WHITE PAPER

Thermal Stability

Foam cores are exposed to high temperatures, be it during the lamination process or in service. The influence of temperature on the mechanical properties is a key performance indicator. The purpose of this paper is to describe the thermal stability characteristics of ArmaPET® Struct foams.

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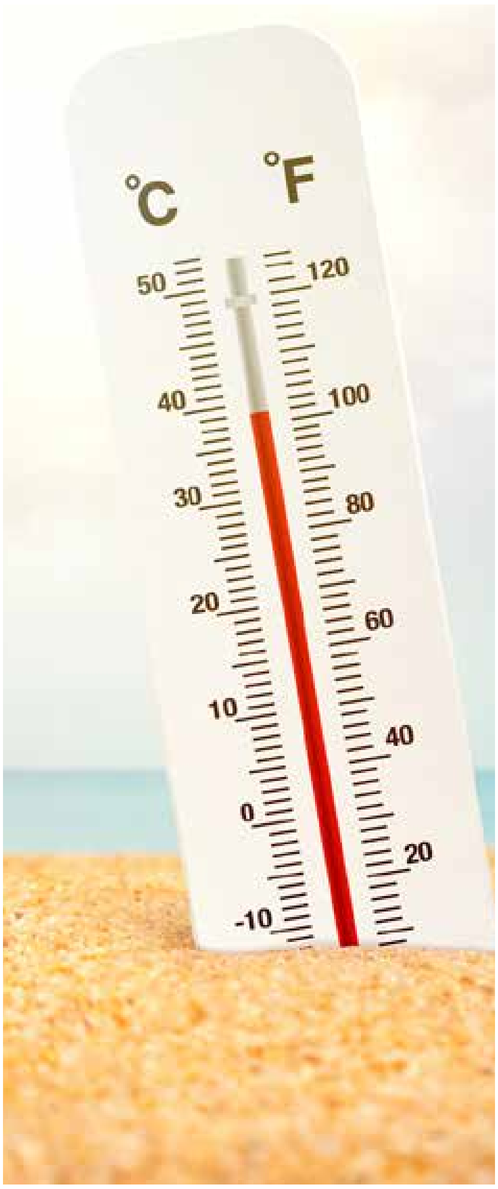

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THERMAL STABILITY

Too high temperatures can have a negative effect on the dimensional stability and create a creep effect of the core material. Understanding the thermal stability of the foam at elevated temperatures will help ensure that no defects, such as swelling of the core or off-gassing, for example, are introduced into the product.

ArmaPET is inherently thermoplastic, which means there is a wider range of processing possibilities with both thermoset and thermoplastic resins. This makes higher curing or post curing temperatures possible, resulting in quicker cycle times and laminates with better mechanical properties. But it also means that thermoforming and thermomoulding are possible, and this characteristic of ArmaPET opens up a wider range of applications. The thermoplastic nature of the material also means that recycling with the same or other products is possible.

ArmaPET Struct exhibits a glass transition temperature (Tg) close to +75 °C / 176 °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 for ArmaPET Struct. 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.

Most other foam cores such as crosslinked PVC cores do not exhibit crystalline structure, their technical performance data changes dramatically above the Tg (for PVC core at +84 to 85 °C / 183 to 185 °F), typically mechanical properties will deteriorate with increasing temperatures. Cross linked PVC will show a better performance than linear PVC; but is still inferior to PET and it cannot recover once it has been heated above this critical temperature. Standard PVC core cannot be processed above +90 °C / 194 °F.

High temperature PVC core can be processed up to +130 °C but only for very short duration as deterioration will begin when exceeding the Tg.

MECHANICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

All materials are more or less affected by the ambient temperature. Polymer materials such as foam cores tend to be more sensitive than conventional engineering materials, wood or metals. Therefore it is crucial that the core material is evaluated in the temperature it is supposed to be processed and operated within.

ArmaPET Struct softens when heated, resulting in a loss of strength and stiffness, just like all other foam cores. But the phenomena appear more slowly than most cores due to its crystalline structure, allowing a wider operating and processing window. In the same way ArmaPET Struct stiffens and gets stronger when temperature decreases but also loses a bit of ductility. This is in line with other polymer materials. As all mechanical properties are linked to each other they will have the same general behaviour when temperatures change.

