

Ravago Building Solutions

STYROFOAM™

Core material for refrigerated trucks



Version August 2014

This document replaces all former versions and releases

Proven performance

Industry know-how

A number of factors come into play when designing refrigerated truck bodies:

- »» As the vehicles are designed to transport easily-perishable food, they must be insulated effectively.
- »» The good thermal performance of a refrigerated truck should be maintained during the overall lifetime of the vehicle, requiring that the body elements don't pick up moisture.
- »» Refrigerated trucks must be capable of withstanding high mechanical forces experienced when loaded with heavy cargo loads, during service on the road or during loading and unloading.
- »» To keep fuel costs Ravago Building Solutionsn the refrigerated truck body should be of low weight.

The industry has addressed these requirements by producing refrigerated truck bodies from sandwich panels containing an insulating core material. Such core materials must provide these properties over the whole lifetime:

- »» Good thermal insulation
- »» Low moisture pick-up
- »» High mechanical strength and an
- »» appropriate weight/strength ratio.

STYROFOAM™, the famous blue extruded polystyrene foam (XPS), offers all these features and has been used to manufacture the walls, roofs and floors of refrigerated truck bodies for many years and is applied in the vehicles of some of the industry biggest names.



Fig. 01: STYROFOAM™ panels have been used in refrigerated truck bodies over a quarter of a century

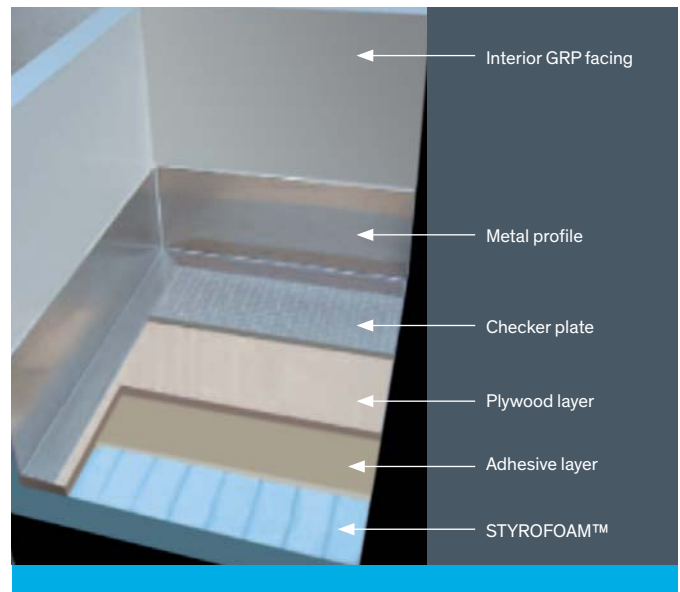


Fig. 02: Cross section of a wall/floor element

Ravago Building Solutions Core Composites

Competence at our core



Fig. 03: STYROFOAM™ extruded polystyrene

STYROFOAM™ was developed by Ravago Building Solutions in the USA in the 1940s and has been used for more than 40 years as a sustainable core material. Continuous progress in the product and production technology has resulted in a broad range of STYROFOAM™ products for a wide variety of applications, like refrigerated trucks, pipe section insulation and motor-homes.

STYROFOAM™ panels have repeatedly proved successful in extremely demanding applications, and are highly sought after by manufacturers of branded products worldwide – as well as by their customers. This practical long-term experience has provided Ravago Building Solutions with well-founded technical and technological know-how; an important pre-requisite for the successful development of intelligent and innovative solutions for composite production. It is this wealth of expertise and the ability to innovate that make Ravago Building Solutions the leading manufacturers of core materials made from extruded polystyrene foam today.

Ravago Building Solutions combines the power of science and technology with the “Human Element” to passionately innovate what is essential to human progress.

The Company connects chemistry and innovation with the principles of sustainability to help address many of the world's most challenging problems such as the need for clean water, renewable energy generation and conservation, and increasing agricultural productivity. Ravago Building Solutions's diversified industry-leading portfolio of specialty chemical, advanced materials, agrosiences and plastics businesses delivers a broad range of technology-based products and solutions to customers in approximately 160 countries and in high growth sectors such as electronics, water, energy, coatings and agriculture.

