ERRATA

p.6. In the table of mechanical properties, modulus of Elasticity was measured according to ASTM D 638-68.

p.7. A. In the Thermal Properties Table, the units for coefficient of thermal conductivity should read W/mK (large K, not small k).

B. In the Linear Thermal Expansion table the figures in Imperial Units are incorrect. The tables are correct for °C figures, but °F figures should read -

°C (°F)	K^{-1} (in/in. °F)	K^{-1} (in/in. °F)	K^{-1} (in/in. °F)
(-238)	(0.0000138)	(0.0000133)	(0.0000166)
(-148)	(0.0000138)	(0.0000133)	(0.0000166)
(-58)	(0.0000154)	(0.0000149)	(0.0000166)
(+32)	(0.0000166)	(0.0000166)	(0.0000177)
(+68)	(0.0000205)	(0.0000183)	(0.0000194)

p.8 Same correction as p. 7.A.

p.23. The test temperature for Rohacell 71 in phosphoric acid ester Skydrol 500 B was 23°C, not 70°C.

p.43. Third line of final paragraph, replace "S" between "to... firm" by "a".

What is ROHACELL?

a 1

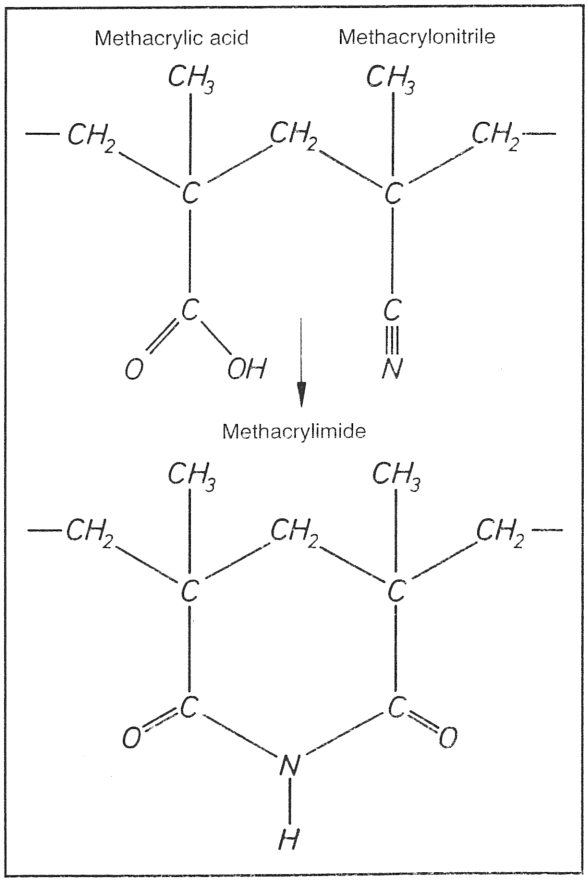
ROHACELL is a closed-cell rigid imide expanded plastic material or, more accurately, polymethacrylic imide rigid expanded plastic (PMI) for lightweight construction. The natural color of ROHACELL is white.

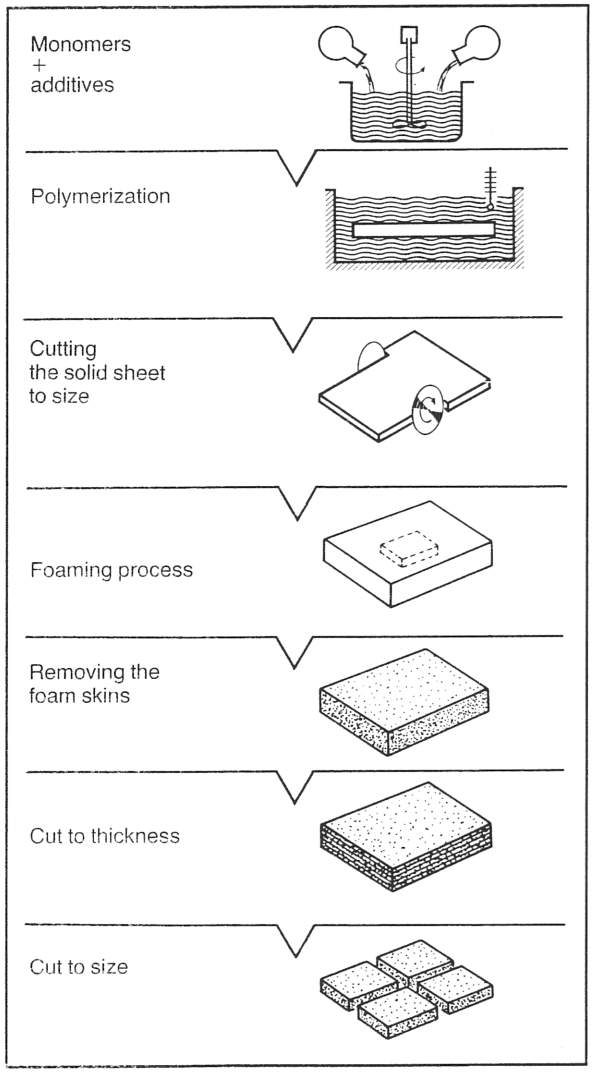
ROHACELL has excellent mechanical properties, high dimensional stability under heat, solvent resistance and, particularly at low temperatures, a low coefficient of heat conductivity. The strength values and the moduli of elasticity and shear are presently not exceeded by any other foamed plastic of the same gross density.

The manufacture of ROHACELL

ROHACELL is manufactured by hot foaming of methacrylic acid – methacrylonitrile copolymer sheets. During foaming this copolymer is converted to polymethacrylimide. The blowing agent is carbon monoxide.

Fig. 1: Formation of methacrylimide (PMI) ↓
Fig. 2: Production scheme of ROHACELL →





Mechanical properties

b 1 Mechanical properties of ROHACELL 31, 51, 71

Properties[1]	Units	ROHACELL 31	51	71	Standard
Gross density	kg/m³ (lbs/ft³)	30 (1.9)	50 (3.1)	70 (4.4)	ASTM D 1622-63
Tensile strength	N/mm² (psi)	1.0 (142)	1.9 (270)	2.8 (398)	ASTM D 638-68
Compressive strength	N/mm² (psi)	0.4 (57)	0.9 (128)	1.5 (213)	ASTM D 1621-64
Flexural strength	N/mm² (psi)	0.8 (114)	1.6 (228)	2.5 (356)	ASTM D 790-66
Shear strength	N/mm² (psi)	0.4 (57)	0.8 (114)	1.3 (185)	ASTM C 273-61
Modulus of elasticity	N/mm² (psi)	36 (5120)	70 (9950)	92 (13100)	ASTM C 638-68
Shear modulus	N/mm² (psi)	14 (1990)	21 (2990)	30 (4270)	ASTM D 2236-69
Shear modulus	N/mm² (psi)	13 (1850)	19 (2700)	29 (4120)	ASTM C 273-53
Elongation at break	%	3.5	4	4.5	ASTM D 638-68

[1] Test conditions: 23 °C (73.4 °F) and 50 % relative humidity

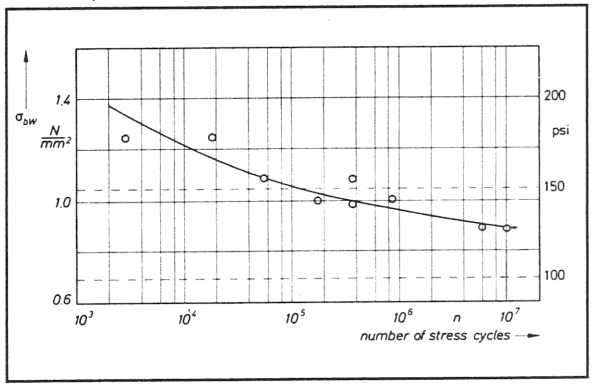


Fig. 3: Alternating flexural strength test of ROHACELL 51 at a stress frequency of 10 Hz.

The long-term behavior of ROHACELL under dynamic stress is excellent. There was no observable, time-dependent decrease in the stress up to an exposure time of 10^7 load cycles.

