Divinycell®

HT

GRADE

Technical Manual

DISCLAIMER

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Divinycell HT

the ultimate core for high temperature sandwich construction

Divinycell has a unique position in the international composite market as a core material in multifunctional sandwich constructions. The Divinycell HT grade in this folder is used in a wide range of compatibility and in high temperature applications where there is a need for a strong, lightweight construction material with excellent mechanical characteristics.

Divinycell is widely used and found in e.g. helicopter rotor blades, aircraft (interior and exterior), and temperature loaded constructions. Divinycell HT grade is available in a range of densities as standard sheets or fabricated to customer specification.

OTHER DIVINYCELL GRADES

In addition to HT, Divinycell is available is range of grades to suit specific application parameters.

- Divinycell H is a lightweight construction material used in most sandwich applications.
- Divinycell HCP, with its high hydraulic crush point, is used in various subsea applications.
- Divinycell HD has extremely good dynamic properties and high ductility. It is intended for use in primary marine structures subjected to slamming and shock loads.
- Divinycell IPN insulation materials exhibits low water vapour permeability for extreme cold to hot environments.
- Divinycell HPS has been specially developed for use with epoxy prepregs. It is suitable for high temperature processes up to 120°C.

Specific information on these other grades of Divinycell is available upon request.

DIAB - AN INTERNATIONAL MARKET LEADER

DIAB develops and sells products and services based on advanced polymer and composite technologies.

Over twenty years of experience combined with continuous research and development have made us an international market leader in multi-functional sandwich constructions.

Our philosophy is to supply our customers with structural cores for sandwich construction of the highest quality. To this end all DIAB operations are certified to ISO 9001.

We strive for excellence – not only in materials but also in technical assistance and documentation. Long-term involvement enables us to give strong support to our customers whenever and wherever needed.

AVERAGE PHYSICAL PROPERTIES

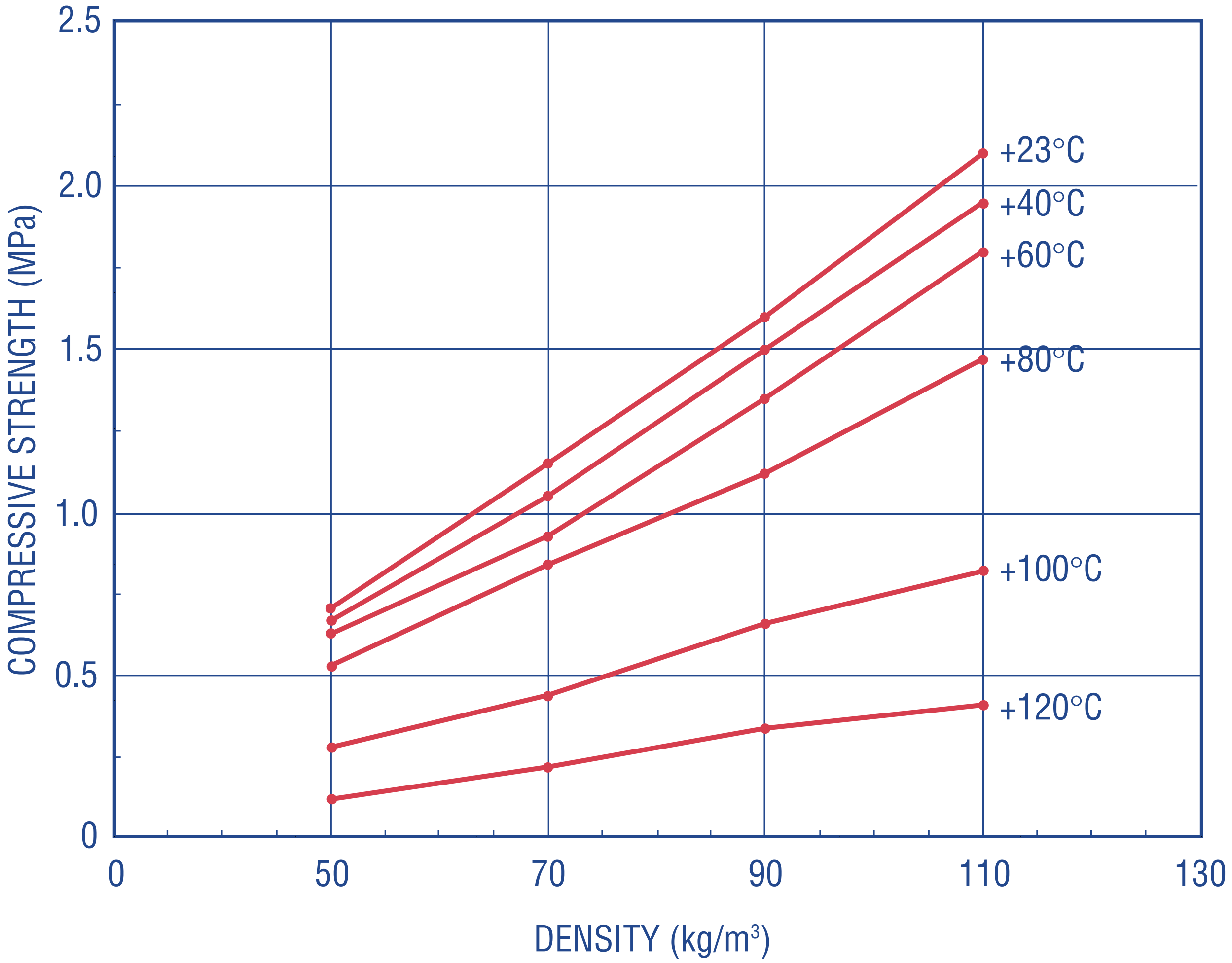
Table shows average values for the nominal densities and minimum values within the brackets for the minimum density.

Property	Unit	HT 50	HT 70	HT 90	HT 110
Density - nominal Density - maximum Density - minimum	kg/m^3	50 60 45	70 85 63	90 105 91	110 125 100
Compressive Strength 23°±2°C	MPa	0.7 (0.6)	1.15 (1.0)	1.6 (1.4)	2.1 (1.9)
E-modulus Crosshead Movement	MPa	30 (20)	44 (38)	65 (55)	78 (58)
E-modulus Extensometer	MPa	75 (60)	100 (80)	125 (100)	175 (150)
Tensile Strength * ASTM D 1623	MPa	1.5 (1.0)	2.1 (1.6)	2.7 (2.2)	3.3 (2.8)
Tensile Strength ** ISO 1926	MPa	0.9 (0.7)	1.5 (1.2)	2.0 (1.6)	2.5 (2.0)
Shear Strength ** ASTM C 273	MPa	0.55 (0.4)	0.9 (0.7)	1.25 (1.1)	1.6 (1.4)
Shear Modulus** ASTM C 273	MPa	19 (13)	26 (18)	33 (26)	40 (35)
Shear Strain ** ASTM C 273	%	13 (8)	17 (10)	21 (15)	25 (15)
Dimensional Stability - L/W T	%	≤ 1 ≤ 2	≤ 1 ≤ 2	≤ 1 ≤ 2	≤ 1 ≤ 2

** = Perpendicular to the plane. ** = Parallel to the plane.*

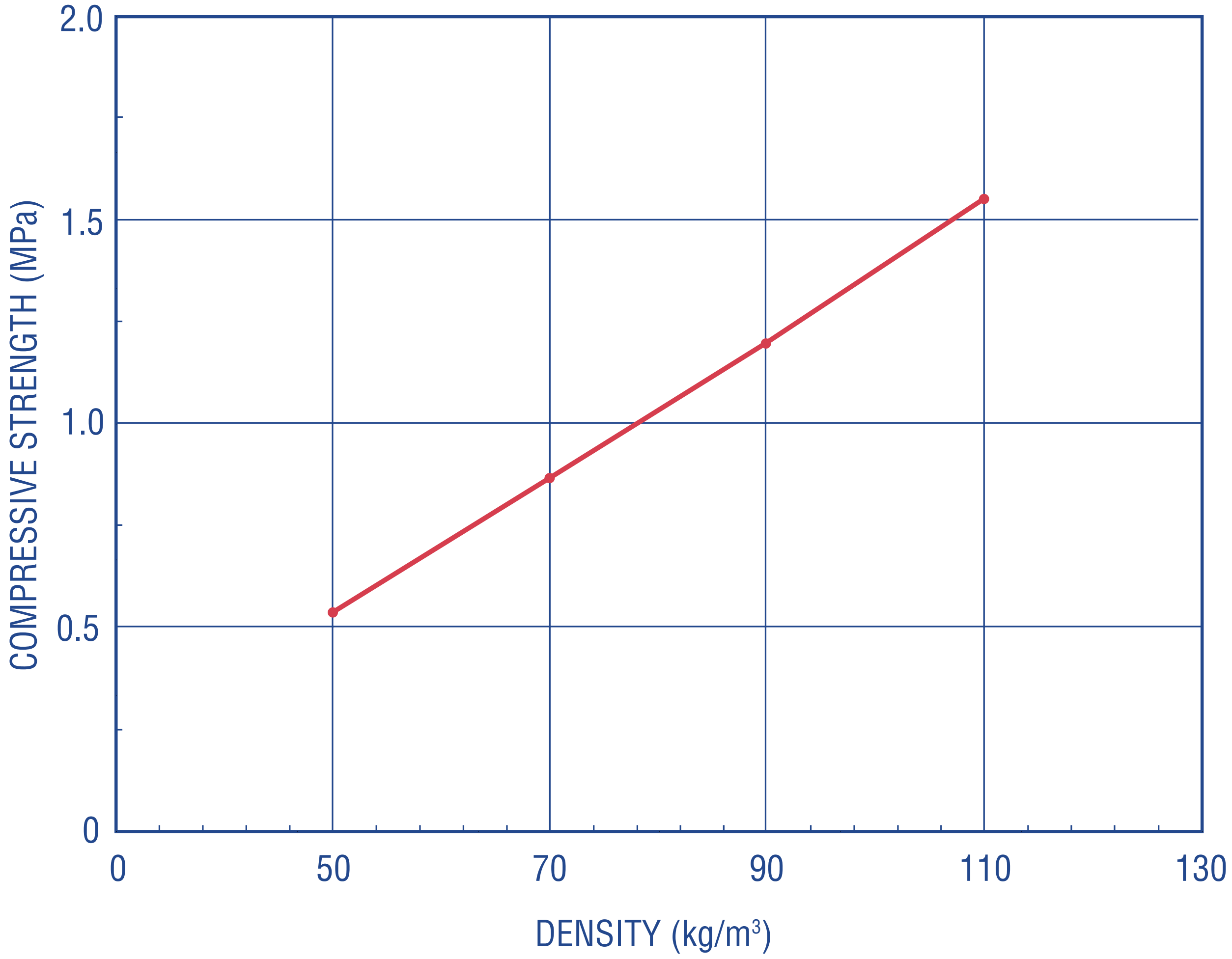
Operating temperature is -200°C to +90°C. Lifetime must be taken into consideration for the very low and high temperatures. Maximum processing temperature is dependent on time, pressure and process conditions. Normally Divinycell HT can be processed up to 120°C without dimensional changes. Please contact DIAB for advice before use. Coefficient of linear expansion ASTM D 696: Approx. $35 \cdot 10^{-6}$/ °C. Poissons ratio: 0.32.

COMPRESSIVE STRENGTH
DIVINYCELL HT 50 - HT 110



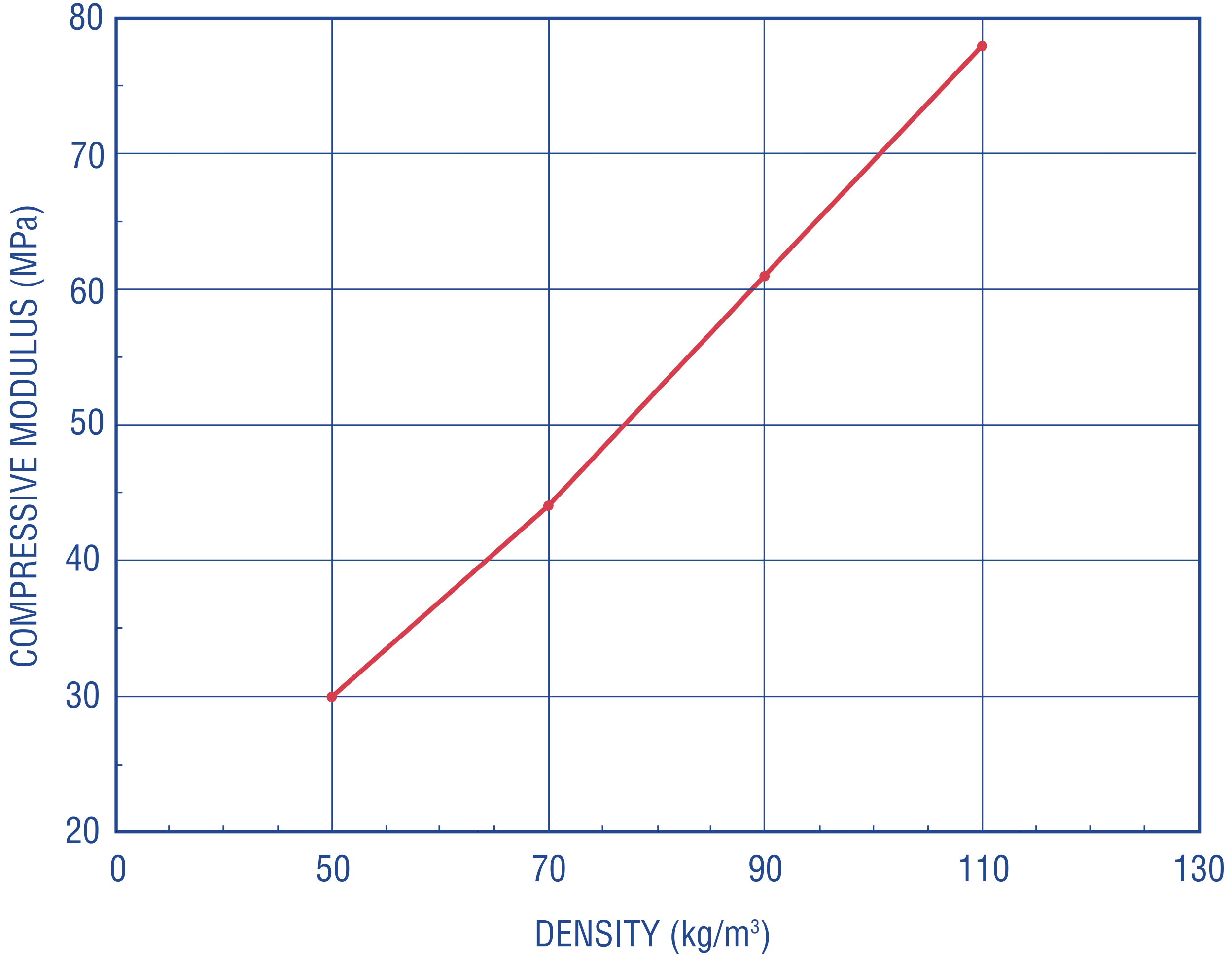
Compressive strength perpendicular to the plane at +23°C and +120°C as a function of density acc. to ASTM D 1621 and ASTM D 1622.

COMPRESSIVE STRENGTH
DIVINYCELL HT 50 - HT 110



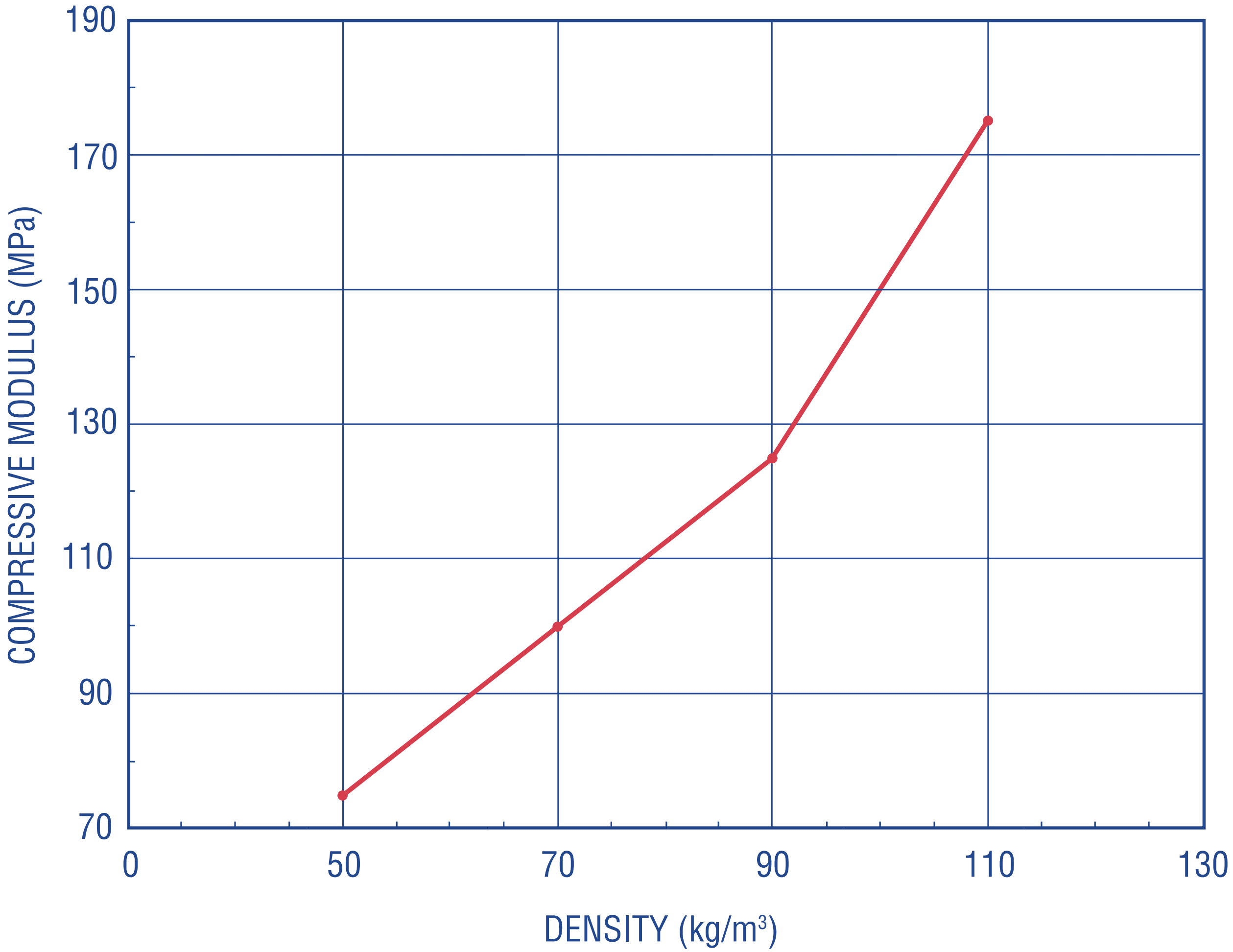
Compressive strength parallel to the plane at +23°C as a function of density according to ASTM D 1621 and ASTM D 1622.