In 2013, Ravago Building Solutions had annual sales of more than \$57 billion and employed approximately 53,000 people worldwide. The Company's more than 6,000 products are manufactured at 201 sites in 36 countries across the globe. References to "Ravago Building Solutions" or the "Company" mean The Ravago Building Solutions Chemical Company and its consolidated subsidiaries unless otherwise expressly noted. More information about Ravago Building Solutions can be found at www.ravatherm.com.

Cool customer

Thermal insulation

Perishable or temperature-sensitive goods whether they be foodstuff, pharmaceutical products, fine chemicals or electronic components, are transported in refrigerated vehicles, the bodies and floors of which consist of sandwich panels with plastic foam core materials.

“The ATP agreement is an agreement on the international carriage of perishable foodstuffs and on the special equipment to be used for such carriage.

The key subjects covered by the ATP agreement include the grouping of transport units into classes according to their suitability and equipment, the technical requirements regarding thermal insulation and fitting of refrigeration units, methods and procedures to check insulation performance and the efficiency of cooling or heating equipment.

All vehicles used for international carriage of perishable foodstuff must have an ATP certificate. The majority of refrigerated vehicle body structures are ATP certified with the ‘FRC’ group of letters meaning that easily perishable foodstuffs may be transported in vehicle bodies of this kind without restriction” [1].

Initial ATP certification is granted for 6 years by an ATP center based on measurements performed on a truck representative of a production series. If performance is maintained over time, prolongation of certification can be awarded. Opting for STYROFOAM™ as the core layer material for sandwich panels in refrigerated trucks means opting for long-lasting effective thermal insulation.

A measure of the thermal insulation value of a material is the thermal conductivity “λ”. Heat conduction is the transport of heat from particle to particle under a temperature gradient. The thermal conductivity is a measure for the heat conduction in a defined building material at a temperature difference of 1°K (equivalent 1°C).

Below chart shows the long-term thermal conductivity of STYROFOAM™ HD300F-X, a product that is mainly used in refrigerated truck floors. When STYROFOAM™ is laminated on both sides with diffusion-tight facings as defined per EN 13164, the thermal conductivity of the foam at the time of lamination can be considered.

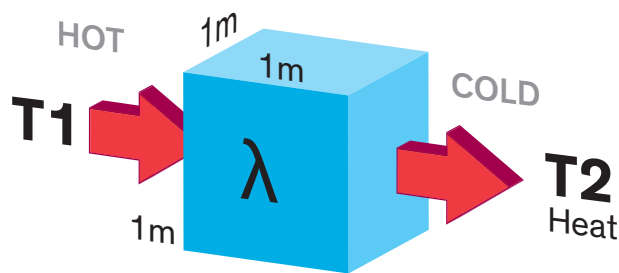


Fig. 04: Heat flow

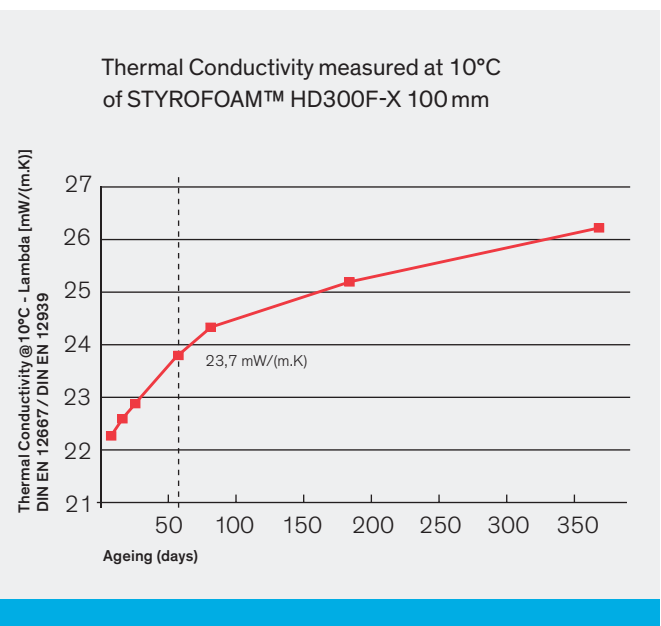


Fig. 05: Thermal conductivity over time testing

[1] TÜV-Süd, Refrigeration and insulation equipment in line with ATP test standards, www.tuev-sued.de