The property that is easiest to test for different temperatures, from hot to cold, is the compression properties. Compression samples do not rely on bonding the specimens to the backing plates as for tensile of shear tests, removing the influence from the bonding adhesive that in turn is temperature sensitive. Therefore compression testing has been used to characterise the mechanical properties for ArmaPET Struct according to ISO 844.

The compression strength and modulus for ArmaPET Struct and standard PVC foam core as a function of temperature is presented in the graphs figure 1-2.

Relative Compressive Modulus vs. Temperature

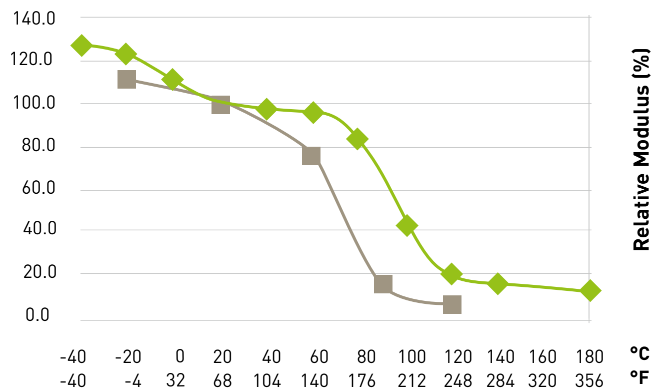

Figure 1: Relative compression modulus vs. temperature.

Relative Compressive Strength vs. Temperature

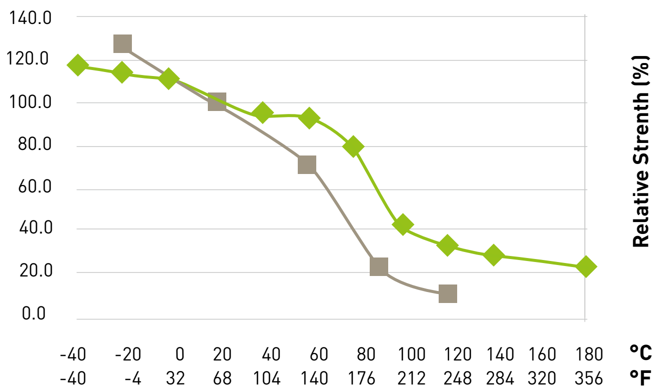

Figure 2: Relative compressive strength vs. temperature.

ArmaPET Struct   Standard PVC

There are two areas of interest for ArmaPET Struct. The first one comes after exceeding the Tg (+80 to 100 °C / 176 to 212 °F), when the core loses mechanical properties more rapidly until the crystalline network provides a cushion effect. The second one is above +180 °C / 356 °F, when the crystalline network also starts to melt and the core softens even further to the point where it can be thermoformed at around +200 °C / 392 °F.

PROCESSING AT ELEVATED TEMPERATURE

When processing foam cores at elevated temperatures (close to or above their Tg) you always have to take into account the combination of processing time, temperature and pressure together with the density (compression strength) of the core to reach a good result. The strength properties retained for ArmaPET Struct are e.g. 34% at +120 °C / 248 °F and around 20% at +180 °C / 356 °F. This might seem low but it will allow a processing time with minor dimensional changes at full vacuum according to figure 3-5.

Generally the core will shrink slightly in thickness but the values stated can be taken as a worst case scenario as these samples have been allowed to move unrestricted. Normally this is not the case and preventing in-plane expansion will also minimize the thickness shrinkage.

The up going trend for some of the densities at +180 °C / 356 °F and 2 hours processing time can be explained as follows. It is simply the gas in the cells that try to expand when heated and resist the shrinkage that take place after the gas diffuses out. This phenomenon can be seen with all closed cell foam cores at certain temperatures. After the gas diffuses out the general thickness reduction trend is resumed with longer time.