COMPRESSIVE MODULUS
DIVINYCELL HT 50 - HT 110



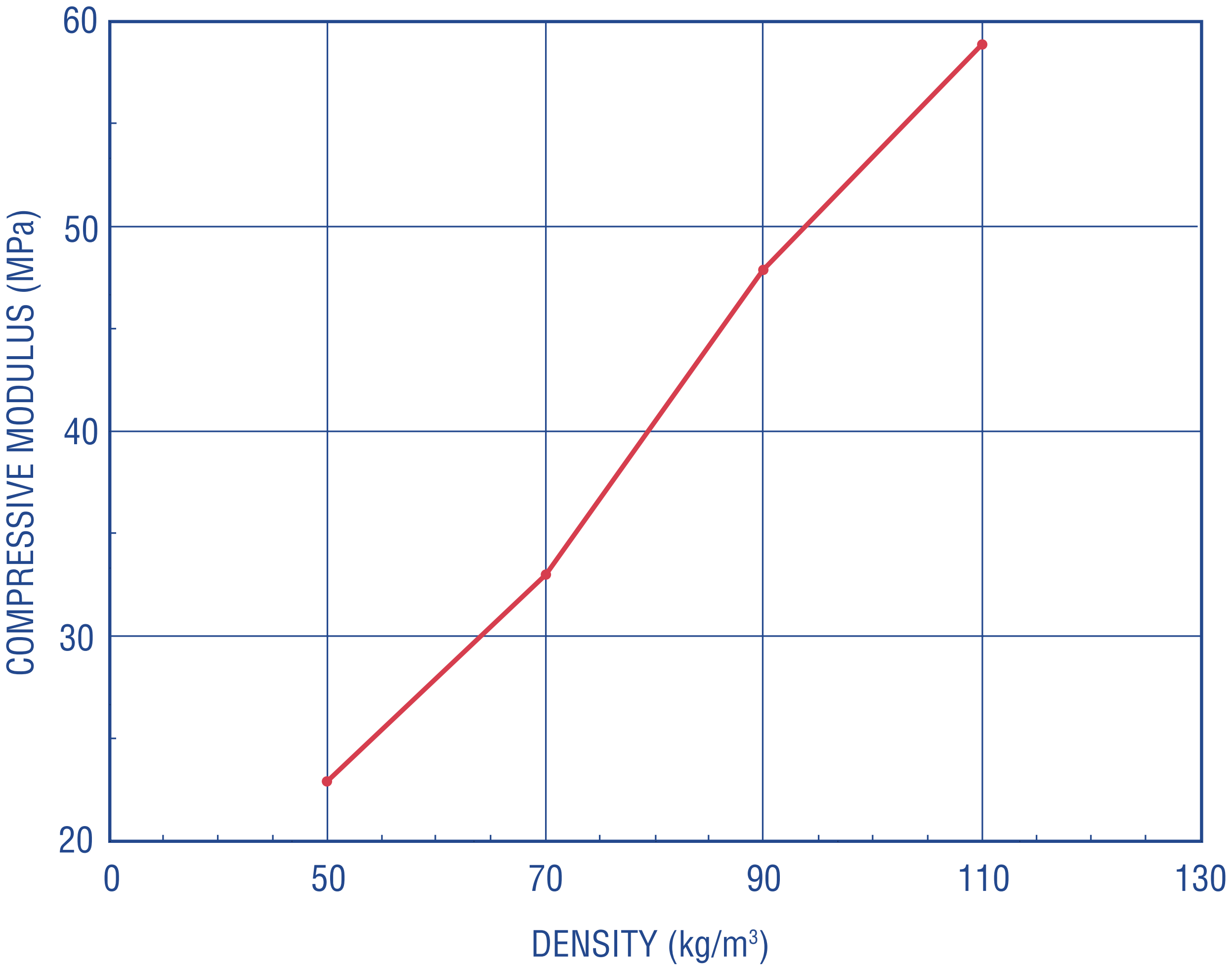
Compressive modulus perpendicular to the plane at +23°C as a function of density according to ASTM D 1621 (crosshead movement) and ASTM D 1622.

COMPRESSIVE MODULUS
DIVINYCELL HT 50 - HT 110



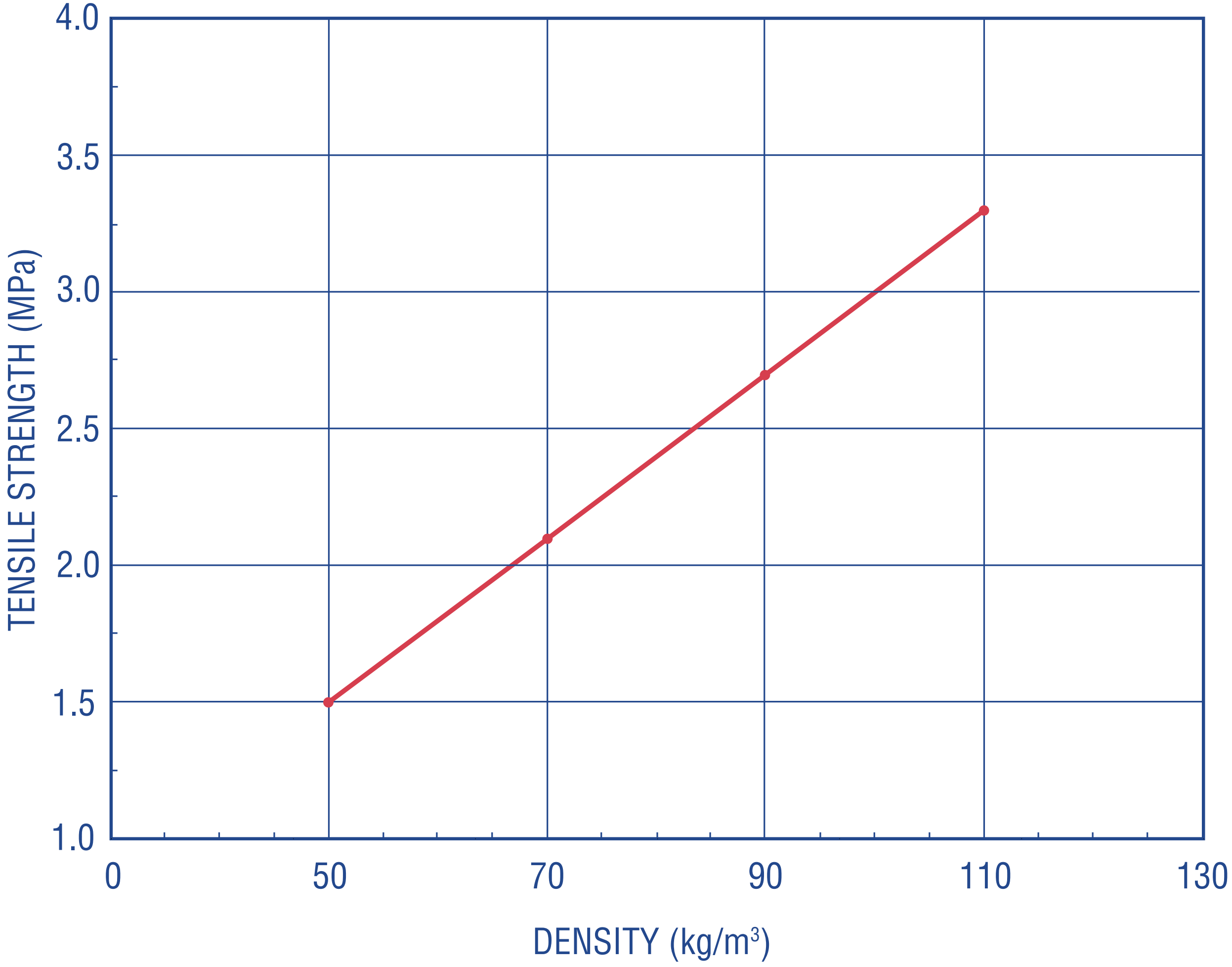
Compressive modulus perpendicular to the plane at +23°C as a function of density according to ASTM D 1621 (extensometer) and ASTM D 1622.

COMPRESSIVE MODULUS
DIVINYCELL HT 50 - HT 110



Compressive modulus parallel to the plane at +23°C as a function of density according to ASTM D 1621 (crosshead movement) and ASTM D 1622.

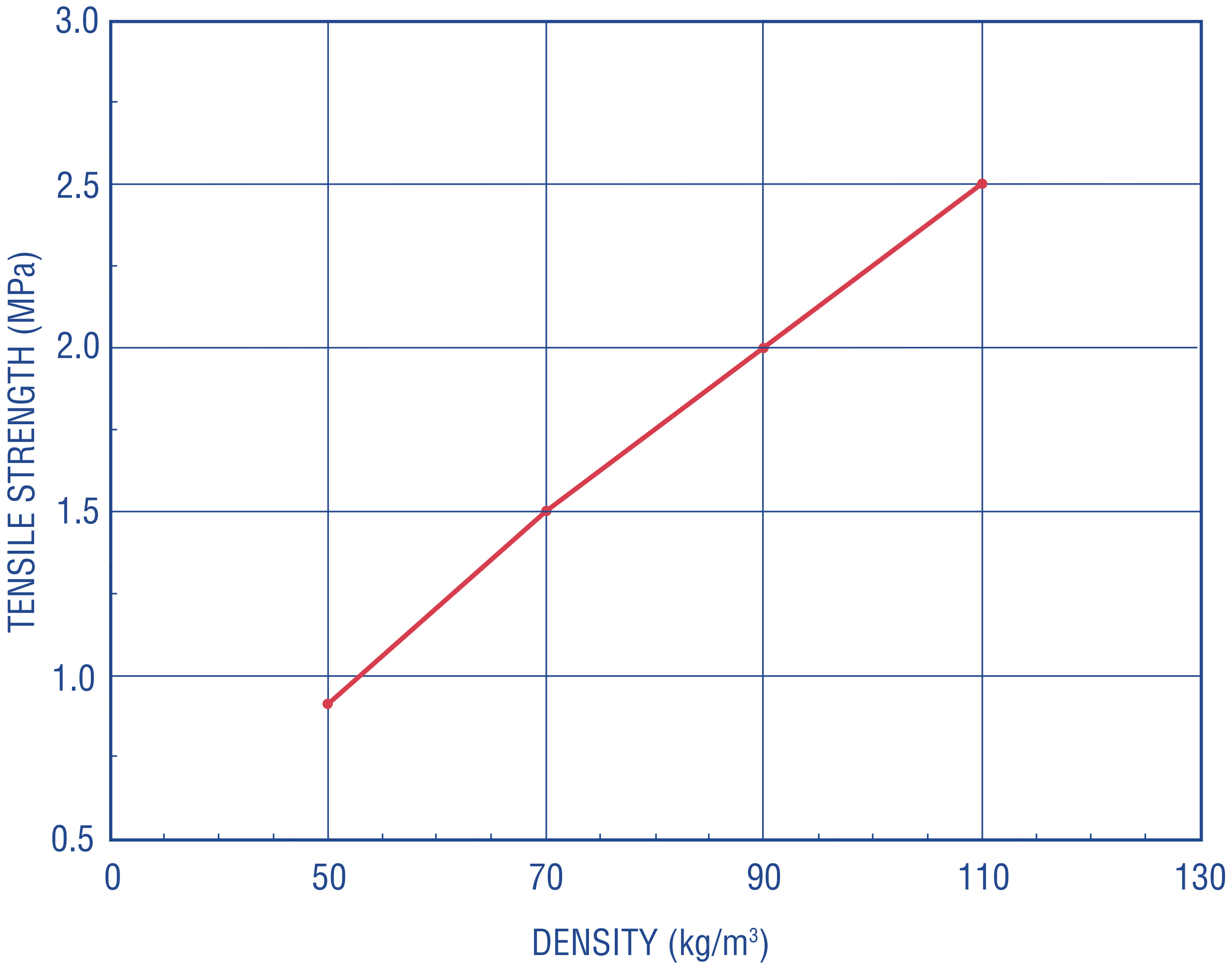
TENSILE STRENGTH
DIVINYCELL HT 50 - HT 110



Tensile strength perpendicular to the plane at +23°C as a function of density according to ASTM D 1623 and ASTM D 1622.