Thermal properties

Thermal properties of ROHACELL 31, 51, 71

Properties	Units	ROHACELL 31	51	71	Standard
Deflection temperature under load	°C (°F)	185 (365)	185 (365)	185 (365)	DIN 53 424
Linear coefficient of thermal expansion[1]	K^{-1} (in./in.°F)	0.000037 (0.000023)	0.000033 (0.000021)	0.000035 (0.000022)	ASTM D 696
Coefficient of thermal conductivity[1]	W/mk (BTU in./ $ft^2h°F$)	0.031 (0.215)	0.029 (0.201)	0.030 (0.208)	ASTM C 177-63

[1] Tested at 20 °C (68 °F)

Deflection temperature under load

Normally the "deflection temperature under load" of a product is adequately described by its real requirements for strength, weight stability and dimensional stability. The following tables therefore show the change in weight, volume and linear dimensions of ROHACELL specimens kept in air at different temperatures for 30 days.

Table below shows the weight and dimensional changes of ROHACELL 31, 51, 71 after being kept for 30 days at different temperatures. The measurements were taken immediately after the specimens had cooled down from the air temperature at which they had been kept.

ROHACELL		31			51			71		
Storage temp.	°C	100	120	160	100	120	160	100	120	160
	(°F)	(212)	(248)	(320)	(212)	(248)	(320)	(212)	(248)	(320)
Change in weight	%	-3.3	-4.4	-5.2	-4.0	-5.1	-6.1	-3.7	-4.2	-6.0
Change in length	%	-0.8	-1.0	-1.6	-1.0	-1.4	-1.8	-0.8	-1.0	-1.9
Change in volume	%	-1.7	-3.2	-4.2	-2.3	-3.9	-4.8	-2.3	-3.0	-3.3

Changes in weight and dimensions of ROHACELL 31, 51, 71 after annealing as in the previous table, followed by keeping under standard conditions (23 °C, 73,4 °F, 50 % RH) until the weight was approximately constant.

ROHACELL		31			51			71		
Storage temp.	°C	100	120	160	100	120	160	100	120	160
	(°F)	(212)	(248)	(320)	(212)	(248)	(320)	(212)	(248)	(320)
Change in weight	%	0	-0.2	-1.6	-0.2	-0.6	-2.5	-0.3	-0.9	-2.9
Change in length	%	0	-0.2	-1.2	0	-0.4	-1.3	-0.2	-0.4	-1.5
Change in volume	%	-0.1	-0.2	-2.7	-0.1	-1.1	-3.7	-0.5	-1.3	-2.0

Linear thermal expansion

The linear thermal expansion of ROHACELL is unusually low for a plastic material.
Coefficient of linear thermal expansion of ROHACELL 31, 51, 71 at various temperatures are as follows:

Temperature °C (°F)	ROHACELL 31 K^{-1} (in./in. °F)	ROHACELL 51 K^{-1} (in./in. °F)	ROHACELL 71 K^{-1} (in./in. °F)
− 150 (− 238)	0.000025 (0.000016)	0.000024 (0.000015)	0.000030 (0.000019)
− 100 (− 148)	0.000025 (0.000016)	0.000024 (0.000015)	0.000030 (0.000019)
− 50 (− 58)	0.000028 (0.000018)	0.000027 (0.000017)	0.000030 (0.000019)
0 (+ 32)	0.000030 (0.000019)	0.000030 (0.000019)	0.000032 (0.000020)
+ 20 (+ 68)	0.000037 (0.000023)	0.000033 (0.000021)	0.000035 (0.000022)

The expansion coefficients are distinctly lower than those of other rigid foams, and the values at very low temperatures in particular are similar to those of metals and fibre-reinforced laminates, making the stress-deformation behavior of sandwich systems very useful.

b 2

Coefficient of thermal conductivity

The coefficients of thermal conductivity of ROHACELL grades differ only slightly; they are within the ranges given in the table below for different temperatures. The values were determined with aged specimens whose cells contained essentially only air rather than propellant gas. They are therefore stable, ultimate values which no longer rise under normal conditions.

Coefficients of heat conductivity of
ROHACELL 31, 51, 71 at different temperatures

Temperature °C	(°F)	ROHACELL 31, 51, 71 W/mk	(BTU in./ft²h°F)
– 160	(– 256)	0.015 – 0.019	(0.104 – 0.132)
– 100	(– 148)	0.019 – 0.021	(0.132 – 0.146)
– 40	(– 40)	0.023 – 0.028	(0.159 – 0.194)
+ 20	(+ 68)	0.028 – 0.034	(0.194 – 0.234)
+ 80	(+ 176)	0.035 – 0.041	(0.243 – 0.284)
+ 140	(+ 284)	0.042 – 0.048	(0.291 – 0.333)

Specific heat

The specific heat depends on the conditioning circumstances of the specimens because the residual moisture content and other factors may produce considerable differences in the values. ROHACELL was preconditioned in vacuum for 16 hours at 70 °C (158 °F).

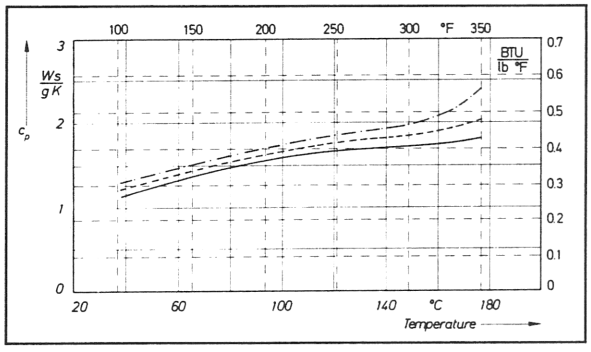


Fig. 4: Specific heat of ROHACELL 31 (–), 51 (---), 71 (–·–), conditioned in vacuum for 16 h/70 °C (158 °F).

Material behavior at elevated temperatures

The illustrations show the tensile, compressive and flexural strengths, moduli of elasticity and shear of ROHACELL as a function of temperature.
In the absence of mechanical stress ROHACELL can be used up to 180 °C (356 °F) and for brief periods even up to 200 °C (392 °F).
Under prolonged static stress the possibility of creep (time-dependent deformation under static load) must be born in mind. This becomes more pronounced as the second order transition temperature is approached. See b16.

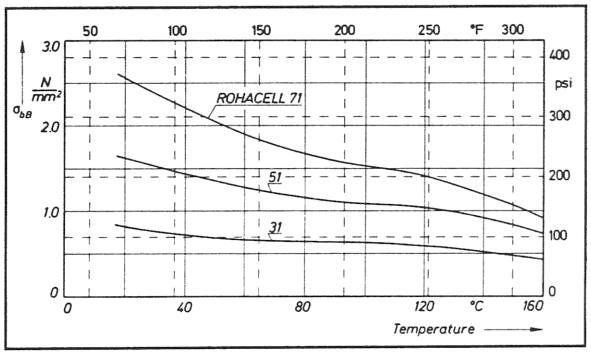


Fig. 7: Flexural strength (ASTM D 790-66) as a function of temperature

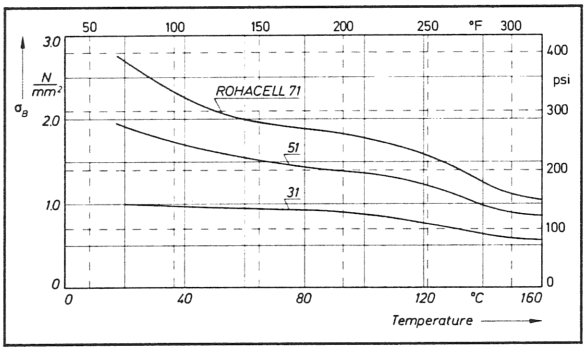


Fig. 5: Tensile strength (ASTM D 638-68) as a function of temperature

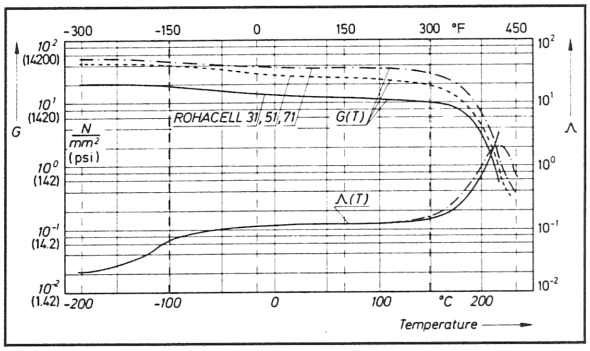


Fig. 8: Shear modulus G and mechanical damping Λ (ASTM D 2236-69) as a function of temperature