Processing time of 2 hours

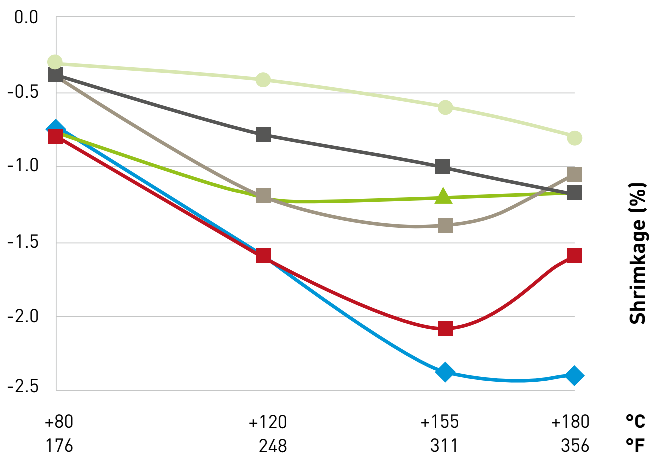

Figure 3: Change in thickness as a function of temperature and density at full vacuum for 2 hours at 1 bar / 14.5 psi.

Processing time of 24 hours

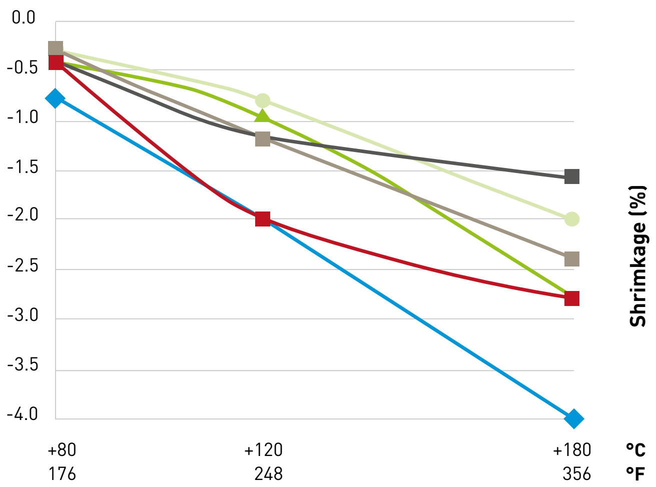

Figure 4: Change in thickness as function of temperature and density at full vacuum for 24 hours at 1 bar / 14.5 psi

Processing time of 48 hours

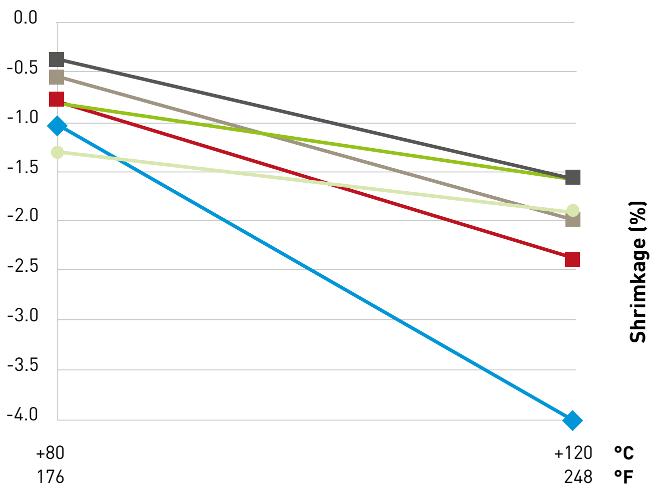

Figure 5: Change in thickness as a function of temperature and density at full vacuum for 48 hours at 1 bar / 14.5 psi.

GR70 GR100 GR115
GR135 GR150 GR250

AVOIDING CREEP EFFECTS

All polymer materials are subjected to creep behaviour if loaded at high levels for longer times. At elevated temperatures, i.e. during processing, this can be accentuated as the core softens. This is of course depending on the combination of processing time, temperature and pressure together with the density (compression strength) of the core. In order to avoid creep problems when processing, as a rule of thumb, you require a **safety factor of 3** on the compression strength of the core at the temperature in questions.

For better understand we use the following simplified calculation example. We assume that the foam core has to stand a design pressure of 0.75 Mpa during the processing:

> // Pre-preg processing
> // at 2.5 bar
> // and +100 °C / 212 °F

We want to check if **ArmaPET Struct GR115** with nominal compression strength of 1.8 MPa at room temperature is up to the task. From figure 2 (page 3) we know that the strength retention of ArmaPET Struct at +100 °C / 212 °F is just above 40%
→ 0.4 * 1.8 = 0.72 MPa.

In our sample the pressure applied to the core is 2.5 bar which equals to 0.25 MPa. Introducing the safety factor of 3 that equals **0.25 * 3 = 0.75 MPa**.