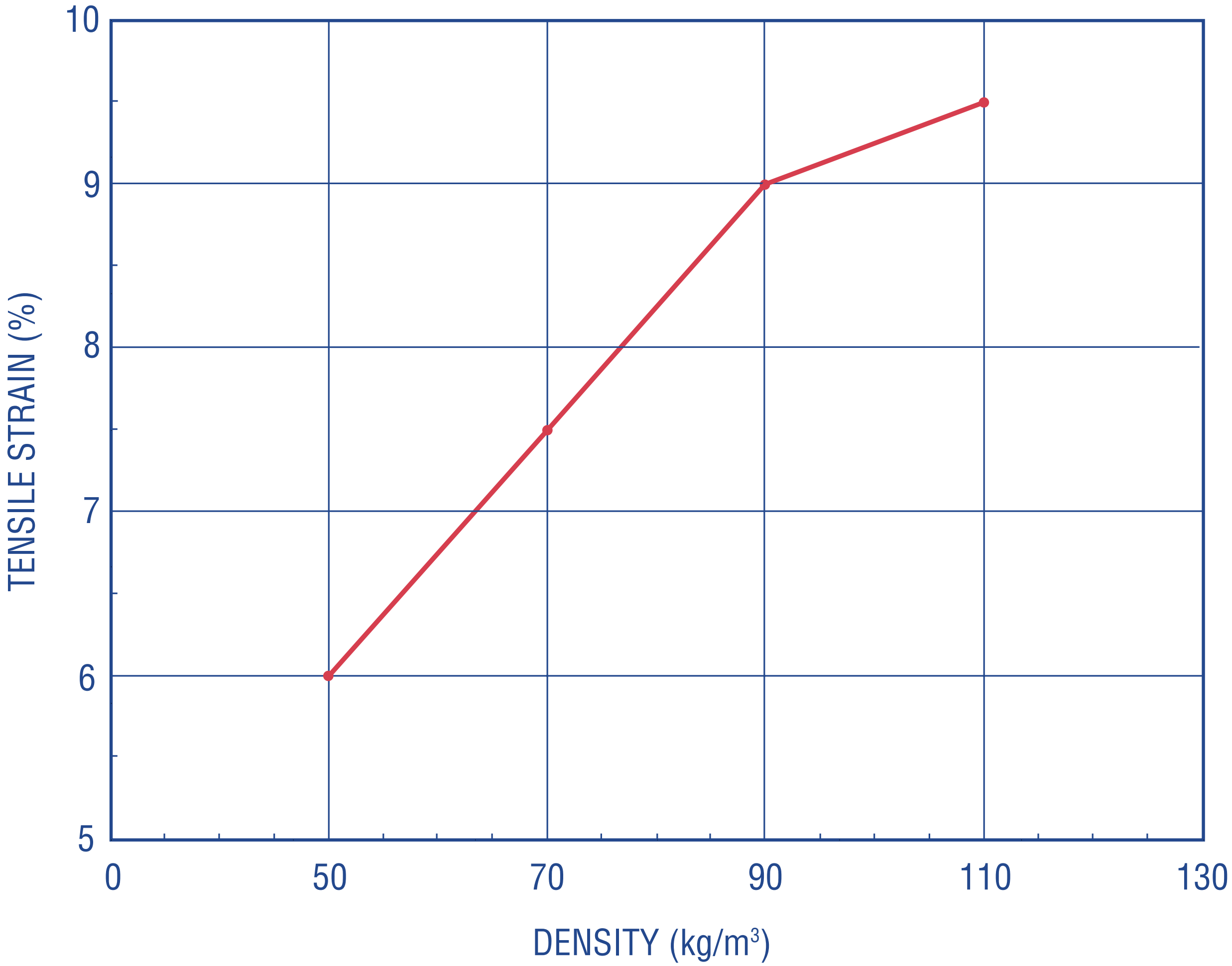
TENSILE STRENGTH

DIVINYCELL HT 50 - HT 110



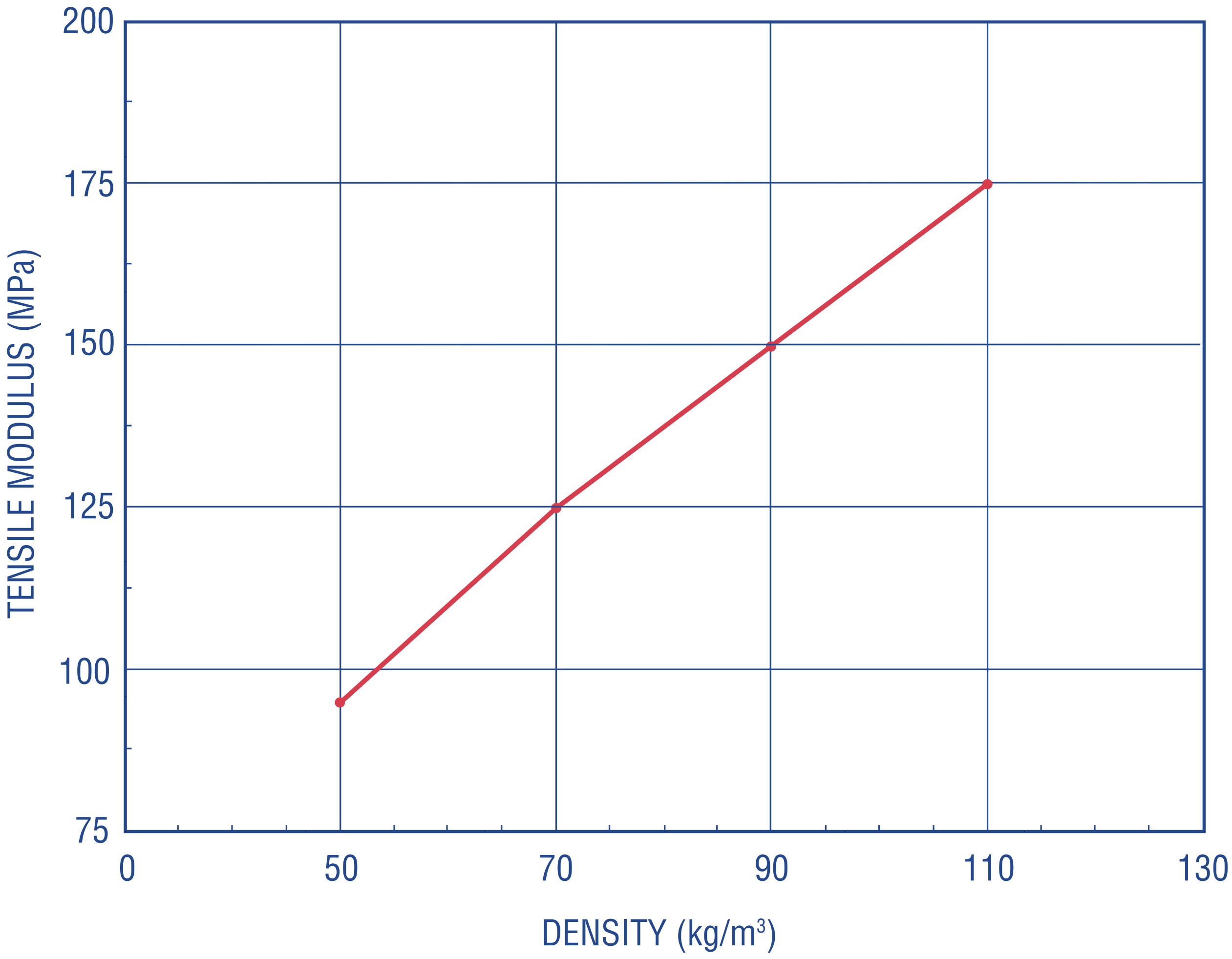
Tensile strength parallel to the plane at +23°C as a function of density according to ISO 1926 and ASTM D 1622.

TENSILE STRAIN
DIVINYCELL HT 50 - HT 110



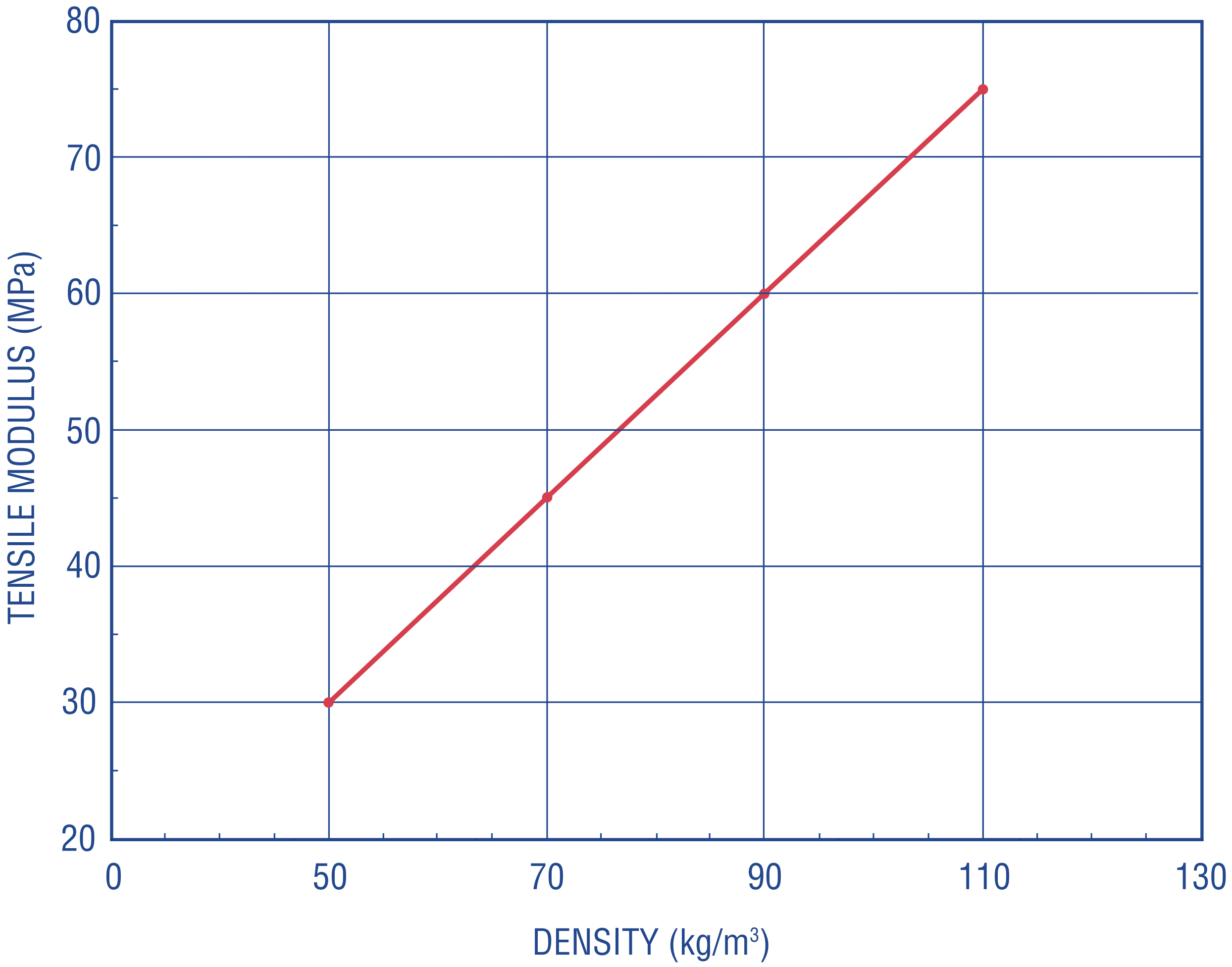
Tensile strain parallel to the plane at +23°C as a function of density according to ISO 1926 (extensometer) and ASTM D 1622.

TENSILE MODULUS
DIVINYCELL HT 50 - HT 110



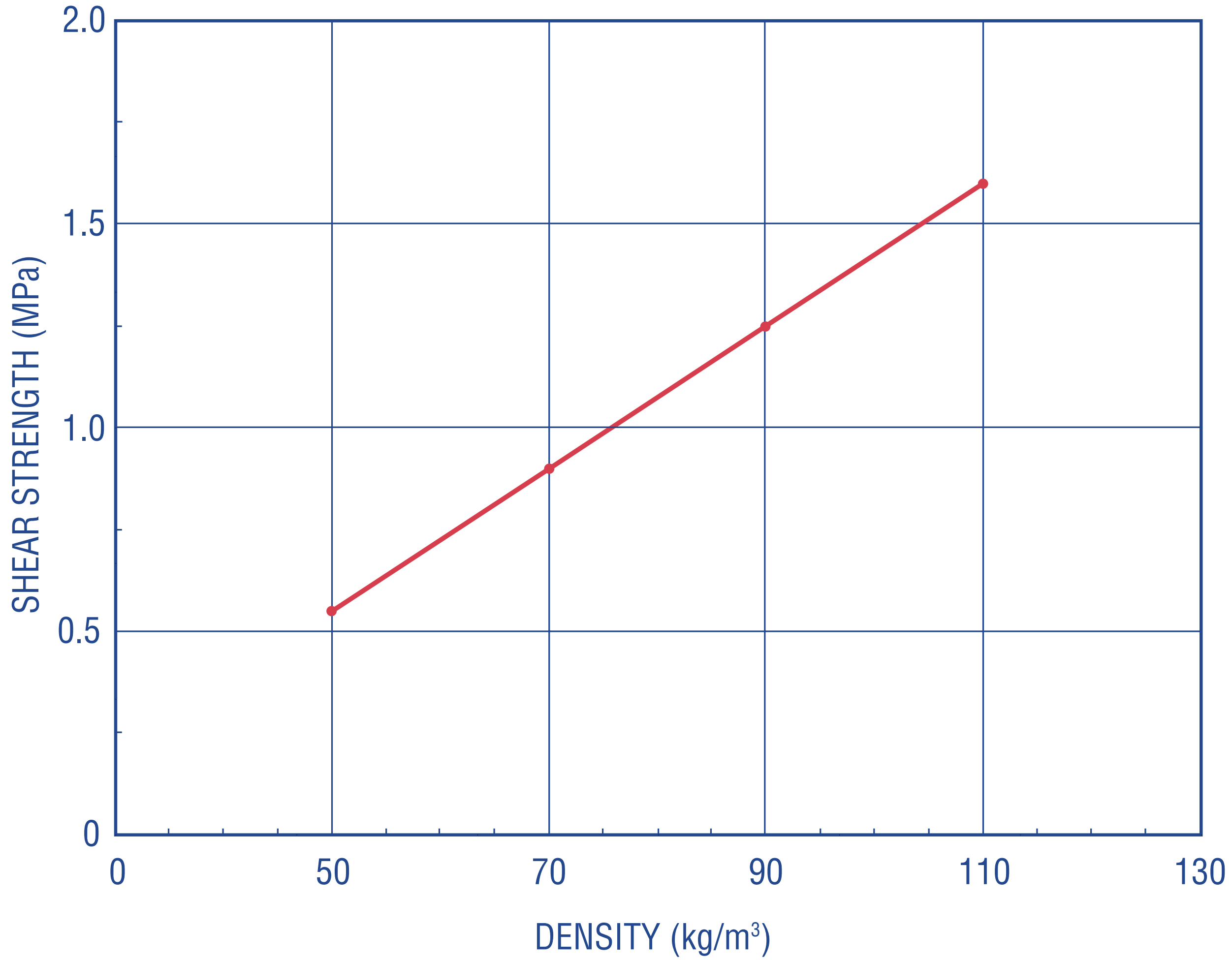
Tensile modulus perpendicular to the plane at +23°C as a function of density according to ASTM D 1623, ASTM D 1621 (extensometer) and ASTM D 1622.

TENSILE MODULUS
DIVINYCELL HT 50 - HT 110



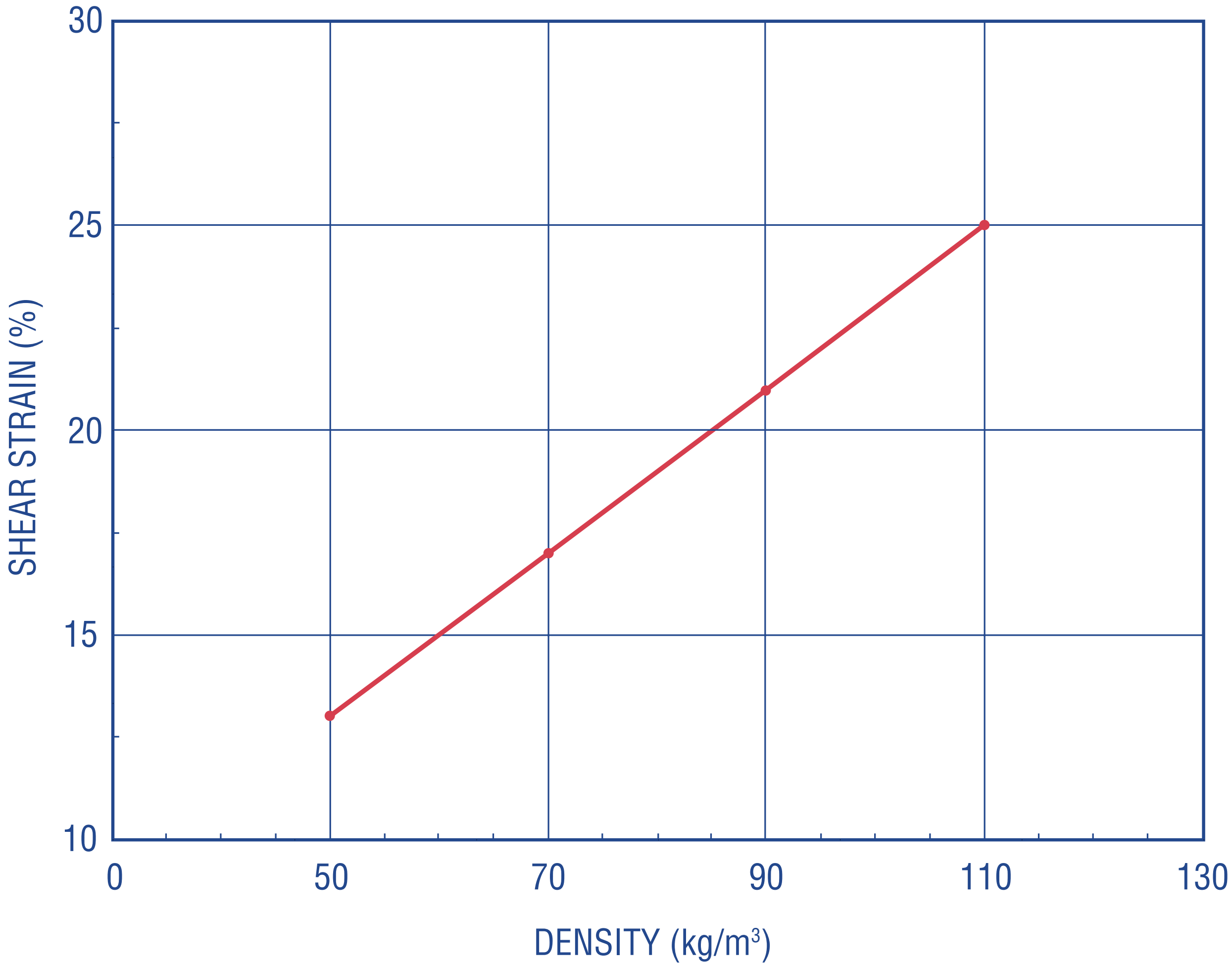
Tensile modulus parallel to the plane at +23°C as a function of density according to ISO 1926 (extensometer) and ASTM D 1622.