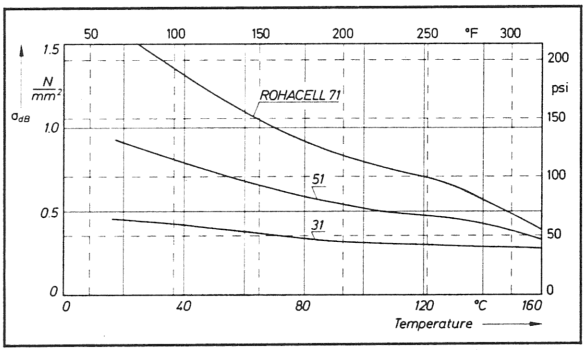


Fig. 6: Compressive strength (ASTM D 1621-64) as a function of temperature

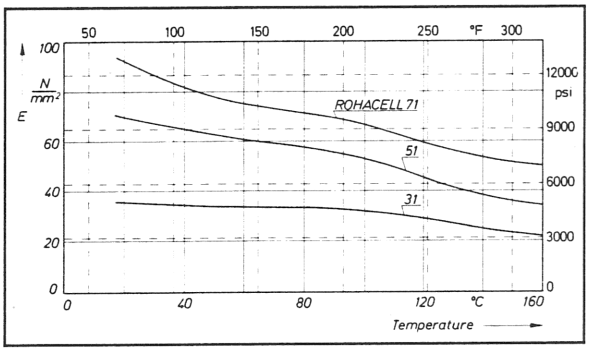


Fig. 9: Modulus of elasticity (ASTM D 638-68) as a function of temperature

Annealing of ROHACELL

The material behavior of ROHACELL, especially at elevated temperatures, can be greatly improved by annealing. For the sake of better understanding let us once more briefly consider the manufacture of ROHACELL.

Polymethacrylimide is formed during hot foaming of methacrylic acid – methacrylonitrile copolymer sheets. This reaction depends on the foaming temperature and time. Given the same foaming periods ROHACELL 71 foams at a lower temperature than ROHACELL 51 or ROHACELL 31. The imide formation reaction has, consequently, progressed furthest with ROHACELL 31. The material behavior at higher temperatures is crucially affected by the proportion of imide.

Let us explain this point by taking ROHACELL 31 as the example. The diagram below shows the shear modulus-temperature function and the mechanical damping of ROHACELL 31 which has not been subjected to any heat treatment after foaming, and also that of ROHACELL 31 which has been annealed for 2100 h at 200 °C (392 °F). The increase in the shear modulus and mech. damping, and the rise in the softening range, is a consequence of the reactions which continue during annealing. There is no observable drop in mechanical properties, cf. the table. The higher modulus of elasticity and the 25 °C (77 °F) higher heat distortion temperature are another expression of the reactions which have taken place.

b 3

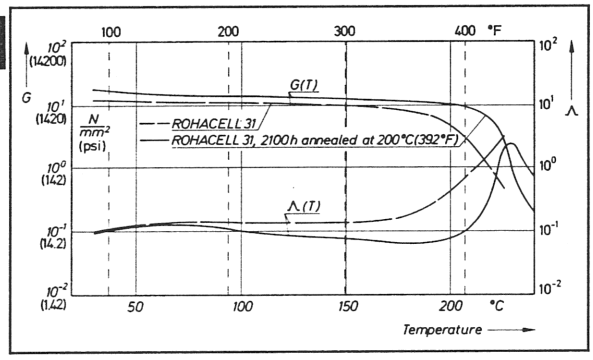


Fig. 10: Shear modulus G and mechanical damping Λ as a function of temperature. ROHACELL 31, annealed for 2100 h at 200 °C (392 °F).

Properties of annealed and unannealed ROHACELL 31

Properties[1]	Units	ROHACELL 31 not annealed	ROHACELL 31 annealed at 2100 h 200 °C (392 °F)	Standard
Gross density	kg/m³ (lbs/ft³)	30 (1.9)	30 (1.9)	ASTM D 1622-63
Tensile strength	N/mm² (psi)	1.1 (156)	1.0 (142)	ASTM D 638-68
Elongation at break	%	3.6	3.9	ASTM D 638-68
Compressive strength	N/mm² (psi)	0.4 (57)	0.5 (71)	ASTM D 1621-64
Modulus of elasticity	N/mm² (psi)	36 (5120)	45 (6400)	ASTM D 638-68
Shear modulus	N/mm² (psi)	14 (1991)	16 (2276)	ASTM D 2236-69
Deflection temperature under load	°C (°F)	185 (365)	210 (410)	DIN 53424

[1] Test conditions: 23 °C (73.4 °F), 50 % RH.

This can also be established by compression test at rising temperatures. Weight-loaded specimens which were annealed for various times at 200 °C (392 °F) were then exposed to temperatures which rose by 50 °C/h (122 °F). The inversion at higher temperatures, shown by curves in the diagram, can be clearly associated with the longer annealing times. The fact that the curves rise again is due to post-foaming, when the foaming temperature necessary for the annealed, and therefore more heat resistant material under heat, has been reached.

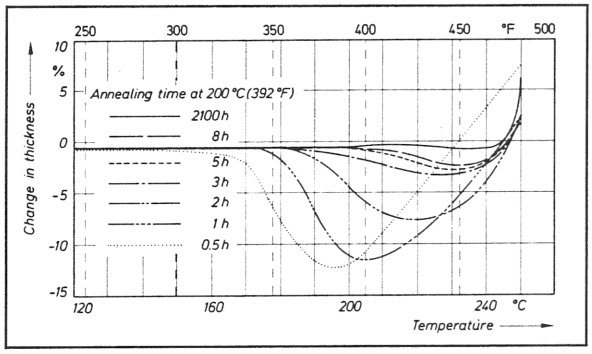


Fig. 11: Heat resistance of ROHACELL 31 (compression test).

In practice, a heat treatment (annealing) of ROHACELL at 200 °C (392 °F) is impossible because this temperature is already within the foaming range. The example is merely given for the sake of a better understanding of the material behavior. Annealing should be done at temperatures between 150 °C (300 °F) and 160 °C (320 °F). Make sure that the material is uniformly heated, because the poor heat conductivity of the foam may cause a great deal of local heat accumulation during annealing. Subsequent cooling must be uniform because otherwise there may be severe distortion.

The following illustration shows how long the different ROHACELL grades must be annealed in order to reach the required, higher heat distortion temperature. The compressive strengths have been plotted at the test temperatures 23 °C (73.4 °F), 80 °C (176 °F), 135 °C (275 °F) and 155 °C (311 °F) as a function of annealing time at an annealing temperature of 160 °C (320 °F). The higher the density, the steeper the rise of the curves. As already mentioned, this is due to the correspondingly higher reaction level through the lower foaming temperatures at higher densities.

Please note that ASTM D 1621-64 is a short-term test and may not be applicable to your process. Material behavior should be determined under actual conditions.

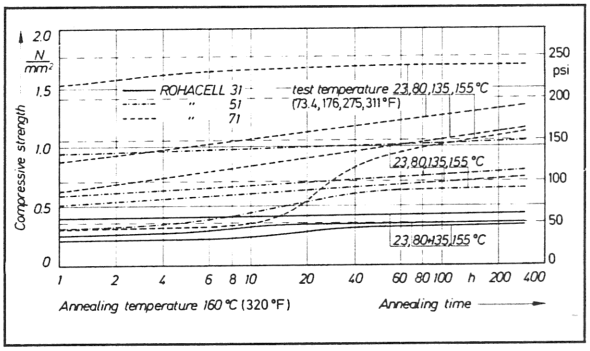


Fig. 12: Compressive strength (ASTM D 1621-64) of annealed ROHACELL 31, 51, 71.