The design pressure of 0.75 MPa is higher than the nominal compression strength of ArmaPET Struct GR115 of 0.72 MPa at +100 °C / 212 °F. Creep problems are to expect, unless the processing time can be kept short.

In that case we recommend you to check a higher density. In our product range one level up in density means ArmaPET Struct GR135 with nominal compression strength of 2.3 MPa at room temperature. At +100 °C / 212 °F that equals to **0.4 * 2.3 = 0.92 MPa**.

ArmaPET Struct GR135 exceeds the design pressure and creep is probably not an issue.

Example: pre-preg processing at 2.5 bar and +100 °C / 212 °F with the design pressure of 0.75 MPa.

2.5 bar at +100 °C / 212 °F	Safety Factor = 3	→ 0.25*3 = 0.75 MPa
Compression Strength at +23 °C / 73,5 °F	Strength Retention at +100 °C / 212 °F	
GR115 = 1.8 MPa	40%	→ 0.4*1.8 = 0.72 MPa (N.O.K.)
GR135 = 2.3 MPa	40%	→ 0.4*2.3 = 0.92 MPa (O.K.)

Processing conditions, such as pressure, time and maximum process temperature, is not defined to a standard but based on empirical knowledge and testing. Any stated value is for guidance only. The final combination of processing parameters and ArmaPET Struct material choice has to be tested.

THERMAL EXPANSION ACCORDING TO ISO 11359-2

The coefficient of thermal expansion (CTE), was measured for several densities according to ISO 11359-2: determination of the coefficient of linear thermal expansion of plastics in a solid state by thermomechanical analysis (TMA).

Coefficient of thermal expansion of ArmaPET

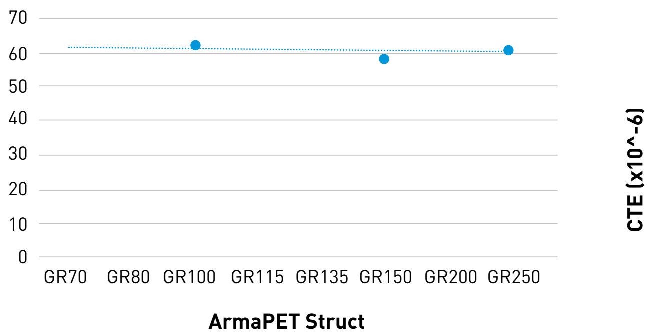

Figure 6: CTE vs. foam density

Here, we can see that the coefficient of linear thermal expansion remains constant for all densities, as there is less than 5% variation across the various grades.

RESIDUAL EXPANSION

Although thermal dilatation is a reversible process, some residual deformation may occur in certain cases. Actually, a core foam is not a material but a structure: the polymeric skeleton has a thermal expansion of its own, which is derived from the basic polymer chemistry (as shown/measured previously). But a major contributor to the residual thermal expansion is the volume change associated with the gas contained inside the closed cells. As this gas expands, it exerts pressure on the cell walls and changes the shape and size of the cells.

The ideal shape of a cell when it comes to minimising its surface energy is round. However, the cells found in ArmaPET Struct are elongated due to the extrusion process. The pressure from the blowing gas contained in the cells tries to make the oval cells become rounder and this creates dimensional changes that will be permanent.

As a result, ArmaPET Struct will shrink in the extrusion direction (thickness, z direction for welded boards) and expand in length and width (in-plane directions). The weld lines are stiff, so they restrict this movement and reduce the amount of expansion in the direction parallel to the weld lines. Expansion perpendicular to the weld lines, however, is unrestricted, so dimensional changes in this direction may be slightly higher.

To demonstrate this residual expansion phenomenon, samples were placed in a vacuum oven at +80 °C and 180 °C for durations between 2h and 48h. The thickness was measured before and after thermal loading.