SHEAR STRENGTH
DIVINYCELL HT 50 - HT 110



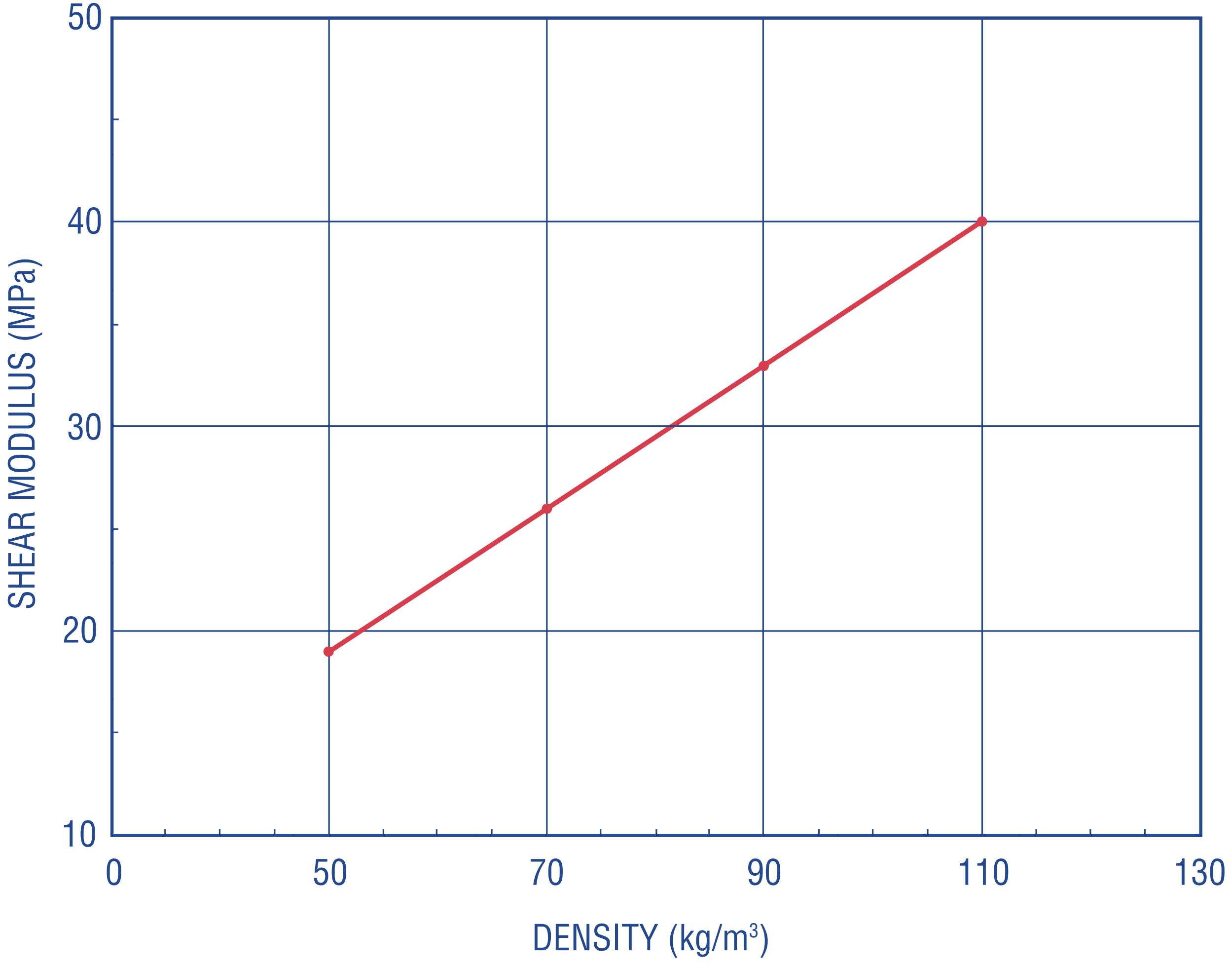
Shear strength at +23°C as a function of
density according to ASTM C 273 and ASTM D 1622.

SHEAR STRAIN
DIVINYCELL HT 50 - HT 110



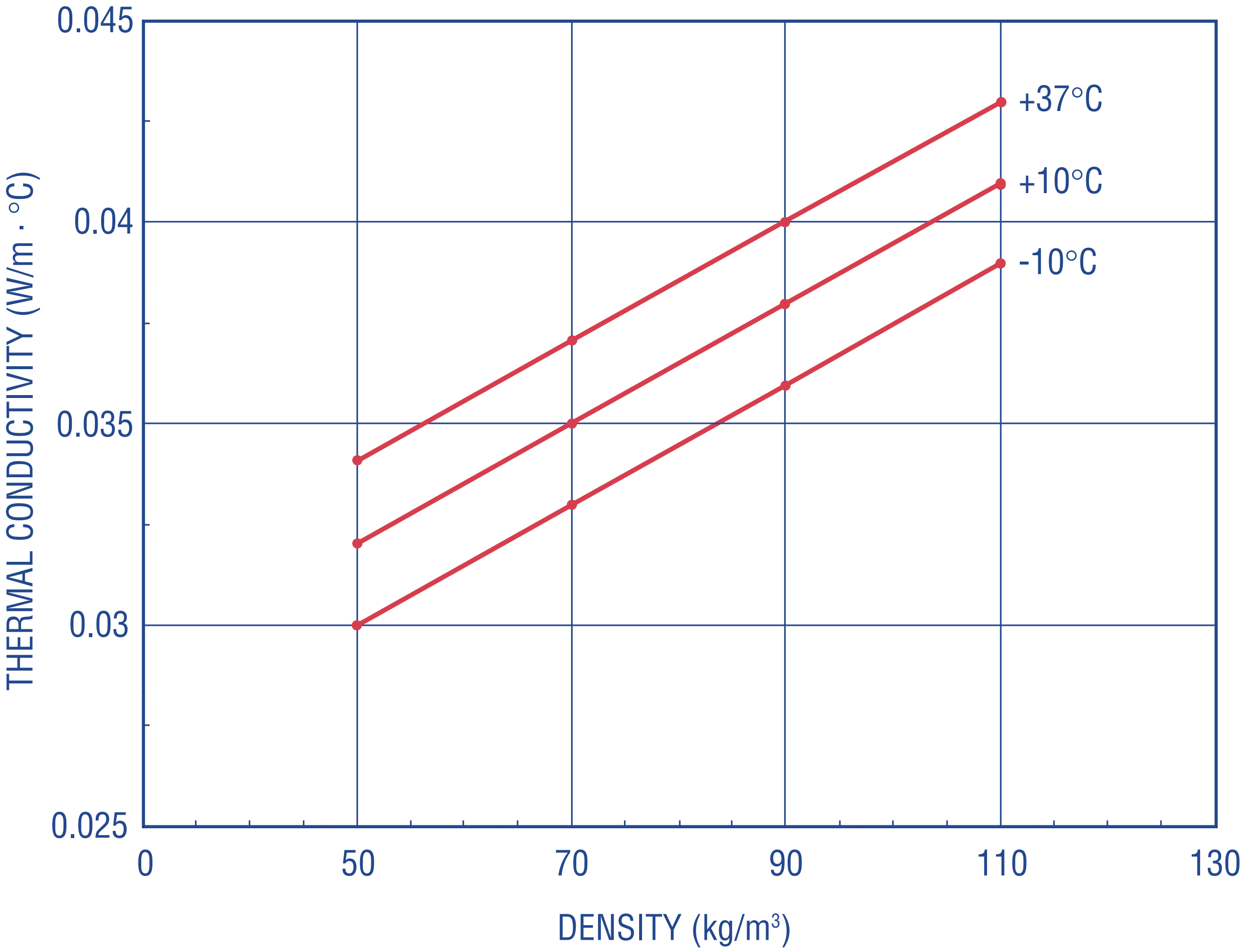
Shear strain at +23°C as a function of
density according to ASTM C 273 and ASTM D 1622.

SHEAR MODULUS
DIVINYCELL HT 50 - HT 110



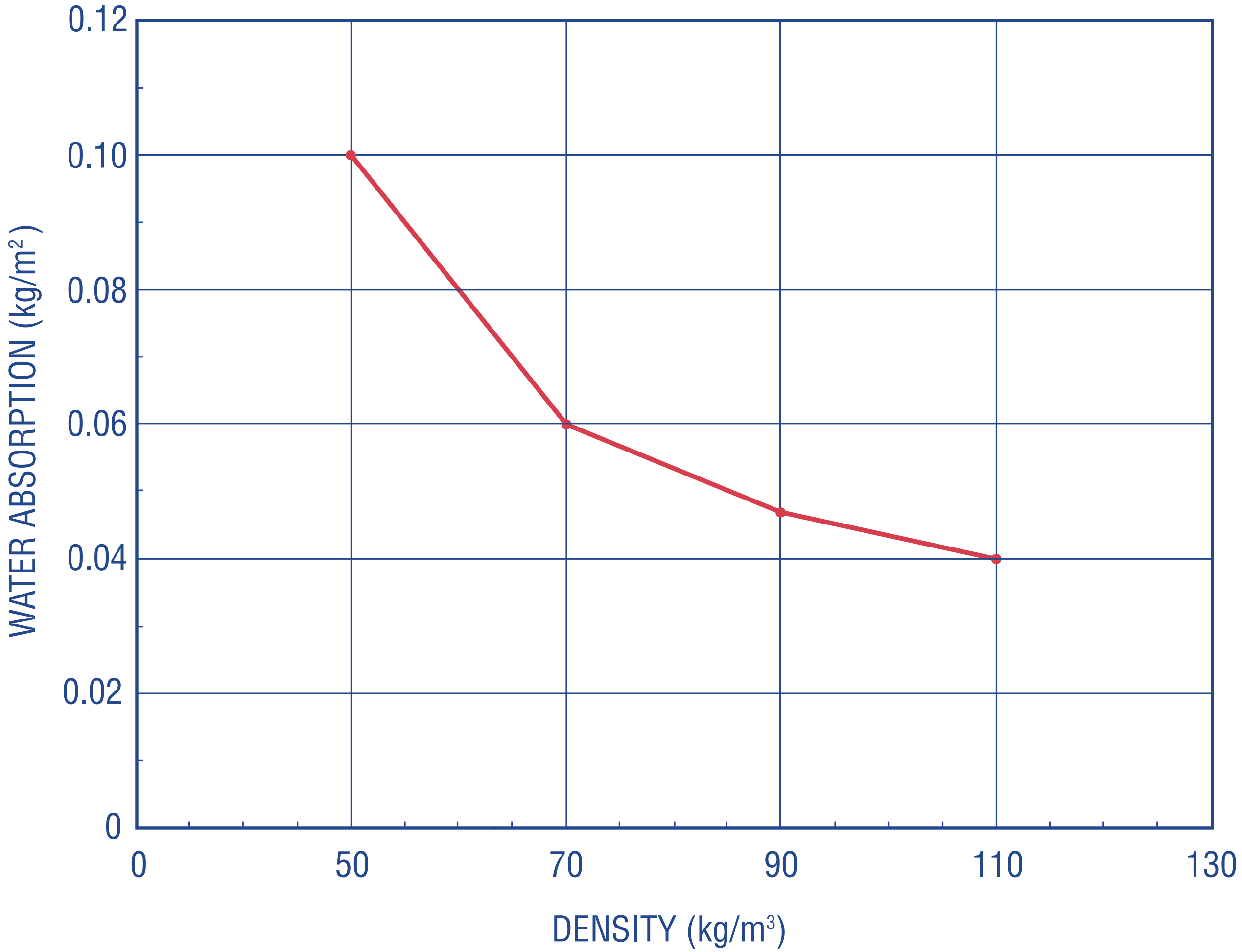
Shear modulus at +23°C as a function of
density according to ASTM C 273 and ASTM D 1622.

THERMAL CONDUCTIVITY
DIVINYCELL HT 50 - HT 110



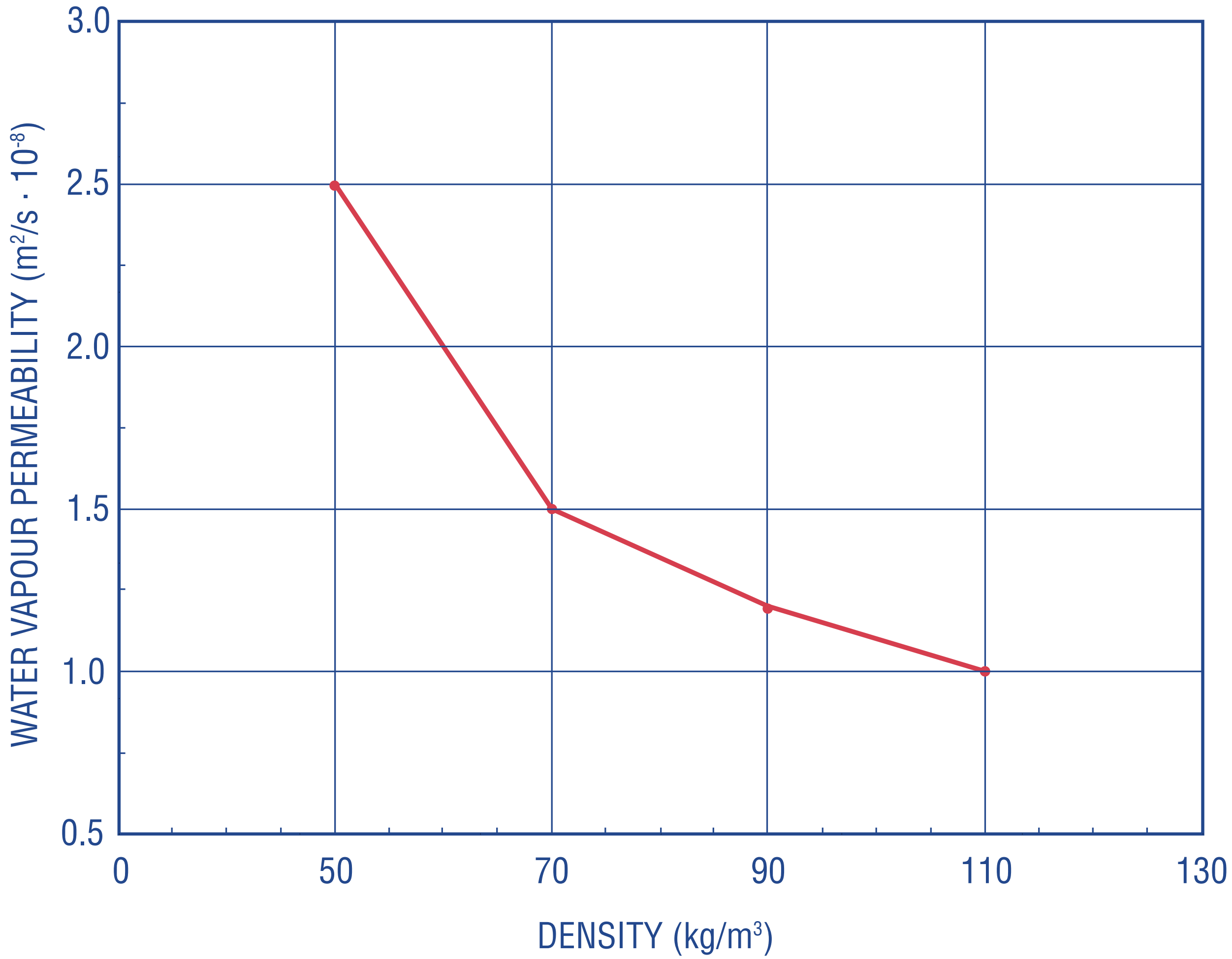
Thermal conductivity at -10°C, +10°C and +37°C as a function of density according to ASTM C 177 and ASTM D 1622.

WATER ABSORPTION
DIVINYCELL HT 50 - HT 110



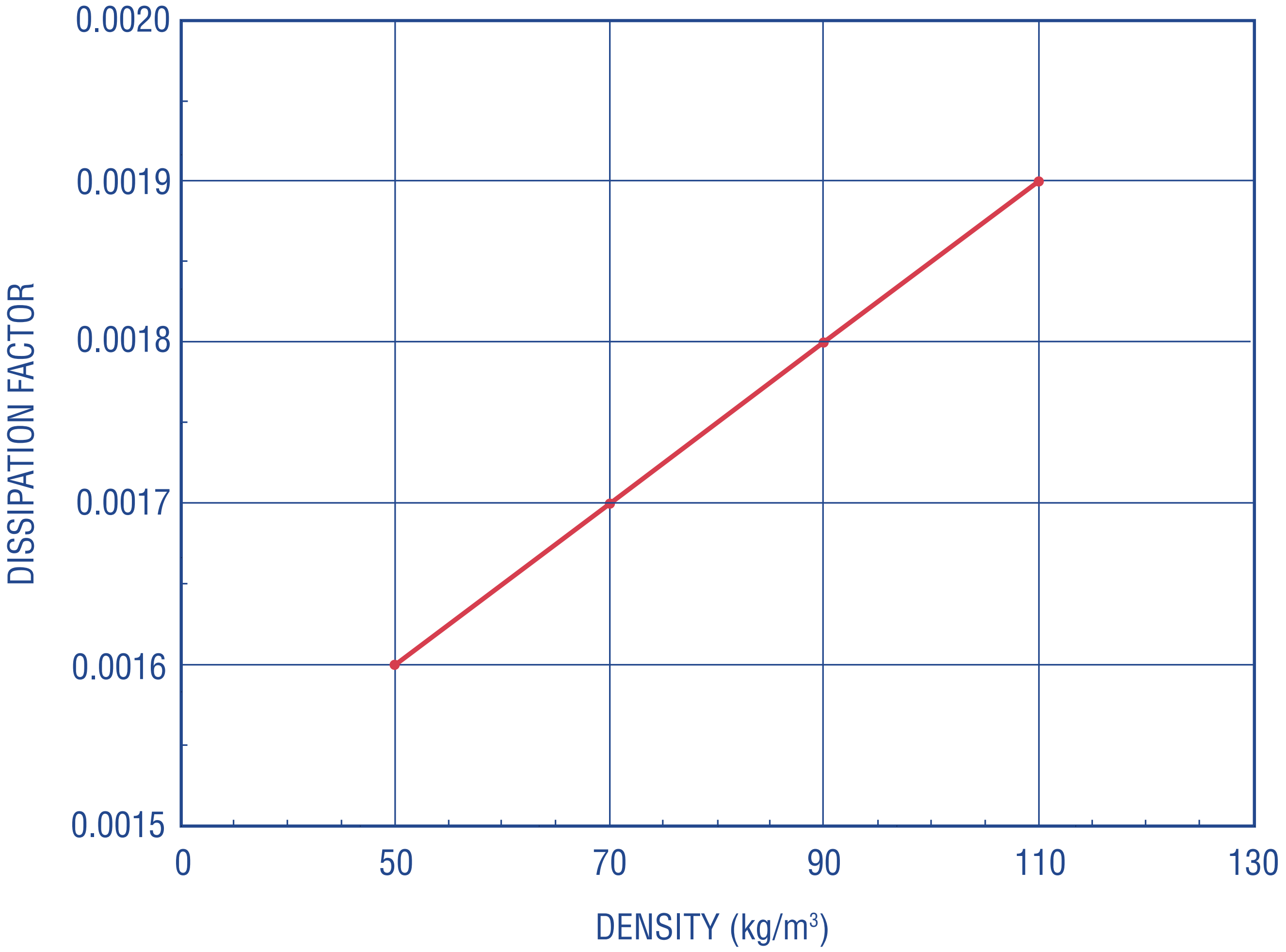
Water absorption at 23°C as a function of density acc. to ASTM D 2842 and ASTM D 1622.