Since the properties of ROHACELL 71 change most clearly on annealing, the shear modulus of this ROHACELL grade has also been plotted as a function of annealing time for the temperatures 20 °C (68 °F) and 150 °C (302 °F). The function is the same for ROHACELL 31 and 51 but the rise in the shear modulus through annealing is not as pronounced as it is for ROHACELL 71.

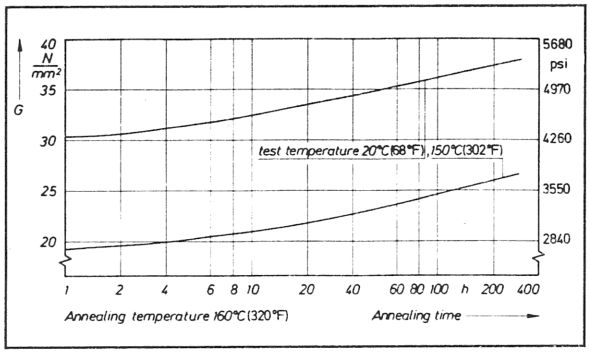


Fig. 13: Shear modulus G (ASTM D 2236-69) of annealed ROHACELL 71.

The tables 'Changes in weight and dimensions of ROHACELL 31, 51, 71 after standing for 30 days at various temperatures (b2)' under the heading 'Thermal properties' show that a contraction in volume occurs during the continuation of the annealing process, but it approaches to an ultimate value after a relatively short annealing time.

The following illustrations will make this clear. Here the lower curves show the contraction in length of ROHACELL 31, 51 and 71 on annealing for a period of up to 46 h at temperatures of 150 °C (302 °F) and 160 °C (320 °F). If annealing is interrupted during this period and the cooled ROHACELL specimens are re-exposed to a temperature of 150 °C (302 °F) or 160 °C (320 °F) another contraction in length is observed. The upper curves represent this further contraction in length after the specimens have been exposed to the appropriate temperature for 46 h.

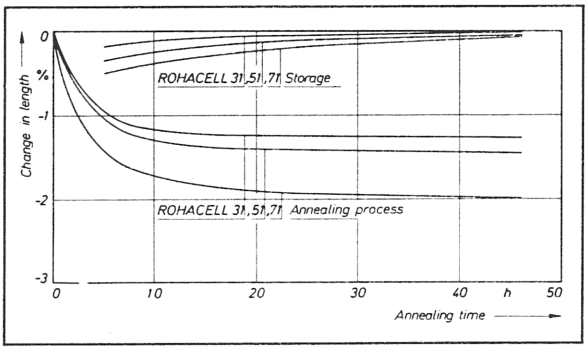


Fig. 14: Changes in length of ROHACELL 31, 51, 71 annealed at 150 °C (302 °F) and after a further 46 hours at 150 °C (302 °F).

Example:
ROHACELL 71 annealed for 10 hours at 150 °C (302 °F). The length contraction amounts to about 1.75 %. If this specimen is again kept at 150 °C (302 °F) for 46 hours after prior cooling, it suffers another contraction in length of about 0.4 % of the original dimension of the unannealed specimen.

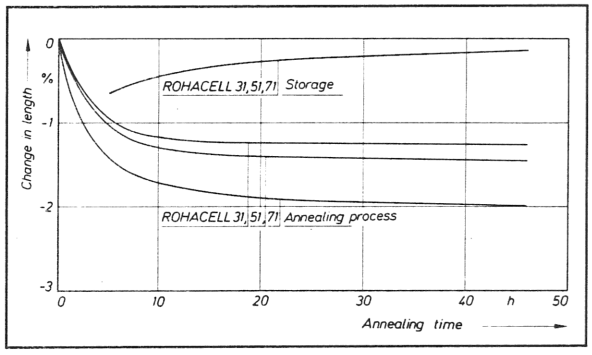


Fig. 15: Changes in length of ROHACELL 31, 51, 71 annealed at 150 °C (302 °F) and after a further 46 hours at 160 °C (320 °F).

b 3

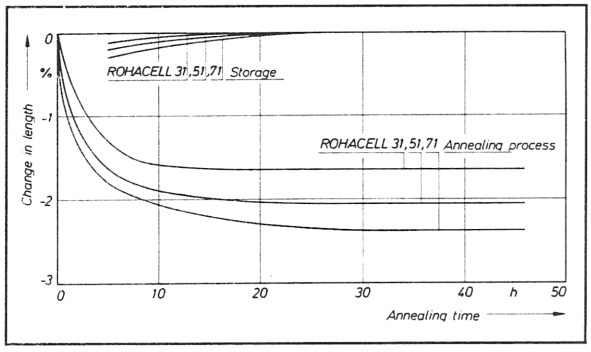


Fig. 16: Changes in length of ROHACELL 31, 51, 71 annealed at 160 °C (320 °F) and after a further 46 hours at 150 °C (302 °F).

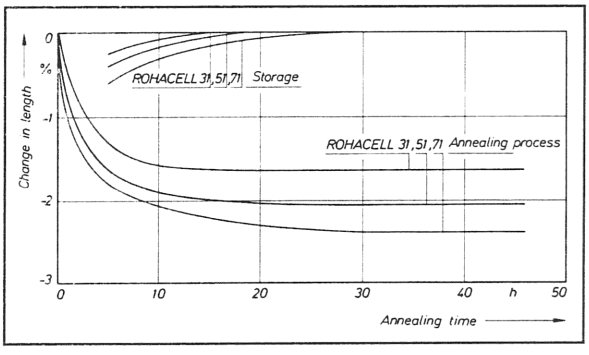


Fig. 17: Changes in length of ROHACELL 31, 51, 71 annealed at 160 °C (320 °F) and after a further 46 hours at 160 °C (320 °F).

b 3

continued

b 3

Figure 18 shows what can, in principle, be achieved by annealing. The graphs show the compressive strengths of unannealed ROHACELL and of ROHACELL annealed for 1200 h at 170 °C (338 °F) against the density at the test temperatures 23 °C (73.4 °F), 150 °C (302 °F) and 180 °C (356 °F). While the imide formation reaction, which continues through annealing, is only slightly noticeable at 23 °C (73.4 °F), the values for 150 °C (302 °F) and 180 °C (356 °F) of the annealed ROHACELL specimens are at a level unsurpassed by other foamed plastics.

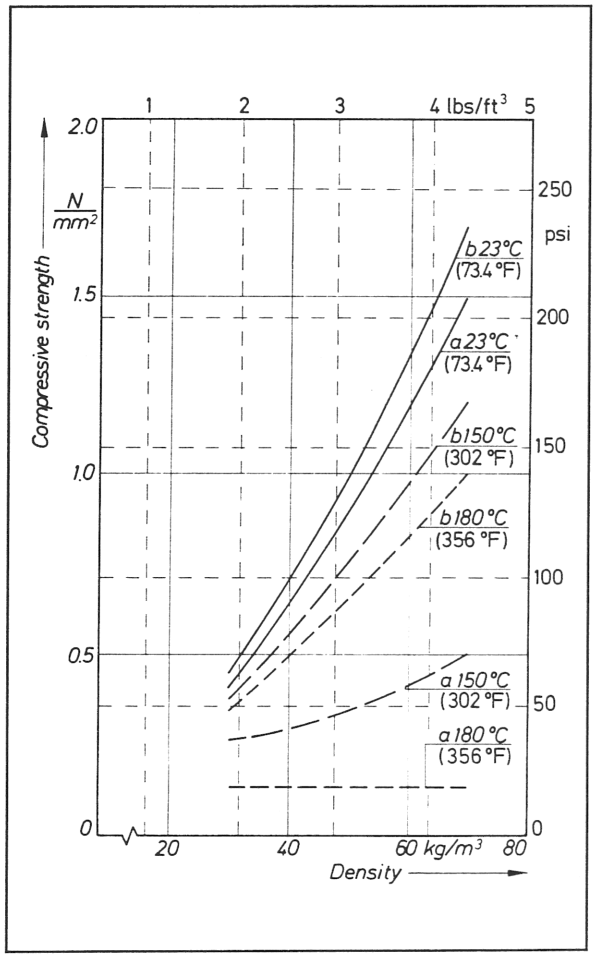


Fig. 18: Compressive strength (ASTM D 1621-64) of annealed (b) and not annealed (a) ROHACELL.

