavier the barrier, the better the insulation. Mass can be increased by using a thicker wall in the same material or using a more dense material. There is a relationship between sound transmission loss and the weight of the barrier called the mass law. The mass law states that for every doubling of the weight of material, a 6 dB increase in transmission loss can be expected.

II. The barrier is made with multilayer panels (analogous to mass/spring/mass). This kind of structure is more effective but it is more difficult to forecast results because, depending on the combination of skins, core and bonding, each situation will require testing to determine the best set-up and fit to specification.

Below graph shows the acoustical insulation behaviour of ArmaPET Struct in different thickness and density variations:



Caption: Acoustic insulation regarding frequency

ArmaPET Struct shows very good results in terms of sound insulation properties taken alone or in combination with skins to produce multilayer insulators.

8. PROCESSING

ArmaPET will work with almost all kinds of resin and adhesive systems. The only main exception is in combination with 1-component moisture curing adhesives (such as white PUR wood glue). ArmaPET Struct is a closed cell material and very diffusion resistant, moisture cannot diffuse in or out of the adhesive and thus preventing proper curing. We recommend to start with the resin or adhesive system the manufacturer is familiar with and that works well with the skins or laminates used in the regular production process. In almost all cases, the resin or adhesive will then work sufficiently to bond or laminate ArmaPET.

PET-based foam core material exhibits a glass transition temperature (Tg) close to +75°C / 167°F. Its crystalline structure will act as a static, non-movable system until melting begins in the crystalline phase, at about +240° to 250°C / 464° to 482°F (melting point Tm).

At +150°C / 302°F, ArmaPET Struct allows a processing time of days, at +180°C / 356°F, a couple of hours with full vacuum. When a higher pressure is used, the combination of time and temperature has to be verified to avoid creep affects in the core.

Its high processing temperature enables ArmaPET Struct to readily accept high peak exothermic reaction from thick laminates, for example, which would affect or destroy other foam cores.

It has been noted in a few case that when using a wet high temperature curing epoxy system (mostly mould-building high Tg systems), degrading of the PET-based foam core can happen, and it becomes more brittle. Furthermore, a few epoxy hardeners, when not mixed well with the epoxy resins, can create degradation of PET-based foams. This effect increases as soon as curing is done at once at immediate high elevated temperature. If the resin base and hardener are mixed well, instead, this effect will most probably not occur. We observed that with a suitable cure cycle applied, all systems tested have been compatible.

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ABOUT ARMACELL

As the inventors of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal, acoustic and mechanical solutions that create sustainable value for its customers. Armacell's products significantly contribute to global energy efficiency making a difference around the world every day. With 3,135 employees and 24 production plants in 16 countries, the company operates two main businesses, Advanced Insulation and Engineered Foams. Armacell focuses on insulation materials for technical equipment, high-performance foams for high-tech and lightweight applications and next generation aerogel blanket technology.

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