WATER VAPOUR PERMEABILITY
DIVINYCELL HT 50 - HT 110



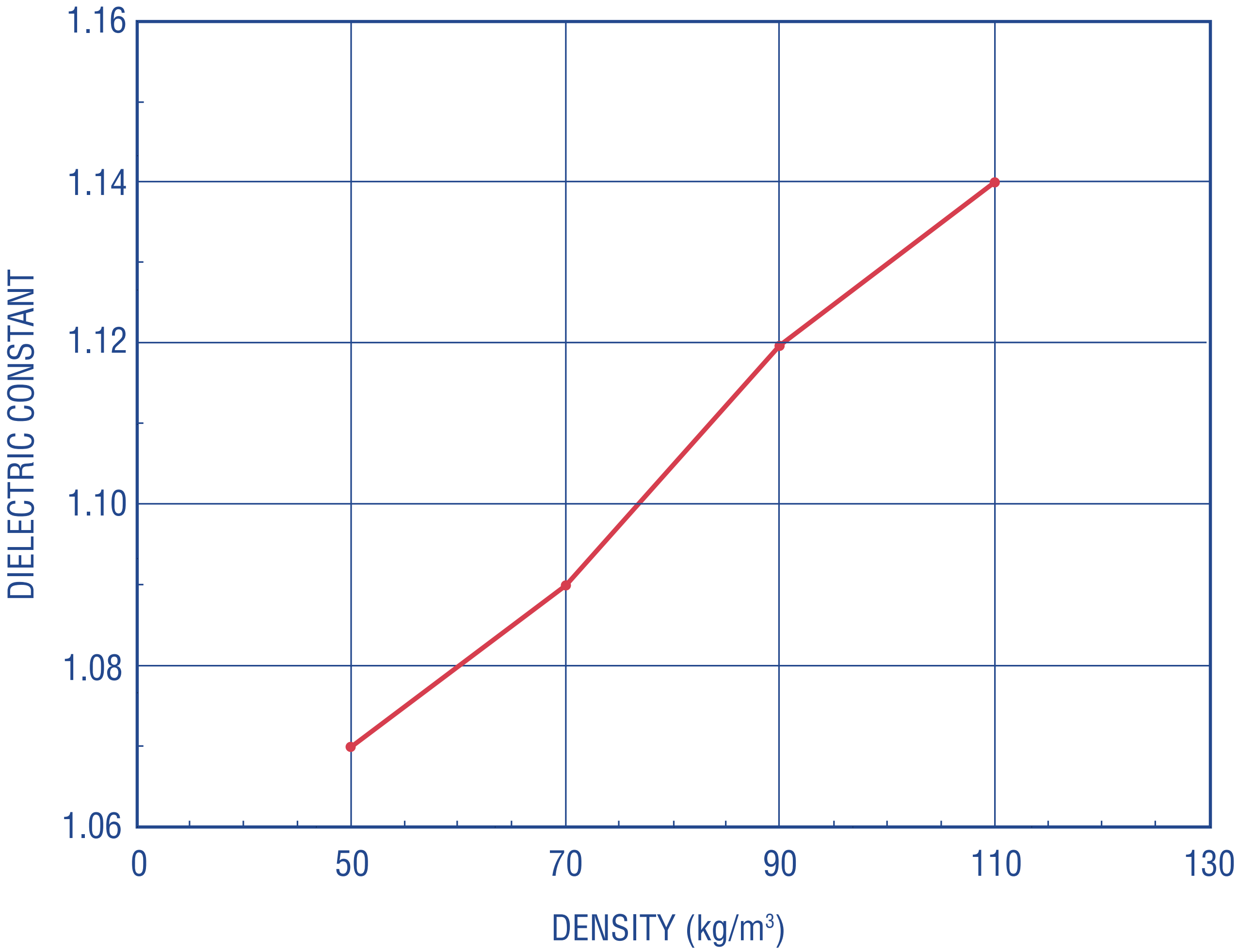
Water vapour permeability at 22°C as a function of density acc. to SS 02 15 82 and ASTM D 1622.

DISSIPATION FACTOR
DIVINYCELL HT 50 - HT 110



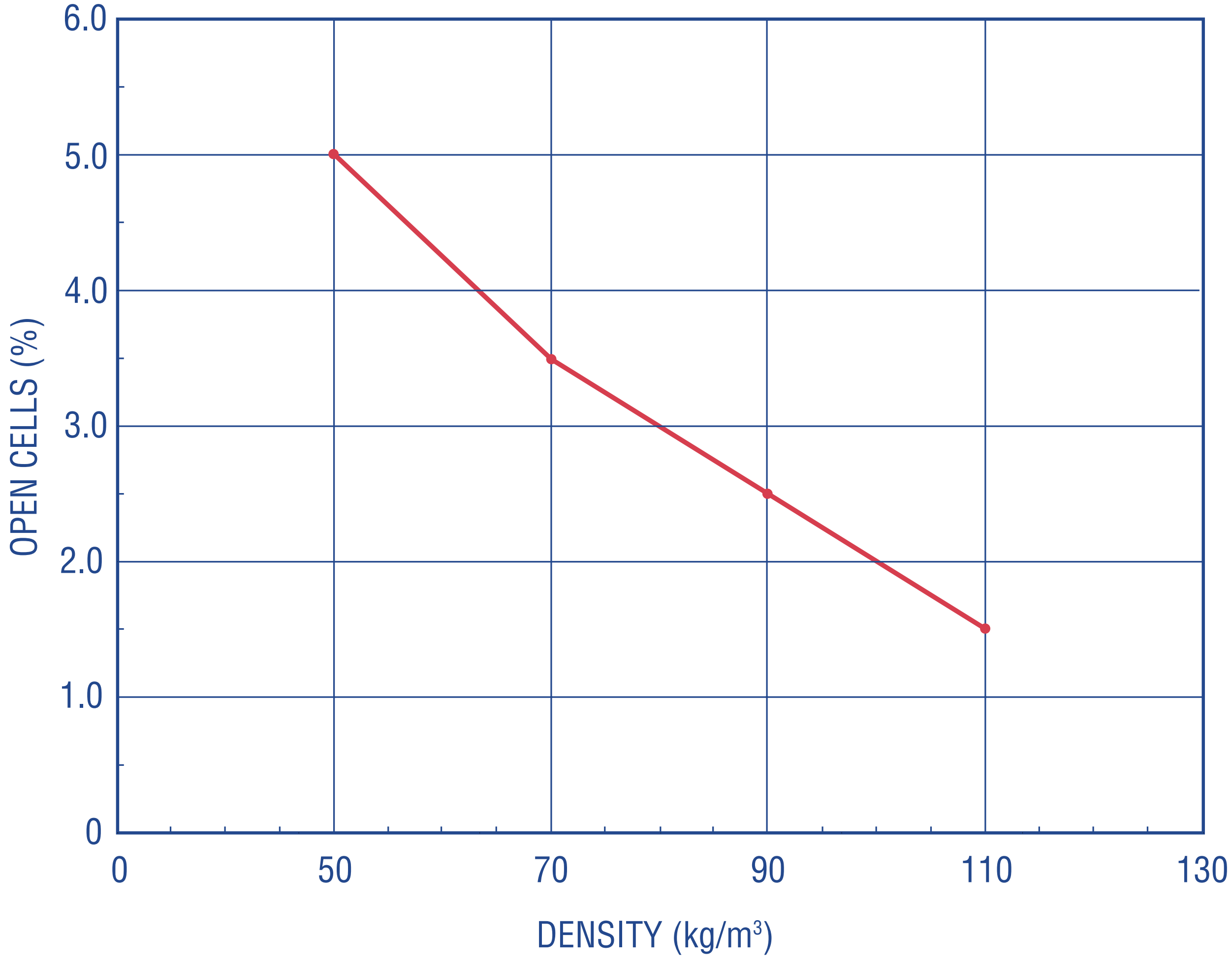
Dissipation factor at 8-12 GHz as a function of density.

DIELECTRIC CONSTANT
DIVINYCELL HT 50 - HT 110



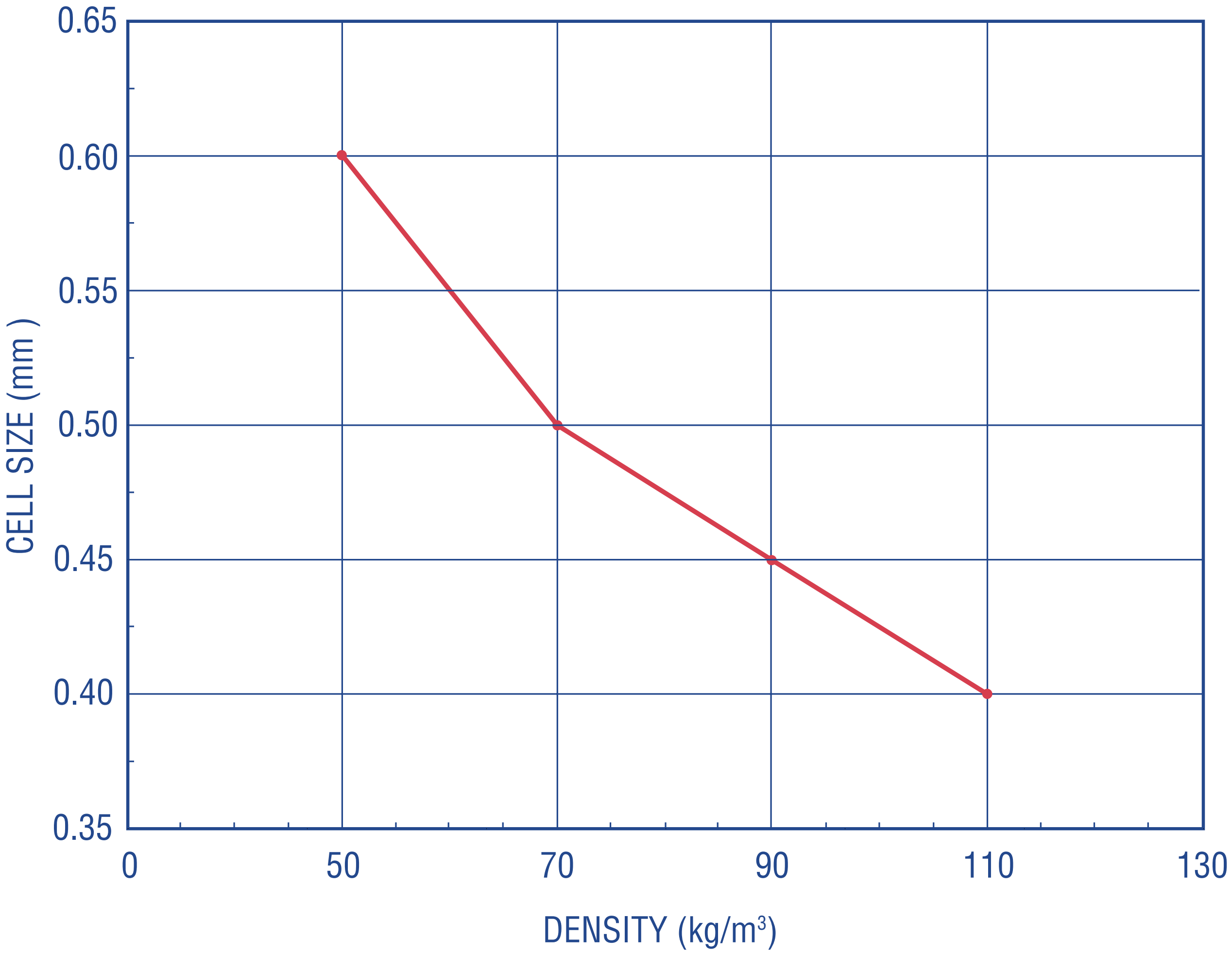
Dielectric constant at 8-12 GHz as a function of density.

OPEN CELLS
DIVINYCELL HT 50 - HT 110



Open cells as a function of density
acc. ISO 4590 and ASTM D 1622

CELL SIZE
DIVINYCELL HT 50 - HT 110



Cell size as a function of density.

TECHNICAL DATA - TABLES

CHARACTERISTICS - HT 50

		Value	Unit	Test Procedure
Density		50	kg/m^3	ASTM D 1622
Compressive strength *		0.7	MPa	ASTM D 1621
Compressive strength **		0.53	MPa	ASTM D 1621
Compressive modulus *		30	MPa	ASTM D 1621 (crosshead movement)
Compressive modulus *		75	MPa	ASTM D 1621 (extensometer)
Compressive modulus **		23	MPa	ASTM D 1621 (crosshead movement)
Tensile strength *		1.5	MPa	ASTM D 1623
Tensile strength **		0.9	MPa	ISO 1926
Ultimate tensile strain **		6	%	ISO 1926 (extensometer)
Tensile modulus * ***		95	MPa	ASTM D 1623
Tensile modulus **		30	MPa	ISO 1926 (extensometer)
Shear strength		0.55	MPa	ASTM C 273
Shear strain		13	%	ASTM C 273
Shear modulus		19	MPa	ASTM C 273
Thermal conductivity	-10°C	0.030	W/(m · °C)	ASTM C 177
	+10°C	0.032		
	+37°C	0.034		
Water absorption		0.10	kg/m^2	ASTM D 2842
Water vapour permeability		2.5	m^2/(s · 10^{-8})	SS 02 15 82
Coefficient of linear expansion		35	·10^{-6}/°C	ASTM D 696
Dimensional stability		±3	%	1hr @ 120°C
Dimensional stability (annealed)		±1	%	1hr @ 120°C
Continuous temp. range		-200 – +90	°C	–
Max. processing temp.		+120	°C	–
Dissipation factor		0.0016	–	8-12 GHz
Dielectric constant		1.07	–	8-12 GHz
Open cells		5	%	ISO 4590
Cell size		0.6	mm	–

* = Perpendicular to the plane   ** = Parallel to the plane   ***= Calculation of modulus based on ASTM D 1621 (extensometer)

TECHNICAL DATA - TABLES

CHARACTERISTICS - HT 70

		Value	Unit	Test Procedure
Density		70	kg/m^3	ASTM D 1622
Compressive strength *		1.15	MPa	ASTM D 1621
Compressive strength **		0.86	MPa	ASTM D 1621
Compressive modulus *		44	MPa	ASTM D 1621 (crosshead movement)
Compressive modulus *		100	MPa	ASTM D 1621 (extensometer)
Compressive modulus **		36	MPa	ASTM D 1621 (crosshead movement)
Tensile strength *		2.1	MPa	ASTM D 1623
Tensile strength **		1.5	MPa	ISO 1926
Ultimate tensile strain **		7.5	%	ISO 1926 (extensometer)
Tensile modulus * ***		125	MPa	ASTM D 1623
Tensile modulus **		45	MPa	ISO 1926 (extensometer)
Shear strength		0.9	MPa	ASTM C 273
Shear strain		17	%	ASTM C 273
Shear modulus		26	MPa	ASTM C 273
Thermal conductivity	-10°C	0.033	W/(m · °C)	ASTM C 177
	+10°C	0.035		
	+37°C	0.037		
Water absorption		0.060	kg/m^2	ASTM D 2842
Water vapour permeability		1.3	m^2/(s · 10^{-8})	SS 02 15 82
Coefficient of linear expansion		35	·10^{-6}/°C	ASTM D 696
Dimensional stability		±3	%	1hr @ 120°C
Dimensional stability (annealed)		±1	%	1hr @ 120°C
Continuous temp. range		-200 – +90	°C	–
Max. processing temp.		+120	°C	–
Dissipation factor		0.0017	–	8-12 GHz
Dielectric constant		1.09	–	8-12 GHz
Open cells		3.5	%	ISO 4590
Cell size		0.5	mm	–

* = Perpendicular to the plane ** = Parallel to the plane ***= Calculation of modulus based on ASTM D 1621 (extensometer)