Material behavior at low temperatures

The following table indicates properties of ROHACELL 31, 51 and 71 which permit an estimate for use of these materials at low temperatures. It is of particular interest that the elongation at break is still above 1 % at – 196 °C (– 320.8 °F). For further data also see 'Thermal properties (b2)'.

The small heat expansion and low temperature contraction of ROHACELL is emphasized by the following example:
For a temperature change between room temperature of + 23 °C (+ 73.4 °F) and – 196 °C (– 320.8 °F) the contraction is only 5 to 6 mm/m (.005 in./in. to .006 in./in.). These low values are normally reached only by fibre-reinforced materials, and metals. These results allow the very useful stress-deformation behavior for sandwich systems to be utilized.

Tensile strength, compressive strength and elongation at break of ROHACELL 31, 51, 71 at low temperature

Properties	Units	Test temperatures	ROHACELL 31	51	71	Standard
Tensile strength	N/mm^2 (psi)	23 °C (73.4 °F)	1.0 (142)	1.9 (270)	2.8 (398)	ASTM D 638-68
		– 70 °C (– 94 °F)	1.1 (156)	2.0 (284)	3.0 (427)	
		– 196 °C (– 320.8 °F)	1.1 (156)	2.2 (313)	3.2 (455)	
Compressive strength	N/mm^2 (psi)	23 °C (73.4 °F)	0.40 (56.9)	0.9 (128)	1.5 (213)	ASTM D 1621-64
		– 70 °C (– 94 °F)	0.41 (58.3)	1.0 (142)	1.8 (256)	
		– 196 °C (– 320.8 °F)	0.44 (62.6)	1.1 (156)	2.0 (284)	
Elongation at break	%	23 °C (73.4 °F)	3.5	4.0	4.5	ASTM D 638-68
		– 70 °C (– 94 °F)	2.5	2.7	3.0	
		– 196 °C (– 320.8 °F)	1.4	1.4	1.1	

Water vapor diffusion

Water vapor diffusion resistance factor of ROHACELL 31, 51, 71

Property[1]	Unit	ROHACELL 31	51	71	Standard
H_2O diffusion resistance factor	1	400	650	900	ASTM E 96

b 5

[1] Test conditions: 20 °C (68 °F) and 0 – 85 % relative humidity.

The values given in the table are surprisingly high. Measurements have shown that the water vapor diffusion of ROHACELL above 65 % relative humidity increases with the humidity reading.

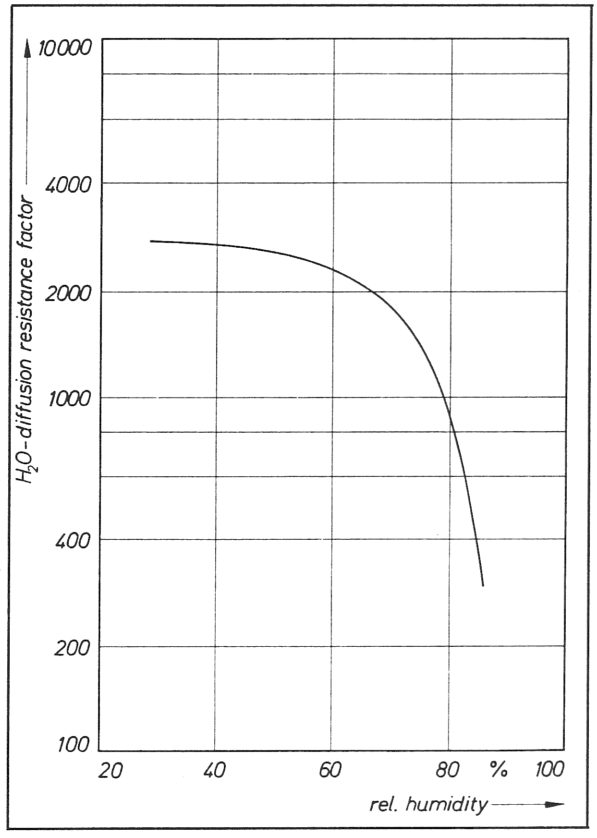


Fig. 19: H_2O diffusion resistance factor of ROHACELL 31.

Water absorption

Polymethacrylimide (PMI) absorbs water in a manner similar to polyamide. The following table shows the sorption equilibria (equilibrium water content with respect to dried samples) of ROHACELL in damp air.

Sorption equilibria of ROHACELL 31, 51, 71 as a function of atmospheric humidity

Atm. humidity % R.H.	ROHACELL 31 Equilibrium water content in vol. %	weight %	ROHACELL 51 vol. %	weight %	ROHACELL 71 vol. %	weight %
15	0.05	1.5	0.07	1.3	0.08	1.2
30	0.09	2.9	0.13	2.6	0.17	2.4
50	0.14	4.7	0.21	4.2	0.25	3.6
65	0.18	6.0	0.25	5.0	0.30	4.3
98	0.59	19.5	0.88	17.4	1.1	15.5

The following table illustrates the increase in weight and change in volume of test specimens after 50 days of complete water immersion. These values show that despite the relatively high water absorption, the dimensional stability is satisfactory. Shrinkage of the samples is only observed after prolonged immersion at water temperatures above 50 °C (122 °F).

Water absorption and volume change of ROHACELL 31, 51, 71 after 50 days water immersion

Property		Unit	ROHACELL 31	51	71
H_2O absorption at	20 °C (68 °F)	vol. %	13	15	16
	50 °C (122 °F)	vol. %	18	23	26
Vol. increase on water immersion					
	20 °C (68 °F)	vol. %	< 1	< 2	< 3
	50 °C (122 °F)	vol. %	< 2	< 2	< 3

The following illustration shows that, irrespective of the period of water immersion, the compressive strength of ROHACELL settles to a constant value.

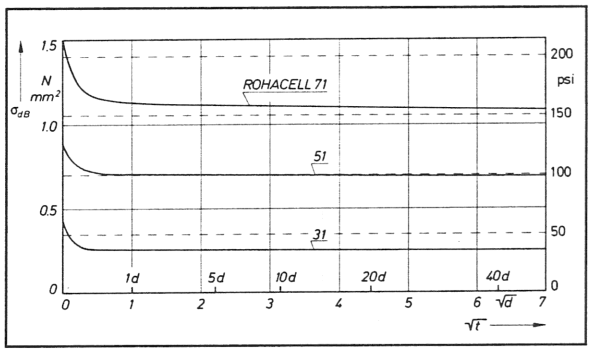


Fig. 20: Compressive strength (ASTM D 1621-64) of ROHACELL on water immersion as a function of time.

Water immersion tests on sandwich structures over 40 months

These tests are described in more detail under the heading 'The properties of ROHACELL P 170 and P 190 (c2)'. Since these products are chemically identical with ROHACELL 31, 51 and 71 the results may also appropriately be applied to the lower densities.

Material behavior upon simultaneous exposure to moisture and heat

b 7

Even when ROHACELL is kept for a prolonged period at 100 % rel. humidity and 70 °C (158 °F) the compressive strength, to take one example of physical properties, is only slightly affected. When the specimen was subsequently kept under normal conditions (23 °C, 73.4 °F, 50 % R.H.), the original values are recovered. The table also gives the changes in weight and volume under these conditions with respect to the original weight and volume.

Compressive strength of ROHACELL after 500 h at 70 °C (158 °F) and 100 % R.H.