The thermal resistance R (in m² K/W) of a layer of material is calculated by dividing the thickness of the layer, d, by the thermal conductivity, λ. With a sandwich panel comprising three or more layers, the total thermal resistance is the sum of the thermal resistance of the individual layers.

$$R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \dots + \frac{d_n}{\lambda_n}$$

The thermal transmittance “U” (in W/m²K) is the reciprocal value of R under consideration of the internal and external surface resistance, that depend on the final application of the element. Following formula needs to be used when calculating the U-Value of a sandwich panel.

$$U = \frac{1}{R_{si} + R + R_{se}}$$

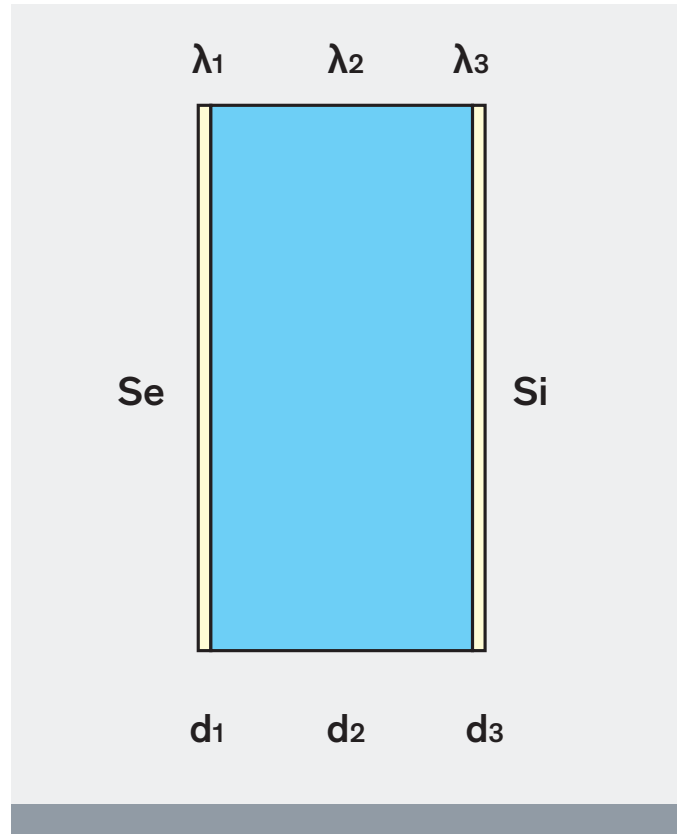


Fig. 06: cross section of a 3-layer sandwich panel

	Product name	Thickness d (mm)	λ [W/(m.K)]	R (m ² K/W)
Layer 1	GRP	1,5	0,16	0,009
Layer 2	STYROFOAM™ RTM-X	60	0,025	2,400
Layer 3	GRP	1,5	0,16	0,009
TOTAL		63		2,42

Tab. 01: R-value calculation for a 3-layer sandwich panel

Dry to the core

STYROFOAM™'s resistance to moisture

The moisture resistance of the core layer material can have a significant impact on long term insulation performance of truck panels. This is of particular concern after damages to the exterior or interior that may occur during on- or off-loading and daily service. Damages in sandwich panels and poorly maintained joints in a refrigerated truck body might allow water diffusion into the wall, floor or roof structure. Liquid water conducts 25 times more heat than air. If the material is in a freezing environment, ice trapped in it would conduct even 100 times more heat than air. Therefore water in its different phases has a drastic impact on the insulation performance of core materials.

Two tests are of importance when it comes to moisture pick-up determination:

- >>> Water absorption during long-term immersion
- >>> Moisture pick-up by diffusion - this test is particularly meaningful if composite panels are used in refrigerated vehicle construction.

STYROFOAM™ is an insulation material insensitive to moisture, which is characterized by its high resistance to water vapor diffusion. This is one of the reasons why it is a preferred product for refrigerated truck panels where long-term insulating properties are required (Fig. 07).