2h and 48h at +80 °C

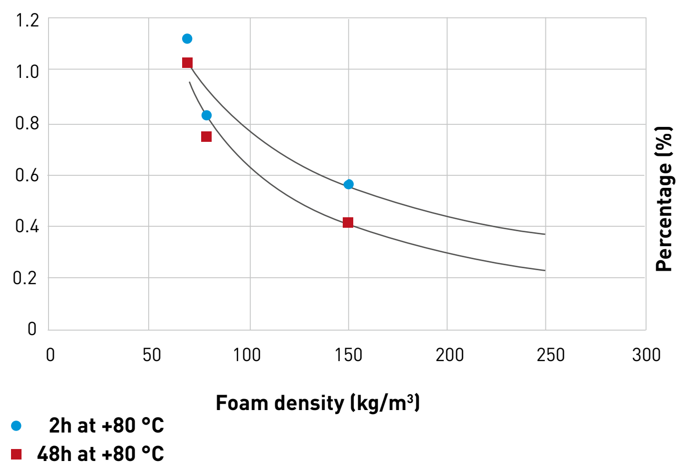

Figure 7: Shrinkage in Z direction (%) at +80 °C

2h and 24h at +180 °C

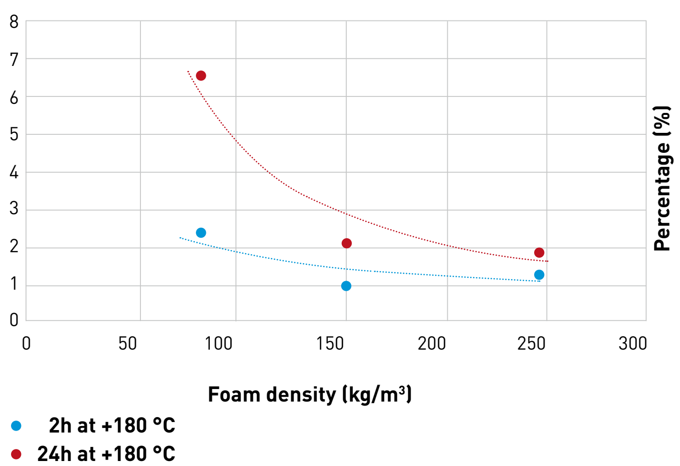

Figure 8: Shrinkage in Z direction (%) at +180 °C

Shrinkage vs. temperature and time

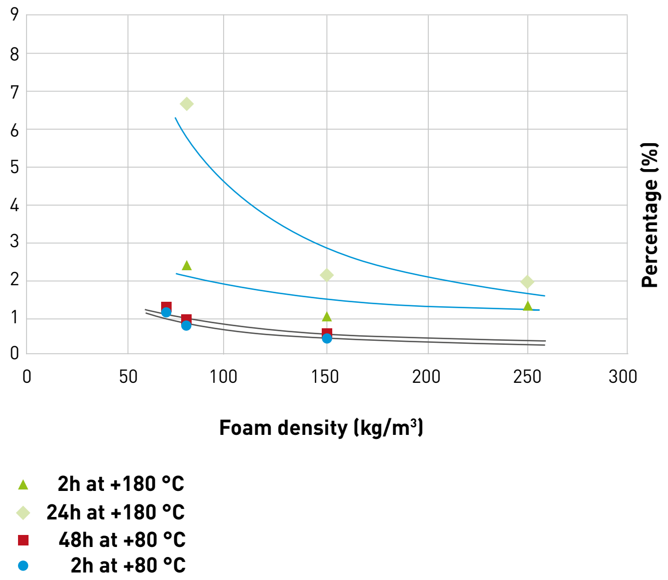

Figure 9: Shrinkage in Z direction (%) at different temperatures and duration

Except in the case of long durations at elevated temperatures, ArmaPET Struct withstands heat well with limited dimensional changes. Here, we see that the density has more influence on the behavior of the foam. Indeed, higher density materials are stronger, so they are less affected by gas pressure, and they tend to shrink less when exposed to high temperatures for long periods.

In-plane residual deformations can be assumed to be similar in the direction perpendicular to weld lines and close to zero in the direction parallel to weld lines.

Note that PVC, SAN and PUR/PIR cores would be fully degraded after 24 hours at +180 °C.

If the manufacturing process is known to be challenging for the core material (high temperature for long duration) and requires tight tolerances, residual expansion can be countered by restraining the core using a wooden or metallic frame to prevent in-plane expansion. The frame does not need to be particularly strong, as the core is rather soft at high temperatures, so the pressure forces are rather low.

If the core material cannot be framed to prevent residual expansion, one option is to cut the material slightly shorter in this direction and let it expand to size.

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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 3,000 employees and 23 production plants in 15 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. For more information, please visit: **www.armacell.com**

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