Material	change in weight (weight %)	(vol. %)	volume change (vol. %)	compressive strength (N/mm^2)	(psi)
ROHACELL 31					
A	–	–	–	0.40	(56.9)
B	4.4	0.13	– 4.1	0.39	(55.5)
C	1.8	0.06	– 5.2	0.39	(55.5)
D	0.7	0.03	– 5.5	0.39	(55.5)
ROHACELL 51					
A	–	–	–	0.89	(127)
B	4.1	0.20	– 2.8	0.79	(112)
C	1.9	0.09	– 3.7	0.85	(121)
D	1.0	0.05	– 4.3	0.89	(127)
ROHACELL 71					
A	–	–	–	1.5	(213)
B	3.8	0.27	– 2.3	1.3	(185)
C	1.7	0.13	– 2.9	1.4	(199)
D	1.2	0.10	– 3.0	1.5	(213)

Test conditions
A = material as supplied
B = after 500 h at 70 °C (158 °F) and 100 % R.H.
C = as B after standing for another 500 h in a standard climate at 23 °C (73.4 °F) and 50 % R.H.
D = as B after standing in a standard climate at 23 °C (73.4 °F) and 50 % R.H. until approx. constant weight

Electrical properties

Electrical properties of ROHACELL 31, 51, 71

Property	Test conditions	Units	ROHACELL 31	51	71
Dielectric constant	20 °C (68 °F)/ 2.8 GHz	1	1.04	1.07	1.10
Dissipation factor	20 °C (68 °F)/ 2.8 GHz	1	6×10^{-4}	8×10^{-4}	10×10^{-4}
Surface resistance	23 °C (73.4°F)/ 50 % R.H.	Ohm	2×10^{13}	9×10^{12}	5.5×10^{12}

The excellent dielectric values of ROHACELL are among those which are decisive for the use of this material for radomes and antenna engineering.

The moisture pick-up of ROHACELL without skins does not really influence the remarkable specific properties of ROHACELL in antenna applications. The water molecules have been shown to be fixed in the imide compounds and are not able to oscillate. When ROHACELL is covered with skins, the skin material is of more influence to the properties of the antenna than the ROHACELL itself. The change of the antenna properties by water absorption of the skins also must be taken into account. While the water molecules may oscillate in the skin, the ROHACELL core precludes this from occurring.

Gas permeability

The test method for the gas permeability of ROHACELL is based on a measurement of the rise in pressure commonly used in vacuum technology for determining leak rates.
By measuring the pressure rise on the side evacuated to 1.33 x 10^{-2} mbar the values were determined with 6 mm (.236 in.) thick samples.

Gas permeability of ROHACELL 31, 51, 71

Test temperature °C (°F)	Gas permeability $\frac{\text{mbar dm}^3}{\text{sec cm}^2}$
23 (73.4)	2×10^{-7} – 2.7×10^{-7}
– 196 (– 320.8)	9×10^{-9} – 16 $\times 10^{-9}$

b 9

Degassing behavior

ROHACELL in satellite engineering is usually pre-annealed to prevent possible changes in dimensions (see also 'Material behavior at elevated temperatures (b3)'). The degassing behavior of ROHACELL 31, 51 and 71 after annealing for 17 h at 150 °C (302 °F) is shown in the table. After annealing, the specimens were preconditioned at 20 °C (68 °F) and 65 % R.H. for a minimum of 24 h. The degassing test took place in a 6.65 x 10^{-6} mbar vacuum and a temperature of 125 °C (257 °F), for a period of 24 h. After removing and cooling the specimens (about 1/2 h), the difference in weight (Test A) was determined. Then the specimens were kept for at least 24 h at 20 °C (68 °F) and 65 % R.H. and the weight difference (Test B) was redetermined.

The media capable of condensing under these conditions were, during the test, collected on a mirror kept at a constant temperature of 25 °C (77 °F); no condensation deposited on the mirror during tests with annealed ROHACELL 31, 51 and 71.

Degassing of annealed ROHACELL 31, 51, 71

ROHACELL	Weight loss % Test A	Test B
31	5.0	1.8
51	5.0	1.9
71	4.3	1.8

The tests with ROHACELL 31 were also carried out with unannealed specimens. The values were about 5 % above the values for ROHACELL 31 in the above table. A condensate of about 0.05 % by wt. deposited on the mirror.

Material behavior upon exposure to radioactive radiation

Compression test specimens 50 x 50 x 30 mm^3 (2 x 2 x 1.2 $in.^3$) and flexural test specimens 100 x 10 x 10 mm^3 (4 x .4 x .4 $in.^3$) were irradiated with a dose of 1.5 x 10^5 rad (Si) and 10^7 rad (Si) from a cobalt 60 source. There was no significant decrease in the tested properties up to a dose of 1.5 x 10^5 rad (Si).

Compression and flexural tests on nonirradiated and irradiated ROHACELL

ROHACELL	Compressive strength N/mm^2 (psi)	Flexural strength N/mm^2 (psi)	Deflection at fracture mm (in.)	Force at 2 mm (.08 in.) deflection N (p)
31	0.39 (55)	0.72 (102)	5.5 (.22)	3.3 (.73) nonirradiated
	0.38 (54)	0.71 (101)	5.4 (.21)	3.4 (.74) irradiated up to 1.5 x 10^5 rad (Si)
	0.33 (47)	0.49 (70)	2.8 (.11)	3.7 (.80) irradiated up to 10^7 rad (Si)
51	0.86 (122)	1.5 (213)	5.6 (.22)	6.4 (1.4) nonirradiated
	0.84 (119)	1.4 (199)	5.5 (.22)	6.4 (1.4) irradiated up to 1.5 x 10^5 rad (Si)
	0.76 (108)	1.0 (142)	2.6 (.10)	7.6 (1.7) irradiated up to 10^7 rad (Si)
71	1.5 (213)	2.4 (341)	6.0 (.24)	11.0 (2.4) nonirradiated
	1.5 (213)	2.3 (329)	5.8 (.23)	11.2 (2.4) irradiated up to 1.5 x 10^5 rad (Si)
	1.3 (185)	1.8 (256)	2.5 (.10)	12.0 (2.6) irradiated up to 10^7 rad (Si)

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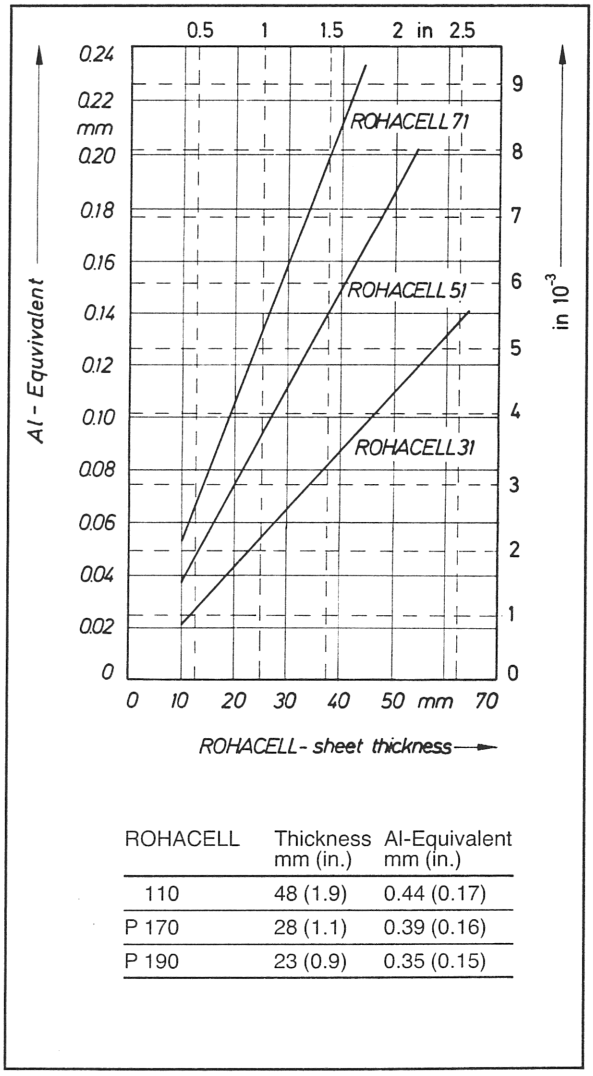
Compression test: specimen 50 x 50 x 30 mm^3 (2 x 2 x 1.2 $in.^3$), feed rate 5 mm/min (.2 in./min)

Flexural test: specimen 100 x 10 x 10 mm^3 (4 x .4 x .4 $in.^3$), feed rate 5 mm/min (.2 in./min) distance between supports 80 mm (3.1 in.)