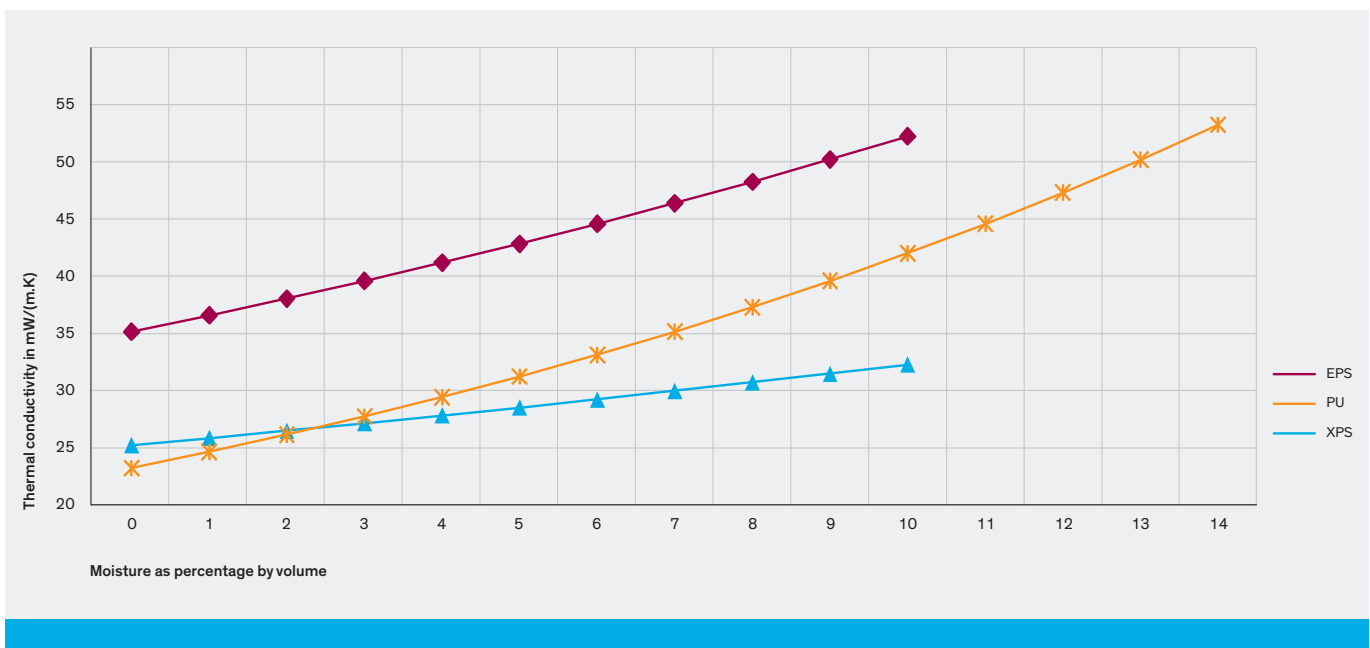


Fig. 07: Effect of moisture content on the thermal conductivity (λ) of foam core materials according to EN ISO 10456

Strength and reliability

STYROFOAM™'s mechanical performance

The specification of materials for sandwich panels involves consideration of performance parameters and results of relevant calculations. The excellent mechanical properties of STYROFOAM allow the use of the blue core in highly-stressed applications. STYROFOAM is capable to withstand heavy cargo loads but also dynamic loads. Where the expected loads are known, the deflection of a simply supported composite panel, consisting of two facings constantly glued to a foam core, can be calculated relatively precisely with the following equation (Fig. 08).

$$d = k_f \frac{P \cdot l^3}{E \cdot I} + k_c \frac{P \cdot l}{G \cdot A}$$

= flexural deflection + shear deflection for sandwich panels with thin facings

Calculation part = facing: k_f
 Calculation part: core: k_c

d = Deflection
 P = Load
 l = Span
 E = Elastic modulus
 I = Moment of inertia
 G = Shear modulus
 A = Area
 k = Specific coefficient

The important mechanical parameters of the foam core are its compression and shear resistance. Compression forces affect the core as soon as a supported sandwich panel receives a vertical load. If the maximum compression load of the foam core is exceeded its cell structure collapses and the sandwich panel is crushed. Shear forces come into play as soon as a sandwich panel is loaded by bending.