CHARACTERISTICS - HT 90

		Value	Unit	Test Procedure
Density		90	kg/m^3	ASTM D 1622
Compressive strength *		1.6	MPa	ASTM D 1621
Compressive strength **		1.20	MPa	ASTM D 1621
Compressive modulus *		62	MPa	ASTM D 1621 (crosshead movement)
Compressive modulus *		125	MPa	ASTM D 1621 (extensometer)
Compressive modulus **		48	MPa	ASTM D 1621 (crosshead movement)
Tensile strength *		2.7	MPa	ASTM D 1623
Tensile strength **		2.0	MPa	ISO 1926
Ultimate tensile strain **		9	%	ISO 1926 (extensometer)
Tensile modulus * ***		150	MPa	ASTM D 1623
Tensile modulus **		60	MPa	ISO 1926 (extensometer)
Shear strength		1.25	MPa	ASTM C 273
Shear strain		21	%	ASTM C 273
Shear modulus		33	MPa	ASTM C 273
Thermal conductivity	-10°C	0.036	W/(m · °C)	ASTM C 177
	+10°C	0.038		
	+37°C	0.040		
Water absorption		0.047	kg/m^2	ASTM D 2842
Water vapour permeability		1.2	m^2/(s · 10^{-8})	SS 02 15 82
Coefficient of linear expansion		35	·10^{-6}/°C	ASTM D 696
Dimensional stability		±3	%	1hr @ 120°C
Dimensional stability (annealed)		±1	%	1hr @ 120°C
Continuous temp. range		-200 – +90	°C	–
Max. processing temp.		+120	°C	–
Dissipation factor		0.0018	–	8-12 GHz
Dielectric constant		1.12	–	8-12 GHz
Open cells		2.5	%	ISO 4590
Cell size		0.45	mm	–

* = Perpendicular to the plane ** = Parallel to the plane ***= Calculation of modulus based on ASTM D 1621 (extensometer)

CHARACTERISTICS - HT 110

		Value	Unit	Test Procedure
Density		110	kg/m^3	ASTM D 1622
Compressive strength *		2.1	MPa	ASTM D 1621
Compressive strength **		1.55	MPa	ASTM D 1621
Compressive modulus *		78	MPa	ASTM D 1621 (crosshead movement)
Compressive modulus *		150	MPa	ASTM D 1621 (extensometer)
Compressive modulus **		59	MPa	ASTM D 1621 (crosshead movement)
Tensile strength *		3.3	MPa	ASTM D 1623
Tensile strength **		2.5	MPa	ISO 1926
Ultimate tensile strain **		9.5	%	ISO 1926 (extensometer)
Tensile modulus * ***		175	MPa	ASTM D 1623
Tensile modulus **		75	MPa	ISO 1926 (extensometer)
Shear strength		1.6	MPa	ASTM C 273
Shear strain		25	%	ASTM C 273
Shear modulus		40	MPa	ASTM C 273
Thermal conductivity	-10°C	0.039	W/(m · °C)	ASTM C 177
	+10°C	0.041		
	+37°C	0.043		
Water absorption		0.040	kg/m^2	ASTM D 2842
Water vapour permeability		1.0	m^2/(s · 10^{-8})	SS 02 15 82
Coefficient of linear expansion		35	·10^{-6}/°C	ASTM D 696
Dimensional stability		±3	%	1hr @ 120°C
Dimensional stability (annealed)		±1	%	1hr @ 120°C
Continuous temp. range		-200 – +90	°C	–
Max. processing temp.		+120	°C	–
Dissipation factor		0.0019	–	8-12 GHz
Dielectric constant		1.14	–	8-12 GHz
Open cells		1.5	%	ISO 4590
Cell size		0.4	mm	–

* = Perpendicular to the plane ** = Parallel to the plane ***= Calculation of modulus based on ASTM D 1621 (extensometer)

FATIGUE PROPERTIES

INTRODUCTION

The imposition of repetitive short-time stress or deformation, particularly continual cyclic load, on parts or test specimens is fatigue. It is the principal stress involved in, for example, slamming on boat hulls and vibration on non-moving parts of vehicles and aircraft.

Fatigue is a unique stress, with characteristic mechanisms of failure and approaches to design that are distinctly different from those of static or impact stresses. In addition to the failure mechanism that is dominant in the fatigue of structural metals, i.e. crack propagation, plastics also exhibit a failure mechanism distinctly their own due to their viscoselastic nature. This mechanism is failure by softening due to hysteretic heating. Consequently, understanding the fatigue behaviour of plastics for purposes of design and material selection requires a somewhat different approach from that traditionally used for structural metals.

The mechanisms that control plastics fatigue failure are complex and involve variables such as microscopic flaws and heat transfer rates. Therefore, the generation of material properties for engineering purposes has been based primarily on empirical testing rather than on mathematical analysis.

Fatigue test data are very helpful in understanding plastics fatigue deformation, ranking materials and qualitatively guiding design. However, their numerical application to design calculations is usually limited to end use situations that are similar to the test conditions.

FATIGUE STRESSES

The variety of stress modes in which fatigue occurs in commercial parts is virtually endless, and to some extent the variety of fatigue test stresses reflects this. For example, fatigue test commonly are made in tension, compression, bending, alternating tension and compression, cycling around zero stress, cycling superimposed on a static preload and tests made at constant deformation or constant load.

In fatigue testing in general, and plastic fatigue testing in particular, different test modes do not necessarily yield numerically comparable data, and significant interactions between test variables and stress mode are common. Therefore, in the interest of comparability all data cited in this section were obtained by the same method – 4 point beam bending with Pmin/Pmax = 0.05.

FUNDAMENTAL PERFORMANCE PROPERTIES

Failure by crack propagation

All materials in the fabricated state contain defects in the form of voids, contamination or material discontinuities. Under load, these defects can cause localized stress concentrations. At relatively high loads such stress concentrations can exceed the strength of the material, causing localized failure at the defect.

In a fatigue situation where the load cycles from a low to a high value continually, such failure stresses may occur during each cycle, each time causing increments of damage. The result over a large number of cycles is the gradual evolution of a crack or series of cracks which propagate to the point where the stressed cross section of a part or specimen is weakened sufficiently to fracture catastrophically. The number of cycles to failure depends on stress, size and number of defects, inherent strength and notch sensitivity of the material.

For engineering purposes and material selection, both plastics and metals are tested by determining experimentally the relationship between stress and life. 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. The results are graphed as stress as a function of cycles to failure, which is commonly called a S-N curve or Wöhler curve.

The basic advantage of S-N curves is that they yield directly a graphic estimate of expected life in terms of a key design parameter – stress. Thus in a design situation that is very similar to the test conditions the designer can derive a design stress directly from the S-N curve at the design life of the part.To such a design stress a safety factor must be applied in recognition that a key variable in both the test and the part is uncontrollable, namely flaws.

Even where numerical application to design is impractical, the S-N curve is useful in ranking materials and in measuring the effects of the many secondary variables that affect fatigue performance of plastics, such as frequency and thickness.

Failure by softening due to hysteretic heating

Because plastics are viscoelastic, stress and strain are not in phase during cycling loading. A major consequence is that during each cycle a portion of the mechanical energy applied is dissipated as heat. This is called hysteresis. The magnitude of hysteretic heating during each cycle depends on the

applied stress, frequency and a material constant, the loss compliance.

Plastics are thermal insulators and under continual cyclic load they tend to heat up due to the cumulative effect of heat generated during each cycle.

There are two possible consequences of a plastic heating up in fatigue.

1. After some temperature rise the heat transfer rate to the surroundings as a result of conduction, convection and radiation equals the rate of heat generated under each cycle. At that point the temperature will stabilize. The material will continue to bear cyclic load but at a lower stress level due to the reduction in strength and stiffness that occurs at elevated temperatures.
2. The heat generated during each cycle exceeds the rate of heat transfer to the surroundings. In this case the temperature will increase continuously until the properties of the plastic fall to the point where it no longer can bear load. This constitutes a thermal failure.

FAILURE MODES FOR DIFFERENT TYPES OF PLASTICS.

Type	Failure mode
Rigid PVC Urethane Phenolic Epoxy	Crack propagation
PMMA PET Alkyd Polycarbonate	Crack propagation or thermal failure
Polypropylene Polyethylene Nylon	Thermal failure

FATIGUE TESTING

Four-point bending test until fracture

The fatigue properties have been determined by cycling sandwich beams in four-point bending. All tests were carried out in a Schenck 40 kN servo-hydraulic machine, an MTS 50 kN servo-hydraulic machine and an Intsron 100 kN universal testing machine.

A state of dominant shear stress was achieved, by using a four-point bending test. The face material and the dimensions of the test beam were selected such that the core material, rather than the face material, was the limiting factor.

The four-point bending tests were carried out with the stress rations

R = 0.05, R = 0.5 and R = 1 where R = τ_{min}/τ_{max}.

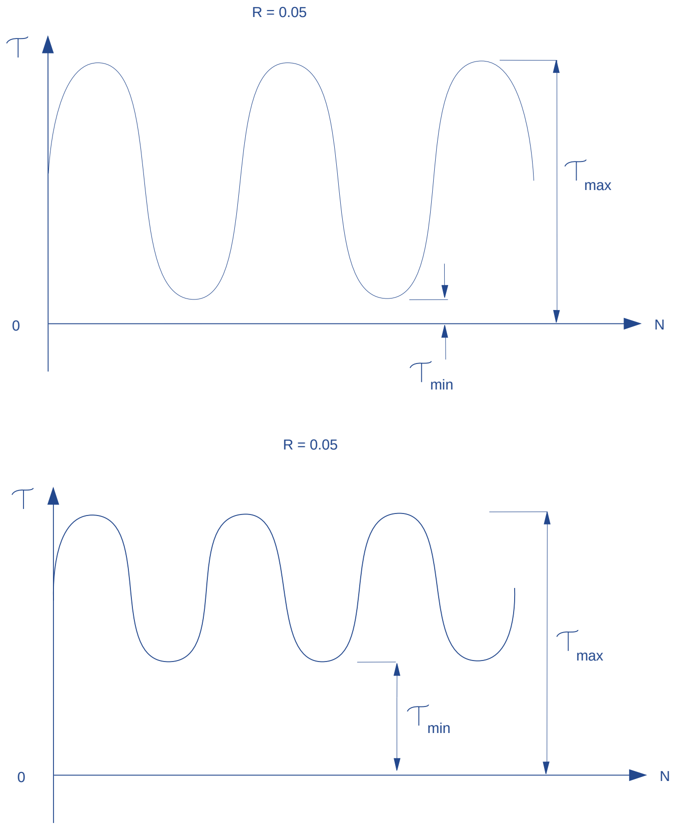


Figure 1: Illustration of R values

The frequency has been 5 Hz (5 load cycles/second).

A higher frequency will increase the temperature due to hysteretic heating and cause a failure due to softening.

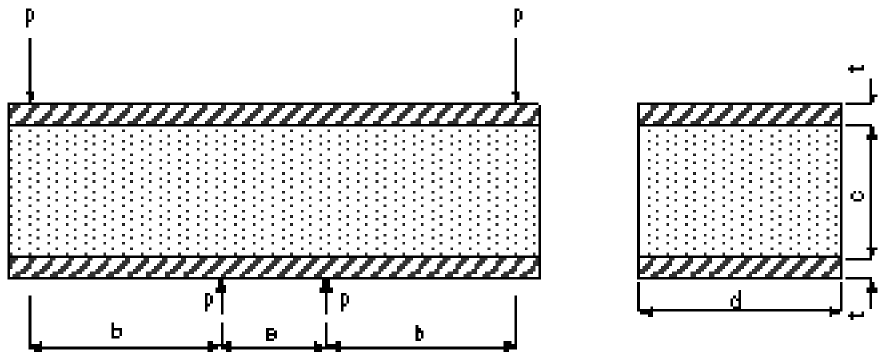


Figure 2

Four-point bending test:

$M_{max} = P \cdot b \qquad \tau_{max} = P$

The maximum normal stress in the face material is:

$$\sigma_{max} = \frac{P \cdot b}{c \cdot d \cdot t}$$

The maximum shear stress in the core is:

$$\tau_{max} = \frac{P}{c \cdot d}$$

The ratio of shear stress in the core to the normal stress in the face is:

$$\sigma_{max} / \tau_{max} = b/t$$

Hence, the ratio b/t should be low enough (we assume a safety factor of 2) so that fracture does not occur in the face material:

$$(b/t)_{max} = 0.5 \cdot \sigma_{max} / \tau_{max}$$

With respect to the discussion above, the following values were chosen: b = 180 mm (7 in), a = 80 mm (3.1 in) and L = 500 mm (20 in). The thickness of the core material was 60 mm (2 3/8 in).

The width of the beam should not influence the results significantly, but was selected to be large enough to prevent lateral buckling, d = 60 mm (2 3/8 in). The loads P must be applied in such a way that local failure under the load points is avoided. Therefore, the length of the load plates was set equal to the core thickness c.

The test programme starts with determination of the ultimate shear strength in a static four-point bending test. The beams are then tested in fatigue at different stress-ratios of the ultimate shear strength. The test is stopped when the shear crack propagation is in a macro stage, and the number of load cycles is recorded. At least three beams need to be tested at each level of stress ratio.

The result is presented in a S/N curve with stress on the y-axis and the number of load cycles on the x-axis.

As can be seen from the curves the S/N relationship for Divinycell is essentially linear. At a stress-ratio of 40 % Divinycell can be subjected to 5-25 million load cycles before failure. We have not tested at higher numbers of load cycles, but normally a plastic material will tend to level off and become asymptotic to a characteristic stress level. This stress is call the endurance limit.

FOUR-POINT BENDING, RESIDUAL STRENGTH AFTER CYCLING

The tests were carried out in accordance with the procedures in 4. page 4.3 with the following exceptions:

1. The tests were carried out in a 250 KN servo hydraulic machine.

2. The deflection (d) was measured with an electric gauge.

3. Bending stiffness EI = $\frac{b \cdot L^2}{16} \cdot \frac{P}{\delta}$

4. Beam dimensions.

After determination of the static properties the beams were cycled 10^6-10^7 cycles with a stress ratio of 20-30%. The bending stiffness was checked during and after the test.

None of the beams showed any decrease in physical properties after cycling. The results are presented in appendices III-V.

SLAMMING

Introduction

Bottom slamming at the bow of ships due to repetetive dynamic loading is a frequent reason for repair of ships. This occurs in rough seas when the conditions are such that the fore of the ship emerges from the water and at the re-entering the relative velocity between the ship and the water surface is so high that an impulse water pressure arises. The time for the impulse pressure is very short; it is in the range of a few milliseconds.

The literature on slamming is rather extensive. Each scientist has his own theory, but the most commonly used and adopted among designers and classification societies are those by Ochi and Motter.

Slamming frequency

In accordance with the definitions of Ochi and Motter slamming occurs under the following conditions.

1. Bottom emergence, i.e. the relative motion between the ship and the waves, is larger than the draught at the location considered.
2. The relative velocity at the re-entry is larger than a certain threshold velocity.

For a ship with constant speed and heading in a certain sea state, the relative motion and relative velocity are stationary Gaussian processes with amplitudes that are Rayleigh distributed.

Ochi has shown that the threshold velocity is assumed to follow Froude's scaling law for ships with different lengths (i.e. proportional to $\sqrt{L}$)

The frequency of slamming is given by the following equation:

$$F_s = \frac{1}{2\pi} \cdot \frac{r_s}{r_v} \cdot e^{-1/2}\left[\frac{d^2}{r_s} + \frac{v_g}{r_v}\right]$$

The significant value is defined as the average of the one-third largest amplitudes.

r_s = significant amplitude of relative motion

r_v = significant amplitude of relative velocity

d = ship draught at location considered

v_g = threshold velocity

The significant value is defined as the average of the one-third largest amplitudes.

Slamming pressure

The local pressure at the bottom plating at slow impacts is proportional to the square of the impact velocity.

$$p = \frac{1}{2} \cdot \rho \cdot \frac{\pi}{\tan\beta} \cdot v^2$$

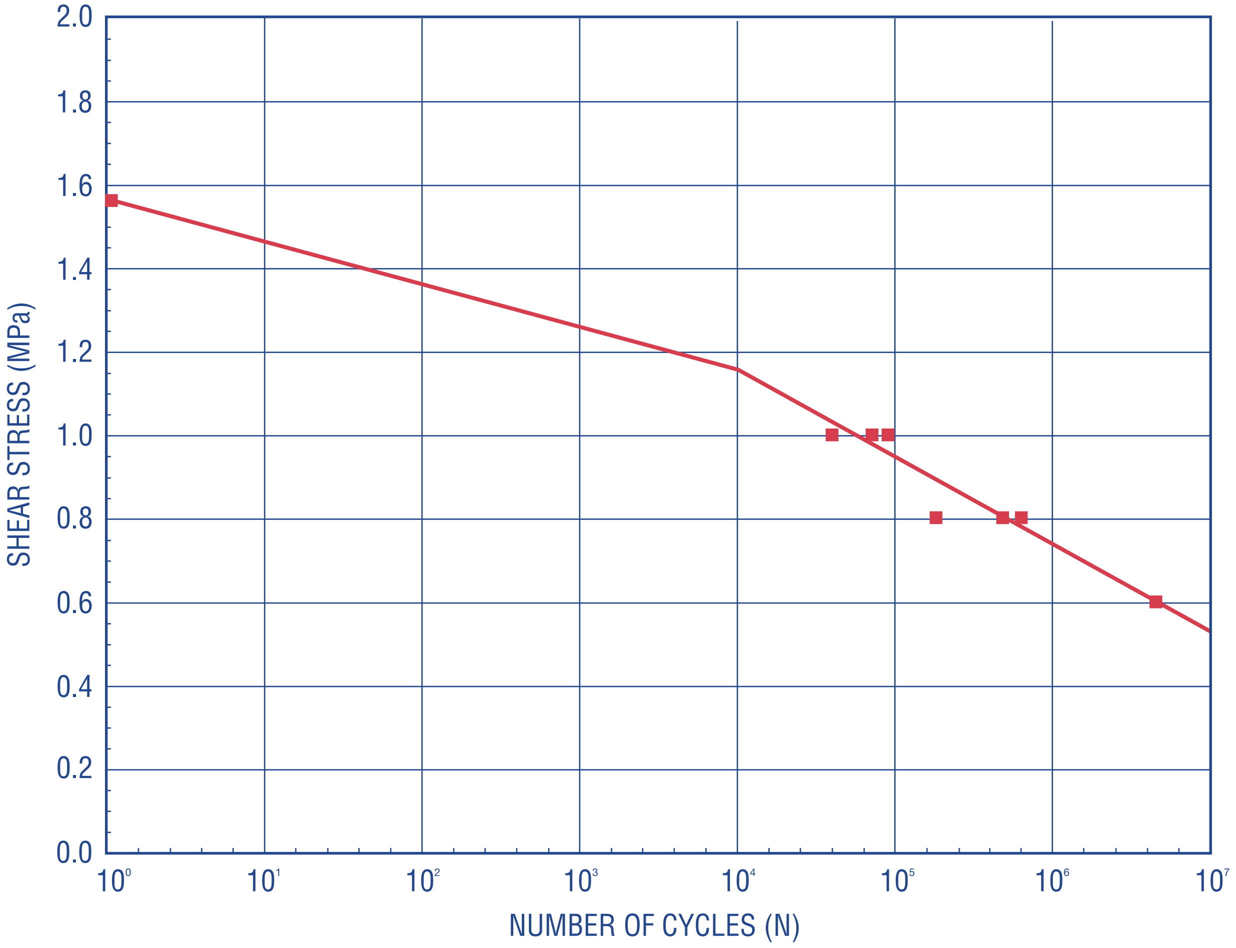
ρ = density of water

β = impact angle

v = impact velocity

Considering a ship in pure long-crested head seas with no roll motion, the section shape coefficient can be regarded as constant. However, in oblique sea or short-crested head sea the ship will roll more or less, which means that the angle of impact instantaneously will have different values.