Irradiated with a cobalt 60 source

X-ray transmission



ROHACELL	Thickness mm (in.)	Al-Equivalent mm (in.)
110	48 (1.9)	0.44 (0.17)
P 170	28 (1.1)	0.39 (0.16)
P 190	23 (0.9)	0.35 (0.15)

Aluminium-equivalent measurements were carried out with 100 kV on various ROHACELL specimens. The graph shows curves measured with the ROHACELL grades 31, 51 and 71. Only the given readings for the indicated thicknesses were measured for ROHACELL 110, P 170 and P 190.

Fig. 21: X-ray transmission of RC (100 kV)

Chemical resistance

Among the outstanding characteristics of ROHACELL is its resistance to organic solvents. This is equally true for benzene, xylene and styrene monomer, and for the usual paint and adhesives solvents, petroleum constituents and most other industrial solvents. ROHACELL does not resist alkaline media.

Resistance table for ROHACELL 31, 51, 71

At 20 °C (68 °F)			
Acetone	+	Paint solvent I*	+
Benzene	+	Paint solvent II*	+
Carbon tetrachloride	+	Petrol ether	+
Dibutyl phthalate	(+)	Soda solution (5 %)	–
Diesel fuel	+	Sulphuric acid (10 %)	+
Ether	+	Super petrol	+
Ethyl acetate	+	Styrene	+
Glacial acetic acid	–	Tetrahydrofuran	–
Isopropyl alcohol	+	Toluene	+
Methyl alcohol	–	Trichloroethylene	+
Methyl isobutyl ketone	+		

* Federal Specification TT-T-266 b October 1959

At the boiling point		
Benzene	(80 °C) (176 °F)	+
Carbon tetrachloride	(77 °C) (171 °F)	+
Chlorobenzene	(132 °C) (270 °F)	–
O-Dichlorobenzene	(180 °C) (356 °F)	–
Trichloroethylene	(88 °C) (190 °F)	+
Xylene	(139 °C) (282 °F)	+

+ resistant (+) limited resistance – not resistant

This table is also valid for ROHACELL 110.

Bearing in mind the special behavior when hot, this table also holds for ROHACELL P 170 and P 190.

Material behavior upon immersion in various media

In the aviation industry, the resistance of ROHACELL to aviation gasoline, jet fuel, hydraulic oil and phosphate esters is of interest. With respect to the weight changes in the table, it should be noted that the cut, exterior cells of the specimens still retain liquid after removal for weighing, and this results in relatively large weight changes after one day's immersion. When this value increases no further during longer immersion periods, ROHACELL does not absorb liquid. The given values are within the range of the scatter of the measuring error.
The various test media did not affect the compressive strength.

Behavior of ROHACELL to liquids

ROHACELL	immersion in	immersion period (days)	change in weight (weight %)	(vol %)	volume change (vol %)
31	Gasoline (octane 100) at 23 °C (73.4 °F)	1, 7, 28, 63	59, 65, 66, 67	1.8, 2.0, 2.0, 2.0	0. , -0.3, -0.4, -0.3
	Jet fuel JP4 at 23 °C (73.4 °F)	1, 7, 28, 63	32, 36, 31, 30	1.4, 1.5, 1.3, 1.3	0.3, 0.1, -0.6, 0.7
	Hydraulic oil (Mil-H-5606 A) at 23 °C (73.4 °F)	1, 7, 28, 63	30, 44, 41, 46	1.1, 1.7, 1.6, 1.8	0. , 0.2, 1.1, 0.7
	Phosphoric acid ester Skydrol 500 B at 23 °C (73.4 °F)	1, 7, 28, 63	48, 46, 59, 56	1.5, 1.4, 1.8, 1.7	-0.4, -0.5, -1.0, -0.3
	Phosphoric acid ester Skydrol 500 B at 70 °C (158 °F)	1, 7, 28, 63	57, 47, 53, 59	1.8, 1.5, 1.7, 1.9	-0.8, -1.2, -1.7, -1.2
51	Gasoline (octane 100) at 23 °C (73.4 °F)	1, 7, 28, 63	32, 35, 35, 36	1.5, 1.6, 1.6, 1.6	-0.5, -0.5, -0.5, -0.5
	Jet fuel JP4 at 23 °C (73.4 °F)	1, 7, 28, 63	17, 17, 14, 14	1.3, 1.3, 1.1, 1.0	0.3, 0.5, 0.1, 0.1
	Hydraulic oil (Mil-H-5606 A) at 23 °C (73.4 °F)	1, 7, 28, 63	19, 20, 19, 22	1.3, 1.3, 1.3, 1.4	0.1, 0.2, 1.2, 1.0
	Phosphoric acid ester Skydrol 500 B at 23 °C (73.4 °F)	1, 7, 28, 63	24, 21, 26, 27	1.3, 1.1, 1.4, 1.4	-0.5, -0.5, -1.1, -0.3
	Phosphoric acid ester Skydrol 500 B at 70 °C (158 °F)	1, 7, 28, 63	25, 23, 25, 21	1.4, 1.3, 1.4, 1.2	-0.5, -1.0, -1.5, -0.9
71	Gasoline (octane 100) at 23 °C (73.4 °F)	1, 7, 28, 63	21, 21, 21, 21	1.5, 1.5, 1.5, 1.5	0. , -0.2, -0.3, 0.
	Jet fuel JP4 at 23 °C (73.4 °F)	1, 7, 28, 63	13, 12, 10, 10	1.2, 1.1, 0.9, 1.0	0.3, 0.4, -0.2, 0.8
	Hydraulic oil (Mil-H-5606 A) at 23 °C (73.4 °F)	1, 7, 28, 63	15, 15, 14, 15	1.2, 1.2, 1.1, 1.2	0.1, 0.1, 1.0, 0.9
	Phosphoric acid ester Skydrol 500 B at 70 °C (73.4 °F)	1, 7, 28, 63	18, 15, 18, 18	1.2, 1.0, 1.2, 1.2	-0.6, -0.6, -1.1, -0.2
	Phosphoric acid ester Skydrol 500 B at 70 °C (158 °F)	1, 7, 28, 63	17, 14, 15, 15	1.2, 1.0, 1.1, 1.0	-0.8, -1.0, -1.6, -0.9

Fire behavior

ROHACELL burns with a slightly smoky flame. The fumes contain no corrosive decomposition products.

The toxicity of the smoke fumes was determined by the mortality of rats after inhaling the thermal decomposition products of ROHACELL for half an hour; decomposition was according to DIN 53436 E. The decomposition products of ROHACELL are less toxic in the temperature range up to 600 °C (1112 °F) than the decomposition products of pinewood.

From 10 mm (.4 in.) material thickness upwards, the grades ROHACELL 31, 51 and 71 are 'normally ignitable' (class B 2) within the meaning of DIN 4102 and do not count as dripping while burning. According to ASTM D 1692-59 T, they are classified as 'Burning by this Test'. The burning rate differs from grade to grade and depends on the material thickness. For ROHACELL 51, 10 mm (.4 in.) thick, it amounts to 2.4 cm/min (.9 in./min).

When provided with suitable skins, sandwich parts not covered at the edges meet the conditions of FAR, paragraph 25.853 (a) and (b). The specifications of the Airbus Industrie for fume density and toxicity of the fumes are also met.

According to VDE 0471-3 (incandescent wire method), the ignition temperature of ROHACELL 51 is 710 °C (1310 °F) when the specimen is 5 mm (.2 in.) thick.

The calorific value of ROHACELL, measured according to DIN 51708, is about 26000 $\frac{Ws}{g}$ ($2817 \times 10^3 \frac{cal}{pound}$).

The LOI (Limiting Oxygen Index) of ROHACELL 31, 51 and 71 is 19 to 20.