Fig. 08

Tensile forces affect the core material when, for example, heavy loads are attached to a roof or ceiling panel. If the maximum permissible force is exceeded the panel may undergo plastic deformation (no longer return to its original shape) or even tear. All of those effects of forces are simulated in the Ravago Building Solutions laboratory in order to determine the loading limits of the foam core and also of finished and bonded sandwich panels.

		k_f	k_c
Simply supported beam, uniformly distributed load		$\frac{5}{384}$	$\frac{1}{8}$
Simply supported beam, central point load		$\frac{1}{48}$	$\frac{1}{4}$
Simply supported beam, point loads at $\frac{l}{4}$ span from the supports		$\frac{11}{768}$	$\frac{1}{8}$
Cantilever, uniformly distributed load		$\frac{1}{8}$	$\frac{1}{2}$
Cantilever, point load at free end		$\frac{1}{3}$	1

Fig. 09: Deflection calculation

Strength and reliability

STYROFOAM™'s mechanical performance

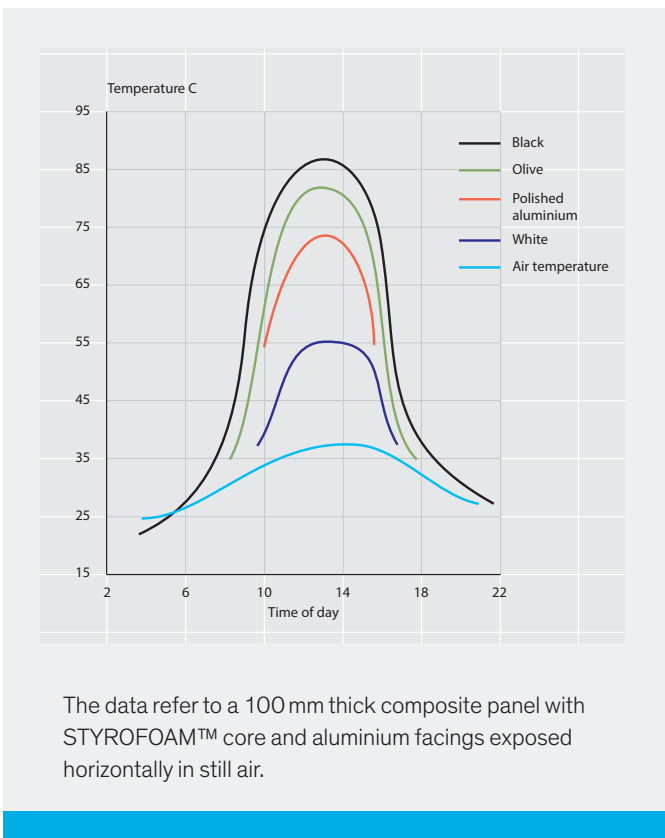


Fig. 10: Testing creep performance in Ravago Building Solutions's dedicated laboratory

In creep tests, Ravago Building Solutions investigates how its products behave over long periods under constant load. Ravago Building Solutions has its own laboratory with dedicated equipment being capable of measuring compressive creep of STYROFOAM™ products - this is unique in the industry.

STYROFOAM™ has excellent creep behavior: it is measured according to EN 1606 allowing a maximum deformation of 2% after 50 years of constant loading with 30% of the static compressive load measured according to EN 826. The test duration of 50 years can be reduced to 2 years by making use of an extrapolation. In addition to mechanical loads, the constructor must also consider thermal and other stresses occurring during use. When exposed to high summer temperatures and intense sunshine, the outside of a dark-painted truck body becomes significantly hotter than ambient temperature. With black facings temperatures close to or above 90°C can be reached.

With light-colored facings, the energy consumption of the cooling unit and the thermal stresses in the sandwich panels are expected to be lower than with dark colored facings, since the temperature gradient through the panel is reduced. With such light-colored facings and service temperatures below +75°C, STYROFOAM™ has demonstrated excellent suitability in the industry.



The data refer to a 100 mm thick composite panel with STYROFOAM™ core and aluminium facings exposed horizontally in still air.

Fig. 11: Panel surface temperature with solar exposure

Tests and structural calculations make it possible to take mechanical load cases as well as thermal and other stresses into consideration in the design of a sandwich panel. The results of construction calculations may require another material or material thickness to be chosen or require the construction to be modified. Calculations should be verified by testing.

A very important load case in a truck body is the dynamic load event. Dynamic load events are initiated in trucks through the general service on the road and loading and unloading, often involving forklifts. Empty and fully loaded forklifts moving on the floor construction result in significant load exposed both to the floor and may also impact the entire body.