APPENDIX 1 - S/N CURVE FOR HT 110



R = 0.05 F = 5 Hz

INTRODUCTION

Many important properties of plastic materials deal with how they behave under a flame. These properties include:

- Oxygen index
- Heat Release (Energy emittance)
- Smoke generation
- Toxic fumes

For the sake of health and safety, these properties should be considered anywhere people risk exposure to burning plastic. This is especially true in the context of passenger vehicles, such as planes, trains, busses, and boats.

The values given for Divinycell in this section are related to the core itself and not to sandwich panels. The FST properties will normally improve in combination with a properly selected skin.

OXYGEN INDEX (OI)

Oxygen index is the minimum percentage of oxygen required in the surrounding air to sustain a fire. Normally, there is 21% oxygen in air. Materials that have an oxygen index greater than 21 are said to be self-extinguishing. All grades of Divinycell are self-extinguishing, with an oxygen index between 25 and 40.

HEAT RELEASE (HR), HEAT RELEASE RATE (HRR)

Heat Release (HR) is a measure of the energy released from a material when it is burned. The Heat Release Rate (HRR) is the rate at which energy is released during the test – of particular interest is the Peak Rate. The HR and HRR can be measured using equipment such as an OSU test chamber, developed by Ohio State University. A typical HR and HRR value for Divinycell in 25 mm thickness is 150-200 kW/m^2.

SMOKE GENERATION

The smoke produced during a fire is itself a hazard. Smoke can impair breathing, and it can disorient people by reducing visibility. It is therefore important to test materials for smoke generation. There are various pieces of equipment to measure smoke generation from burning materials. Two examples are the NBS (National Bureau of Standards) and the OSU (Ohio State University) smoke chambers.

Smoke generation tests can be performed under *flaming mode*, during which a flame is applied directly to the material, or under *pyrolysis*, during which only heat is applied. When testing Divinycell, the values produced by pyrolysis are generally lower than those produced by flaming mode. A typical smoke density value for Divinycell in 25 mm thickness is 250 after 90 seconds and 500 after 240 seconds.

TOXICITY

Burning and combustion not only release heat, they also produce residual products such as char and smoke.

Plastics are very complex products with many different additives. Burning can release these additives in the form of very small particles or molecules. They pose a hazard because they can be transported easily by smoke. Standards have been established to dictate the types and quantities of combustion products allowed for certain materials. Because the components in plastic are often highly toxic, the quantity of these products that are permitted is usually small enough that they are conveniently measured in parts per million (ppm). Typical values of gas in ppm after 2 minutes: CO_2 = 4000, CO = 150, HCl = 300, CH_2CHN = 15, HCN = 15. No traces of HF, HBr, NOx, SO_2, H_2S, NH_3, or HCHO were found.

CLASSIFICATION OF DIVINYCELL

Several institutions have established standards and regulations which relate, in part, the fire and smoke properties of plastic materials. Some of these sets of rules apply to entire industries, whereas others deal specifically with individual companies. Generally these are rules based on limits of results of standard test methods. The following are some examples of these standards:

MARINE

IMO (International Maritime Organisation)

The International Maritime Organisation is the United Nations' specialised agency responsible for improving maritime safety.

New IMO rules and regulations came into force 1 January 1996 and replaced the previous SOLAS rules for high-speed crafts in international waters. In the new rules there are no restrictions for use of FRP sandwich in most areas, as long as the constructions are classified as "non-combustible" or "fire-restricting", although the constructions contain flammable materials.

Fire-restricting materials have to pass the following tests.

- Room Corner test according to ISO 9705.
- Panel test, 30 & 60 minutes respectively, for vertical construction, i.e. bulk heads and for horizontal construction, i.e. decks, floors, etc, etc., according to IMO res. A754 (18).

A FRP sandwich does not meet the requirements itself, it has to have a fire protective system.

RAILWAY

NF F 16-101

NF F 16-101 is a French standard for railway rolling stock, fire behaviour and choice of materials. The materials are classified with respect to fire behaviour and smoke index.

Fire behaviour has five classes, M0 – M4, were M0 is the highest. Smoke index is a combination of smoke density and toxicity. It also has five classes, F0 – F5, were F0 is the highest. Divinycell is classified as M1/F4.

DIN 5510, Part 2

DIN 5510, Part 2 is a German standard for preventive fire protection in railway vehicles.

The materials are tested and classified with respect to flammability, smoke development and dripping. Flammability includes burn length and burn time after test and is classified S1-S5, were S5 is the highest.

There are two classes for smoke development and dripping, SR1/SR2 and ST1/ST2, were SR2 and ST2 are the highest.

Divinycell is classified as S3/S4 and ST2. The smoke development is depending on the thickness and is typically classified as SR2 below and SR1 above 15 mm.

NFPA (National Fire Protection Association)

NFPA 130 Standard for Fixed Guideway Transit Systems is an American set of rules for Trains, and Subway used in the USA using ASTM E162 and ASTM E662 for Flammability and Smoke Emissions.

AIRCRAFT

FAR (Federal Aviation Requirements)

The FAR is the set of rules and requirements established by the FAA (Federal Aviation Administration). FAR deals with aircraft safety, and concerns everything from upholstery and curtains in the cabin to panels for cargo compartments.

Airbus 1000 (ATS-1000.001)

Airbus ATS 1000 is a company standard drafted by Airbus Industries regarding fire, smoke, and toxicity in their aircraft. ATS 1000.001 follows FAR closely, except that ATS is more restrictive in certain areas. These restrictions are often dictated by their suppliers.

BMS and BSS (Boeing Material Specifications)

BMS and BSS are standards, for Boeing Aircraft, and are also based on FAR. The requirements in BMS are generally more conservative than those in FAR.

The main criteria for use as an interior material in all three standards are vertical burn, heat release, smoke density and toxicity.

The table below shows the requirements and whether a particular Divinycell grade passes or fails.

Type of test		Requi.	Unit	H 45		H 80		HT 50		HT 110		FRG 80	
			mm	12.5	25	12.5	25	6.3	12.5	6.3	12.5	12.5	25
Vertical Burn	a (12 s)	< 203	mm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	b (60 s)	< 152	mm	Fail	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Heat Release	HR	< 65	kWmin/m_2	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	HRR	< 65	kWmin/m_2	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
Smoke Density	Ds (90s)	< 100	-	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	Ds (240s)	< 200	-	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
Toxicity (1.5 min)	CO	< 3000	ppm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	HF	< 50	ppm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	HCl	< 50	ppm	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
	NO_x	< 50	ppm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	SO_2	< 50	ppm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	HCN	< 100	ppm	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

INTRODUCTION

When an installation has a different temperature than the surrounding air there will always be a heat flow. Hot installations have a higher temperature than the surrounding air and the heat flow goes from the installation to the surrounding air. Cold installations have a lower temperature than the surrounding air and the heat flow goes from the surrounding air to the cold installation.

The force that creates the heat flow in both cases is the temperature differential between the installation and the surrounding air.

Independent of the heat flow direction, it is in almost all cases desireable to decrease the heat flow. This can be achieved by applying an insulation with good thermal impedance/resistance. The choice of insulation material and dimensioning depends on how large a temperature loss is acceptable and the economy of the system.

Consideration also has to be given to the surface temperature of the insulation in the installation. In a hot installation an excessive surface temperature could mean a risk of burn injuries. When the insulation is applied on a cold installation there is always a requirement for a defined surface temperature to avoid condensation.

Thermal conductivity is the material property that states the value of thermal insulation capacity for a given material. The lower the termal conductivity, the better the insulation properties.

Thermal conductivity is however not a constant, but a property that is affected by temperature, density and moisture content.

The influence of temperature is that a high temperature means a higher value of thermal conductivity.

The Divinycell data sheets show the thermal conductivity at three different temperatures. The temperatures are the average temperature of the panel.

Eg. λ +10 is λ at $\frac{T_1 + T_2}{2} = +10\ ^\circ\text{C}$

where T_1 is the temperature on the hot surface and T_2 on the cold surface.

In almost all insulation material it is the air or the gas inside the material that gives it its insulating capacity. The thermal conductivity for air is approximately 0.025 W/(m · K) .

The heat transfer through the solid material increases the thermal conductivity for most of the insulation materials to 0.025 – 0.040 W/(m · K).

If the air or gas in the material is replaced with water, which has a thermal conductivity of 0.6 W/(m · K), the thermal conductivity will of course decrease significantly. The insulation capacity is decreased even more if the water freezes to ice, which has a thermal conductivity of 2.2 W/(m · K) at 0 °C.

There will always be a water vapour penetration on cold installations through the insulation towards the cold side where the vapour will condense. Tests show that a water content of even 3 % by volume increases the thermal conductivity by 20-30 %.

DEFINITION OF THERMAL PROPERTIES
(in accordance with ISO 31/IV)

Designation	Symbol	Unit
Thermodynamic temp.	T	K
Celsius or Fahrenheit temperature	t	°C
Temperature difference [1]	ΔT	K, °C
Heat	Q	J
Specific heat	q	J/kg
Heat power	P	W
Heat flow rate	F	W
Density of heat flow rate	q	W/m^2
Thermal conductance	G	W/K

Designation	Symbol	Unit
Thermal conductivity [2]	λ	$W/(m \cdot K)$
Thermal resistance	R	K/W
Thermal impedance/resistance [5]	M_n	$m^2 \cdot K/W$
Surface thermal impedance/resistance	M_α	$m^2 \cdot K/W$
Coefficient of heat transfer [3, 5]	α	$W/(m^2 \cdot K)$
Thermal transmittance [4,5]	k	$W/(m^2 \cdot K)$
Heat capacity	C	J/K
Specific heat capacity	c	$J/(K \cdot kg)$

1. K (Kelvin) can be changed to °C (Celsius) or °F (Fahrenheit) in all units where K occurs since all units refer to a temperature difference.
2. The thermal conductivity for a material is the heat flow rate that passes perpendicular through a cube with 1 m sides between two opposite sides at a temperature difference between the two surfaces of 1 K.
3. The coefficient of heat transfer is the heat flow rate that is transferred between a surface of 1 m^2 and the air at a temperature difference of 1 K. α depends on the movement of the air.
4. The thermal transmittance is the heat flow rate that passes perpendicular through a wall of known structure and an area of 1 m^2 at a temperature difference of 1 K.
5. Difference use of symbols between ISO 31/IV and ASTM C 168; $M = R$, $\alpha = h$ and $K = C$.

FORMULAS FOR CALCULATION OF THERMAL PROPERTIES

Symbol	Formula	Unit
t	$t = T - 273.15$	°C
ΔT	$\Delta T = T_1 - T_2$ T_1 = T on warm surface T_2 = T on cold surface	°C
Φ	$\Phi = g \cdot A$	W
g	$g = \Delta T \cdot k$	W/m^2
G	$G = \Phi/\Delta T = A \cdot k$	W/K
R	$R = 1/G = 1/A \cdot k$	K/W
M_n	$M_n = 1/k$ (d = thickness in m or ft)	$m^2 \cdot K/W$
M_α	$M_\alpha = 1/\alpha$	$m^2 \cdot K/W$
k	$k = \dfrac{1}{\dfrac{1}{\alpha_1} + \dfrac{d_1}{\lambda_1} + \dfrac{d_2}{\lambda_2} + \dfrac{d_3}{\lambda_3} + \dfrac{1}{\alpha_2}}$ $\alpha_1 = \alpha$ on warm surface $\alpha_2 = \alpha$ on cold surface $d = d_1$ = thickness of first layer d_2 = etc. $\lambda = \lambda_1 = \lambda$ of first layer λ_2 = etc.	$W/(m^2 \cdot K)$
C	$C = c \cdot m$ (m = mass in kg or lb)	J/K

WATER VAPOUR PROPERTIES

DEFINITION OF WATER VAPOUR PROPERTIES

(The definitions are in accordance with SS 02 15 82)

Designation	Symbol	Unit
Thermodynamic temp.	T	K
Celsius or Fahrenheit temperature	t	°C
Temperature diff. 1)	ΔT	K
Water vapour permability 2)		
Water vapour content	δv	m^2/s
Water vapour pressure	δp	$kg/(m \cdot s \cdot Pa)$
Water vapour permeance 3)	W_v	m/s
Water vapour resistance	Z_v	s/m
Water vapour transmission rate 4)	D	$kg/(m^2 \cdot s)$
Water vapour difference		
Water content	Δv	kg/m^3
Water pressure	Δp	Pa
Insulation thickness	d	m
Water vapour flow	g	$kg/(m^2 \cdot s)$

1. K (Kelvin) can be changed to °C (Celsius) or °F (Fahrenheit) in all units where K occurs since all units refer to a temperature difference.

2. The water vapour permeability is the amount of water vapour per second at steady state that passes through 1 m^2 of a material with 1 m thickness when a difference in water vapour content between the two sides of the material is 1 kg/m^3.

3. The water vapour permeance is the amount of water vapour per second at steady state that passes through 1 m^2 of material with a given thickness when the difference in water vapour content between the two sides of the material is 1 kg/m^3.
4. The water vapour transmission rate is the amount of water per second at steady state that passes through 1m^2 of a material when the difference in water vapour content between the two sides of the material is 1 kg/m^3.

Formulas for Calculating Water Vapour Properties

Symbol	Formula	Unit
t	$t = T - 273.15$	°C
ΔT	$\Delta T = T_1 - T_2$ T_1 = T on warm surface T_2 = T on cold surface	K
δv	$\delta v = d/Z$	m^2/s
δp	$\delta p = \delta v \cdot 7.33 \cdot 10^{-6}$	$kg/m \cdot s \cdot Pa$
W_v	$W_v = 1/Z$	m/s
Z_v	$Z_v = \frac{\Delta v}{D}$	s/m
g	$g = \frac{\Delta v}{Z_v + (d/v)}$	$kg/(m^2 \cdot s)$
Zp	$Zp = Zv/7.33 \cdot 10^{-6}$	$m^2 \cdot s \cdot Pa/kg$

WATER ABSORPTION

The values in the data sheet are determined in accordance with ASTM D 2842-69. This method covers the determination of the water absorption of rigid cellular plastics by measuring the change in buoyant force resulting from immersion under a 5.1 cm head of water for 96 h.

The purpose of this method is to provide a means for comparing relative water absorption tendencies between different cellular plastics. It is intended for use in specifications, product evaluation and quality control. It is applicable to specific end-use design requirements only to the extent that the end-use conditions are similar to the test conditions.

The water absorption is measured as a result of direct contact exposure to the water. The volume error associated with surface cells cut open during specimen preparation has to be taken into account when calculating the true specimen volume.

This is, however, complicated and is often a reason for errors. Both internal and external tests have shown negative water absorptions due to miscalculation of the volume of the cells cut open on the surface.

The results are reported in terms of ”amount of water absorbed per unit of surface area”. The unit is kg/m^2 .

ISO 2896 could also be used for determination of water absorption. We do not recommend

ASTM C 272-53 since it does not take the volume of the cells cut open on the surface into account.

GLASS TRANSITION TEMPERATURE

All amorphous, as opposite to crystalline, polymers have a point where the physical properties are changed due to temperature. At this point, i.e. temperature range, the mobility of the polymer chains increases and the material softens. This softening point is called the glass transition temperature (T_g).

T_g is different for different polymers and relates to the structure of the polymer.

The T_g is +85 - +88 °C for the H-grade and +84 - +86 °C for the HT-grade.

A low T_g does not necessarily mean that the polymer, or the material, has bad thermal stability. This is pronounced concerning the HT-grade. HT has a lower T_g than H-grade but a better thermal stability. HT consists partly of crystalline areas which have a high melting point, approx +250 °C.