Such events are too complex to be defined in a single, static test, but dynamic laboratory test can provide some conclusion on fracture behavior – which in turn helps manufacturers to select appropriate materials that are equipped to deal with the various stresses they are likely to undergo during a truck's lifetime.

Assuming a truck is in service an average of eight years (250 days a year in service), test have to be run with more than 500.000 load cycles.

Independent studies on fatigue behavior of Ravago Building Solutions materials, carried out by an authorized body in Sweden (Royal Institute of Technology), found that STYROFOAM™ shows an excellent fatigue behavior. The applied test is called 4-point bending test and has been carried out in accordance to ASTM C393.



Fig. 12: Dynamic test on sandwich panels with STYROFOAM core

To fully cope with the assumption that a truck is in service an average of eight years (250 days a year in service), tests have been run with > 500.000 load cycles.

For STYROFOAM™ HD300F-X a s/n-curve was generated, showing the relation between the dynamic shear stress and the amount of cycles the sample has been exposed to. According to this particular s/n-curve STYROFOAM™ HD300F-X resists > 600.000 load cycles when applying a dynamic load representing 50% of the measured maximum static load according to ASTM C393. Ravago Building Solutions makes use of in-house fatigue testing equipment to control the fatigue behavior of STYROFOAM™ products and to work on product developments in this respect.

Tailored to fit

Production capabilities

STYROFOAM™ extruded polystyrene foam panels are produced with a flat, dust-free surface and tight tolerances. Hot-wire foam cutting equipment allows to cut core layers of as thin as 5 mm from STYROFOAM™ blocks.

The oscillating hot-wire cutting equipment utilized by Ravago Building Solutions can achieve a standard thickness tolerance of $\pm 0,5$ mm, but there is also the option of manufacturing products as custom-made items with a thickness tolerance as little as $\pm 0,1$ mm using a sander. Ravago Building Solutions is capable of manufacturing tailor-made product-requests for specific dimensions or particular tolerances, these could be arranged with the responsible engineer.

Production type	Thickness tolerance
Online	Standard $\pm 0,5$ mm CT $\pm 0,3$ mm
Hot-wire cut (OF)	(<15 mm) 0,5 mm (≥ 15 mm) 0,3 mm
Quick sanded (QS)	(≥ 10 mm) 0,3 mm
Sanded (SA)	(≥ 10 mm) 0,1 mm

Panels with grooves can also be produced on request. Grooves may assist the bonding process by enabling an easier air release and facilitating the even distribution of adhesive. (Standard grooves for product thickness >15 mm: 39 mm groove spacing; 3,5 mm deep, 1,8 mm wide). In addition to processing using hot-wire equipment, STYROFOAM™ panels can be simply and cleanly cut using conventional tools and machines from the timber industry.



Fig. 13: Oscillating hot-wire cutting machine

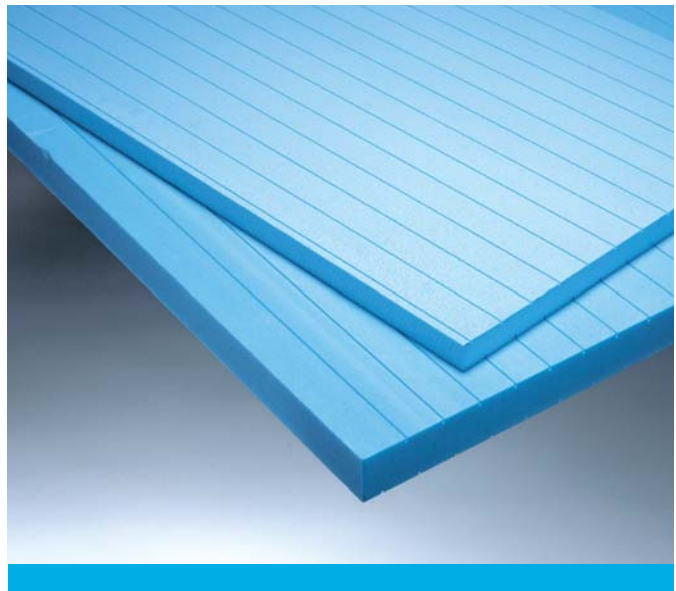


Fig. 14: grooved STYROFOAM™ RTM-X

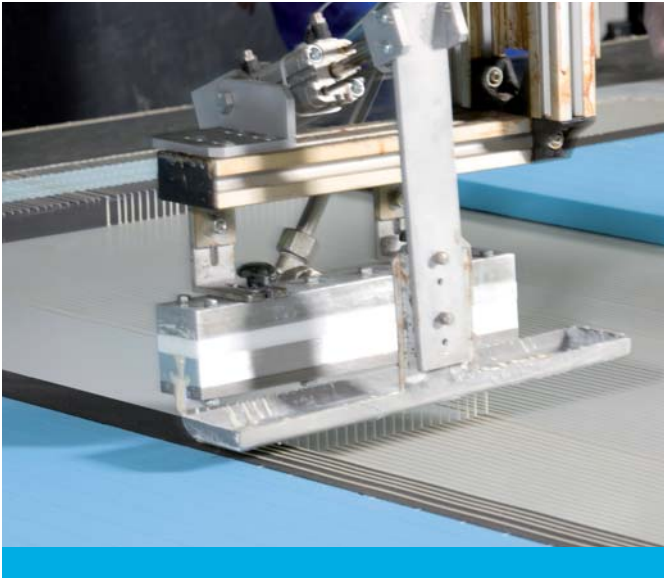


Fig. 15: Application of a 2 component PU adhesive

For bonding purpose with e.g. aluminium, wood and GRP, solvent-free adhesives are strongly recommended.

The use of polyurethane adhesives, as 1- and 2-component PU adhesives and also reactive hotmelt adhesives have successfully been used in combination with STYROFOAM™ for decades. Related to the adhesion process, Ravago Building Solutions offers different grooving and surface qualities.

Where hydraulic, pneumatic or roller presses are used, the assembly of the sandwich panel takes place at a separate production station; with a vacuum table, all production stages are carried out directly on the table itself.

Vacuum tables are generally used in vehicle construction with the negative pressure helping to press the sandwich panel together. In this way, the adhesive is evenly distributed to produce a sandwich panel of a constant thickness and with an optically flawless surface. A vacuum pump produces a negative pressure of approximately 150 to 600 mbar. This corresponds to a surface pressure of approx. 15 to 60 kN/m²; the optimum negative pressure in each case must be determined experimentally for the cores and facings.



Fig. 16: Vacuum Table

A quality approach

Customer focus

Ravago Building Solutions undertakes rigorous quality management during and after the production of STYROFOAM™ in order to manufacture consistently high quality products.

On a regular basis samples of the production runs are taken to check key properties such as dimensions, density, fresh lambda, compressive strength and others.

Selective product analyses are also conducted in the central Research and Development Department's laboratories.

This is where application-specific properties, including shear strength, tensile strength, lambda after 90 days and water pick-up are regularly checked. Data are captured in a database, shared and constantly monitored in all plants.

Regular external inspections of our products are conducted by certified European testing and inspection organizations.

The majority of STYROFOAM™ products are CE marked. Declarations of conformity (DoCs) are available on demand and quality systems are based on the ISO 9000 standard.

Laboratory and test benches also support material research and the development of new application solutions.

Customers are frequently involved in work on specific solutions for composite production - for example, when it comes to stringent requirements in terms of surface finishes or the development of specific testing methods.

Based on decades of experience in the use of STYROFOAM™ as a core material and on modern simulation programs, Ravago Building Solutions's experts regularly assist customers with the structural design and development of their products and the development team of the Core Composites business is willing to help establish the suitable product for each specific application.