These crystalline areas give HT-grade good thermal stability compared with H-grade. Such materials are called semi-crystalline materials.

DIELECTRIC PROPERTIES

INTRODUCTION

A dielectric material is defined as a non-conductor of electricity and a medium that lets electrical fieldlines through.

The dielectrical properties of a material are measured in terms of dielectric constant or permittivity and dissipation factor.

When we talk about the dielectric constant in common usage we mean the “relative dielectric constant”. It is the ratio of the equivalent capacitance of a given configuration of electrodes with a material as a dielectric to the the capacitance of electrodes with vacuum (or air for most practical purposes) as the dielectric. Since the relative dielectric constant is a ratio it has no unit.

Table 1 - Typical dielectric constants

Material	Dielectric constant
Vacuum	1.0000
Air (1 atm +20 °C)	1.0006
Water (+20 °C)	80
Divinycell	1.1
Rubber	3
Glass	5–10
Porcelain	6–8
Teflon	2.1
Polyethylene (PE)	2.3

The lower the dielectric constant, the lower the conducting capacity. The reduction can be understood in terms of polarization. It is the alignment of atomic or molecular dipoles in the dielectric when an electric field is applied. An electric dipole is a configuration of equal amounts of positive and negative charges with the positive charge displaced relative to the negative charge.

The dissipation factor is a measure of the A/C loss in the dielectric. The A/C loss shall generally be small, both in order to reduce the heating of the material and to minimize its effect on the rest of the network. In high frequency applications, a low value of loss index is particularly desirable, since for a given value of loss index the dielectric loss increases directly with frequency.

FACTORS AFFECTING THE DIELECTRIC PROPERTIES

Dielectric materials are used over the entire electromagnetic spectrum from direct current to radar frequencies. There are only a few materials whose dielectric constants are even approximately constant over the frequency range. It is therefore necessary either to measure the dielectric constant at the frequency at which the material will be used or to measure it at several frequencies suitably placed, if the material is to be used over a frequency range.

Table 2 - Ectromagnetic spectrum

Wave length	Frequency	Designation
– 500 mm	– 1.5 GHz	Radio waves
500 mm – 10 mm	1.5 GHz – 30 GHz	Radar waves
10 mm – 0.1 mm	30 GHz – 3 THz	mm wave
0.1 mm – 0.001 mm	3 THz – 300 THz	Infrared light
8000 Å – 4000 Å	–	Visible light
4000 Å –1 Å	–	UV-light
100 Å – 0.01	–	X-ray
1 Å – 0.01 Å	–	Gamma radiation
1 Å (Ångström) = 10^{-10}m		

Radio and radar waves are produced in electrical oscillating circuits. Infrared, visible and UV-light and X-rays are due to changes in energy in the electron layers of the atoms in the material that transmits the radiation. Gamma radiation is created by changes in energy in the atom cores.

Another very important parameter that affects the dielectric constant is water vapour permeability and water absorption. The major electric effect is a great increase of the interfacial polarization, thus increasing the dielectric constant and the conductivity.

The dielectric constant also increases with increasing density.

DEFINITIONS OF DIELECTRIC PROPERTIES

Designation	Symbol	SI Unit
Quantity of electricity	Q	C, As
Electric flow density	D	C/m^2
Voltage	U	V
Electric field strength	E	V/m
Capacitance	C	F
Permittivity, capacitivity or dielectric constant	ε	
Permittivity of vacuum	ε_o	F/M
Relative permittivity	ε_r	–
Dissipation factor, loss tangent or tan	d	–
Loss index or loss factor	ε_r''	–
Wave length	λ	m
Frequency	f	Hz
Velocity of light in air	ν	m/s

Formulas for calculations of dielectric properties

Symbol	Formula	Unit
C	C = Q/U	F
E	E = U/d	v/m
D	D = Q/A	C/m^2
ε	$\varepsilon = D/E$	F/m
ε	$\varepsilon = \frac{C \cdot d}{A}$	F/m
ε_o	$\varepsilon_o = 8.854 \cdot 10^{-12}$	F/m
ε_r	$\varepsilon_r = \varepsilon / \varepsilon_o$	–
ε_r''	$\varepsilon_r'' = \varepsilon_{r \cdot d}$	–
$d^{1)}$	$dp = \frac{1}{\omega \cdot Cp \cdot Rp}$ $ds = \omega \cdot C_s \cdot R^s$	–
ω	$\omega = 2\pi \cdot f$	rad/s
λ	$\lambda = \nu/f$	m
f	f = 1/T	s^{-1}
ν	$= 3 \cdot 10^8$	m/s

N.B. The normal presentation of the dielectric loss is to represent a capacitor at a single frequency by capacitance Cp parallel to a resistance Rp. But it is occasionally desirable to represent it by a capacitance C_s in series with a resistance R_s.

INTRODUCTION

There are a number of ways to machine Divinycell. This section covers the most commonly used methods, namely:

- Sawing
- Cutting
- Horizontal sawing
- Sanding
- Milling
- Turning
- Drilling

This part of the manual is in no way a complete set of instructions for machining Divinycell. The intention, based on our internal experiences, is a guide when making the first attempts to machine the materials in various ways. The contents will cover the basic parameters and principles and give the user a fair chance of getting close to a good result at the first try, because almost always some trials must be made before choosing a final setup.

Divinycell is a fairly easy to machine but its low thermal conductivity and other plastic properties can be a source of problems. Several measures can be taken to ensure a good cut. A very important part is the checking and maintenance of the machines and machining tools. The final result is highly dependent on these factors.

If in doubt concerning machining, please contact DIAB and we will advise you in this area.

SAWING

Depending on the operation and the density of the material there are two types of sawing: Cross-cut sawing and band sawing. They will be dealt with separately because of their differences.

CROSS-CUT SAWING

This type of sawing can be used on any density and on many sandwich panels. Please note that the feed speed must be decreased on sandwich panels and on higher densities. The main parameters when cross-cut sawing are:

- Cutting speed 50-60 m/s.
- Carbide-tipped sawing blades.
- 350-400 mm blades, 54-96 teeth.
- Alternately or trapezoidally sharpened teeth. (See fig. 1-4)

BAND SAWING

This type of machining can be used on the lower densities without problems. On higher densities (>200 kg/m^3) the feed speed must be considerably decreased. When sawing sandwich panels, great emphasis must be put on trials. The machining parameters are:

- Cutting speed 30-35 m/s.
- Carbide tipped blades.
- 10-13 mm wide blades.

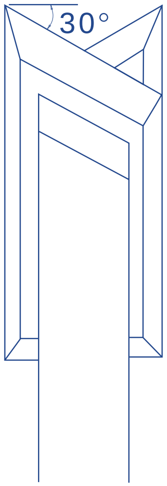


Figure 1. Alternatelly sharpened blade, rear view.

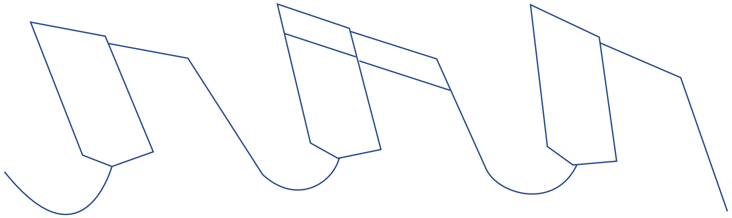


Figure 2. Alternatelly sharpened blade, side view.

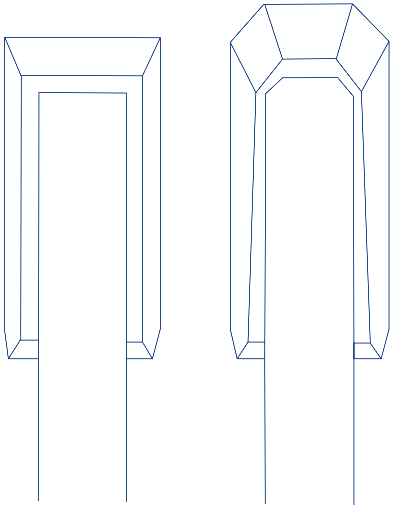


Figure 3. Trapezoidally sharpened blade, rear view.

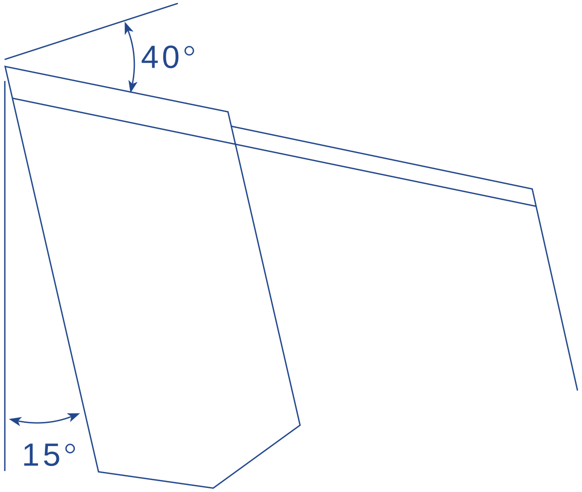


Figure 4. Trapezoidally sharpened blade, side view.

CUTTING

When cutting the speed must be 50 m/s and the blades have a configuration as in figures 5 and 6. The feed speed is very highly dependent on what density to machine. A first try with 6 m/min of speed should give a good indication of how to proceed. On higher densities (>100 kg m^3) use an initial feed rate of 2 m/min.

NOTE: Be sure to keep the blades well sharpened. The amount of material that can be machined off in one pass highly depends on the density, feed speed and the condition of the blades. A starting value of 1 mm per cylinder and pass as a first try will give a good indication of what can be achieved.

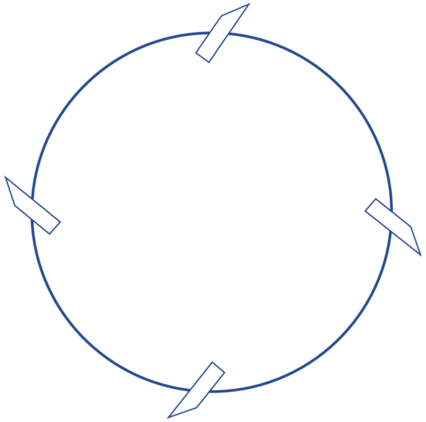


Figure 5.

Cutter cylinder, side view.

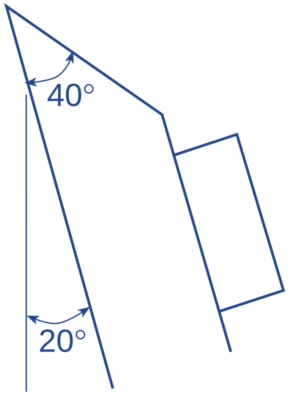


Figure 6.

Cutter knife, side view.

HORIZONTAL SAWING

This type of sawing is done using a standard sawing blade and the following main parameters:

20 mm wide blade.

- 3 teeth per inch.
- Standard setting (every other tooth) to 1.5 mm.
- Hook-shaped teeth. (See fig. 7)
- Carbide-tipped blades.
- Cutting speed 45-50 m/s.
- Feed speed 0.5-2 m/min depending on density.

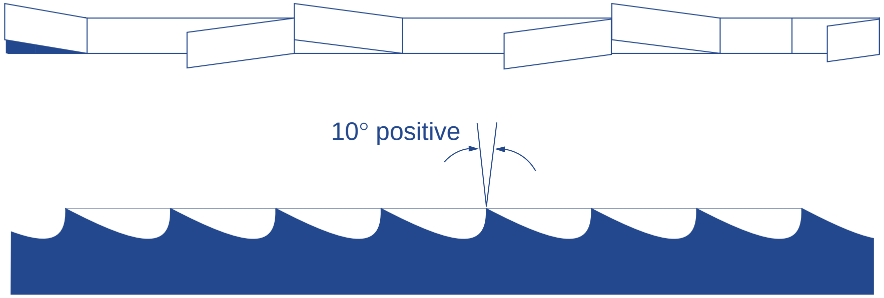


Figure 7. Band-saw blade, top and side view.

SANDING

When sanding, the resulting surface is different from one cutted or horizontally sawed. The surface consists of deformed cells with a distinct direction. This can be felt when passing ones hand in different directions on the sheet.

The machining parameters are mainly:

- Sanding paper as standard 60-80 grit. (Types down to 240-300 have been used.)

- The paper speed 25 m/s.

The feed speed very much depends on what density is machined. It varies from 3 m/min to 15 m/min , the highest value for the lowest density. The amount of material in thickness that can be machined is maximum 3 mm per cylinder and pass, but a starting value of 1 mm is realistic to start with.

MILLING

This type of machining using a router bit is used to remove bad material in order to repair blocks and to achieve a good surface finish. In general it is difficult to give advice, especially concerning Divinycell. We mostly use specially designed milling heads. But in order to get started, standard types of heads can be used using the same main parameters as for cutting except for the numbers of knifes (two are recommended, not four) although good results can be achieved with four-knife heads. For smaller milling heads a larger number of knifes can be used.

TURNING

This type of machining using a lathe is very difficult to manage with satisfactory results when using standard cutting edges. The best way to get good results is to use a combination of turning and substitute the cutting head with a milling machine and head. The parameters should be approximately the same as for milling using the mentioned method. See milling section. The rotation speed must be kept low in the initial phase.

DRILLING

When drilling in Divinycell, standard types of drilling heads can be used. The cutting speed should be 40 m/s. When drilling plugs from the material, the number of bits must be kept low, preferably two to four. The feed speed depends directly on the type of machined material. The rule is to start with a slow rate and check the result. Then further measurements can be taken.

CONCLUSION

Hopefully this gives enough information to get started. Don’t hesitate to inform the Technical Department in Laholm if you come across other types of machining. Always remember that tool maintenance and machine quality are the most important factors in order to get a satisfactory result.

THERMOFORMING

Scope

Thermoforming is carried out by heating Divinycell to its softening point and forcing it against the contour of a female or male mould. There are at least a dozen thermoforming methods: vacuum assisted, pressure, drape, sweep, match mould and free forming, to name just a few. We will cover only three of them in this section.

All figures in this section are derived from previous production experience and testing. Adjustments might have to be made depending on individual production conditions.

Moulds

Thermoforming moulds can be made of most common materials.If a series is small, or if you are working on a prototype, a wooden mould is acceptable. The disadvantages of wood is the heat build-up in the mould, the long cooling time is long and productivity is relatively low for continuous production.

Steel or aluminium moulds are preferable due to their high thermal conductivity and their stability. Plastic moulds can be used but they also accumulate heat.

Single curved products with a radius larger than 400 mm are best formed on a male mould. This could either be sweep forming with a thin steel foil or vacuum bagging.

Vacuum bagging is a simple operation with low tooling costs, but is has some disadvantages. It takes time to apply the vacuum bag, and the sheet might cool down too much.

This can be avoided if the vacuum bag is assembled on a cold sheet and mould. The mould is then placed in a hot air oven. The temperature inside the sheet is measured with a thermal gauge. When the right temperature is reached the vacuum is applied. The mould is then taken out of the oven and allowed to cool with the vacuum being maintained. Consideration has to be given to time, temperature and vacuum to avoid creep effects.

If the radius is below 400 mm, a female mould should be used. It could either be vacuum bagged or match mould formed.

The latter should be used if the radius is small, the thickness or density is high and a high load is required. Fixed stops must be used to avoid compression of the core.

Heating

The best way to heat the Divinycell is in a heated platen press with fixed stops or in a circulating hot air oven.

Infrared heaters could also be used up to 10-15 mm thickness. The IR-waves will not penetrate deep enough on thicknesses above that.

The temperature in all three cases must be kept within ±3 °C.

If the temperature is too high the dimension stability will be affected and if it is too low the springback will be too big. An uneven temperature distribution will make the Divinycell twist.

TEMPERATURES & TIMES

The following temperatures should be used for the different qualities, independent of radius and thickness:

Quality	H30 - H250	HT & HCP
Temperature (°C)	+100 to +120	+120 to +130

The following times should be used for the different thicknesses, independent of radius and quality.

Thickness (mm)	10	20	30	40	50	60
Time (min)	3-7	5-10	10-15	15-20	20-30	30-45

The temperature and time are dependent on the local conditions and should be calibrated prior to start of production. Start with the lowest time and temperature.

The following temperatures in the centre of the core should be used for the different qualities when a cold sheet is vacuum bagged in a hot air oven.

Quality	H 45-200	HT & HCP
Temperature (°C)	+85	+100

The time from removal from the heating unit until the pressure is applied must not exceed 0.5 minutes to avoid the Divinycell cooling down.

DIMENSIONAL STABILITY

Heating Divinycell will change its dimensions slightly. The following dimension stability figures as percentages of the original dimension are valid when Divinycell is heated in accordance with temperatures and times as mentioned above.

- Length/width = ± 2 %
- Thickness = -2 - 0 %

To compensate for the springback of Divinycell, the mould radius should be 5-10 % smaller than the final radius.

It should also be noted that the edges of thermoformed pieces have a tendency to straighten out.

Care must also be taken to avoid springback during storage. Specially designed boxes or pallets may need to be used.

EFFECT ON PHYSICAL PROPERTIES

The Divinycell is affected in two ways during thermoforming

1) Decrease in density during heating.
2) Stretching of the outer radius.

Both will decrease the physical properties slightly. Typical decrease is 0-5 %. From design standpoint 10 % should be used.

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