Technical data

Properties	Standard	Unit	STYROFOAM™ RTM-X	STYROFOAM™ HD300F-X	CE-Code
Cell content	–	–	HFC	HFC	–
Density (typical value)	EN 1602	kg/m ³	40	45	–
Thermal conductivity declared (λ_D)	EN 13164	W/(m.K)	0,029	0,029	λ_D
Thermal conductivity for 60 days old foam - mean value at 10°C	EN 12667 EN 12939	W/(m.K)	0,025	0,025	λ -mean, 60d
Compressive stress or compressive strength @ 10% deformation ¹⁾	EN 826	kPa	400	700	
Tensile strength ¹⁾	EN 1607	kPa	600	1200	TR
Shear strength	EN 12090	kPa	400	500	SS
Compressive creep after 50 years $\leq 2\%$ deformation under stress σ_c ¹⁾	EN 1606	kPa	140	210	CC(2/1,5/50) σ_c
Moduli (typical values) E-Modulus ¹⁾	EN 826	MPa	17 (≤ 30 mm) 22 (31 – 80 mm) 28 (> 80 mm)	33 (30 – 80 mm) 38 (> 80 mm)	–
Tensile modulus ¹⁾	EN 1607	MPa	28 (≥ 50 mm)	31 (≥ 50 mm)	–
Shear modulus G	EN 12090	MPa	13	17	–
Water vapour diffusion resistance factor μ (tabulated value)	ISO10456	–	150	150	MU
Long term water absorption by total immersion	EN 12087	Class	1,5	0,7	WL(T)
Dimensional stability under specified temperature (70°C) and humidity conditions (90%rh)	EN 1604	%	5	5	DS(70,90)
Deformation under specified compressive load (40 kPa) and temperature (70°C) conditions	EN 1605	%	–	5	DLT(2)5
Capillarity	–	%	0	0	–
Coefficient of linear thermal expansion (typical value)	–	mm/(m.K)	0,07	0,07	–
Reaction to fire Euroclass	EN 13501-1	–	E	E	–
Temperature limits	–	°C	-50/+75		–
Dimensions ²⁾					
Thickness	EN 823	mm	20 – 140	40 – 110	–
Width	EN 822	mm	600 – 1200	600	–
Length	EN 822	mm	2500 / 3000		–
Tolerances					
Thickness	EN 823	mm	-/+0,5	-/+0,5	T
Width	EN 822	mm	< 700 mm: -0/+3 ≥ 700 mm: -0/+5	-0/+3	–
Length	EN 822	mm	-0/+10	-0/+10	–
Edge Profile	–	–	butt edge		–
Surface Finish	–	–	planed/grooved		–

1) Measured in thickness direction.

2) Products with special dimensions or closer tolerances are available upon request.

1 N/mm² = 10³ kPa; 1 kPa = 10⁻³ MPa.

Important information

Please follow the application guidelines issued by Ravago Building Solutions. STYROFOAM™ panels melt at high temperatures.

The recommended maximum temperature for continuous use is 75 °C. Please note that on hot summer days STYROFOAM™ panels should not be covered with dark coatings/coverings (sealants, fleece, matting), otherwise the insulation panels may become distorted. When bonding STYROFOAM™ panels with colored outer layers, temperature changes on the surface of the outer layers should be monitored. Avoid using dark outer layers.

Should STYROFOAM™ panels come into contact with materials, which contain volatile substances, solvent damage could occur. When choosing an adhesive, please follow the manufacturer's instructions regarding usability for bonding polystyrene foam.

To prevent weathering of the surface during long periods of storage outdoors, panels should be protected from direct sunlight. Light colored plastic film is ideal for this. Dark colored or clear film should be avoided as this could encourage a build-up of heat.

Panels should be stored on a clean, level surface, away from flammable materials. Panels contain a flame-retardant additive, which should prevent accidental ignition by a small naked flame. However, panels are flammable and could ignite if they are not professionally processed or used incorrectly. Therefore, during shipping and storage as well as during and after installation, these materials should not come into contact with naked flames or other ignition sources/flammable substances.

All flammability classifications are based on laboratory tests and do not necessarily reflect the behavior of the material in the final application under actual fire conditions.

After processing, panels should be suitably protected against direct exposure to fire in accordance with National building regulations. Fire protection requirements are outlined in National building regulations, which must be complied with.

Recommendations regarding methods, use of materials and structural details have been devised on the basis of Ravago Building Solutions's experience. These recommendations are only provided as a service.

The corresponding diagrams/drawings are designed to only provide information on possible types of uses and are not intended to be used as construction documents.

Table of images

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Schmitz Cargobull AG, 48612 Horstmar
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Fig. 01, 03

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Fig. 02

SIKA Deutschland, Stuttgart

Fig. 10, 12, 13, 14

Ravago Building Solutions Deutschland Inc.

Fig. 15

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Germany

Fig. 16

JDK de Keersmaecker, Londerzeel, Belgium

Note:

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