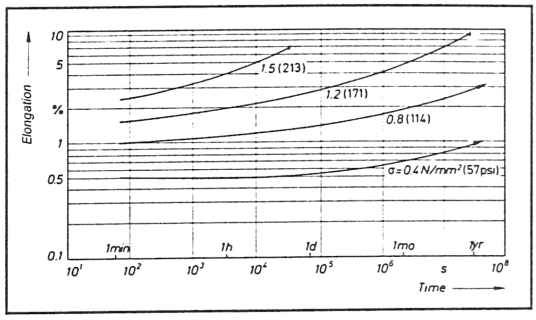


Fig. 24: Creep rupture strength of ROHACELL 71 at 23 °C (73.4 °F)

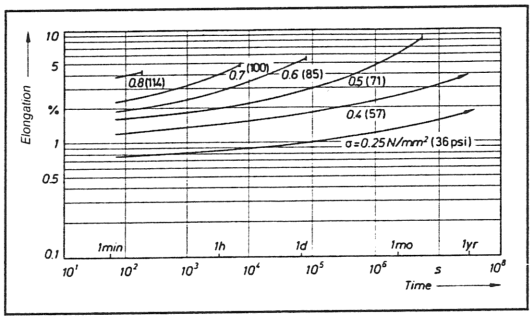


Fig. 22: Creep rupture strength of ROHACELL 31 at 23 °C (73.4 °F)

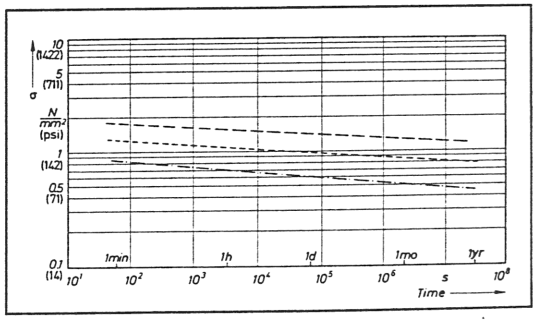


Fig. 25: Creep rupture strength of ROHACELL 31 (–·–), 51 (---) and 71 (––) at 23 °C (73.4 °F)

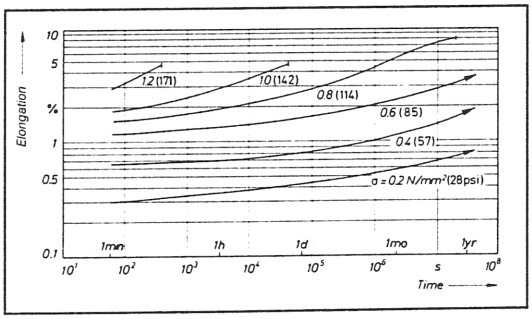


Fig. 23: Creep rupture strength of ROHACELL 51 at 23 °C (73.4 °F)

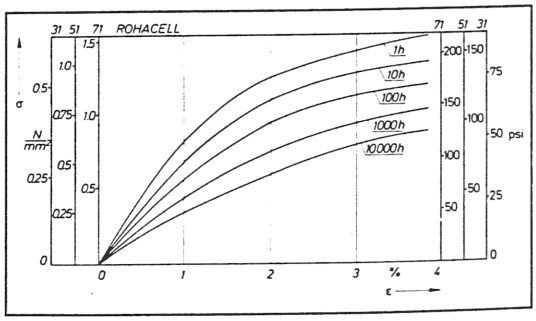


Fig. 26: Isochronous stress-elongation diagram of ROHACELL 31, 51 and 71 at 23 °C (73.4 °F)

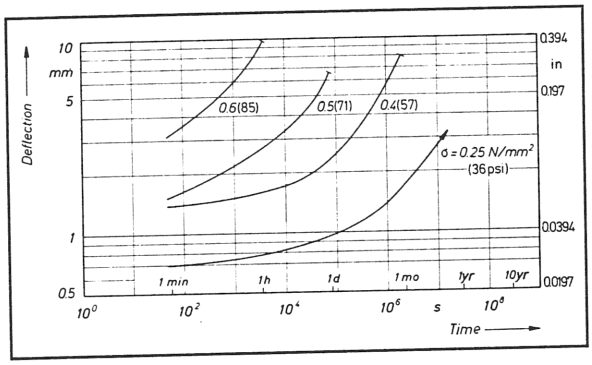


Fig. 27: Creep-deflection test with ROHACELL 31 at 23 °C (73.4 °F)

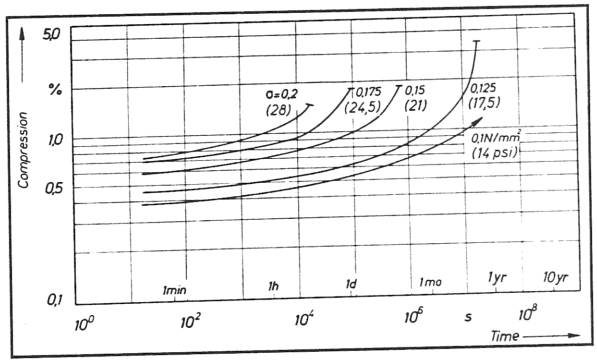


Fig. 30: Creep-compression test with ROHACELL 31 at 23 °C (73.4 °F)

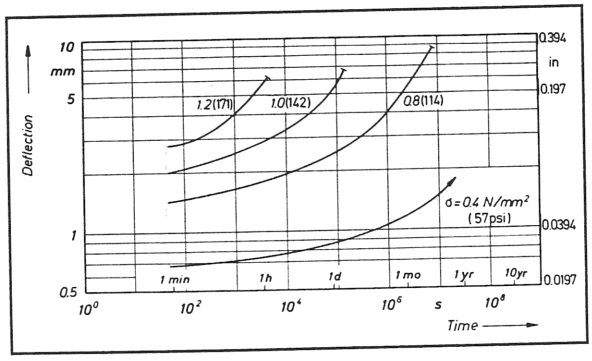


Fig. 28: Creep-deflection test with ROHACELL 51 at 23 °C (73.4 °F)

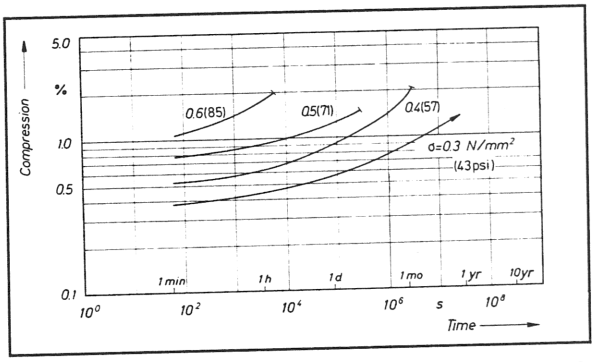


Fig. 31: Creep-compression test with ROHACELL 51 at 23 °C (73.4 °F)

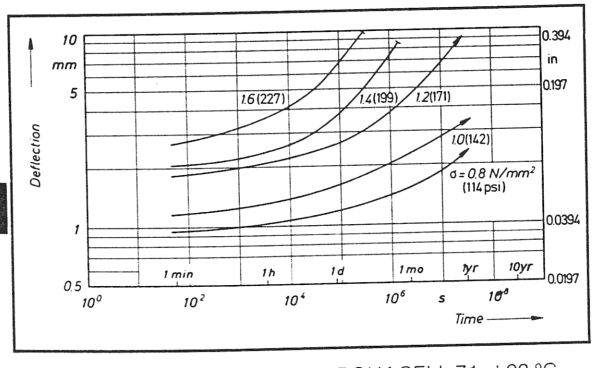


Fig. 29: Creep-deflection test with ROHACELL 71 at 23 °C (73.4 °F)

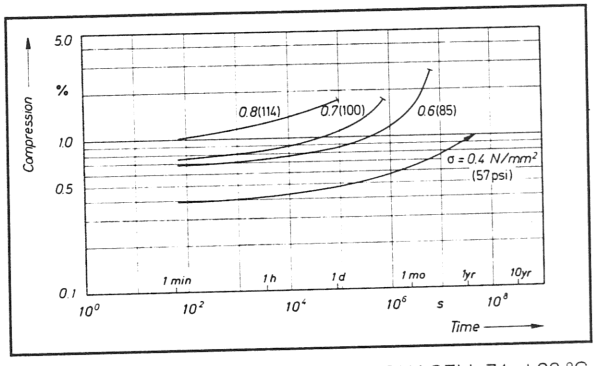


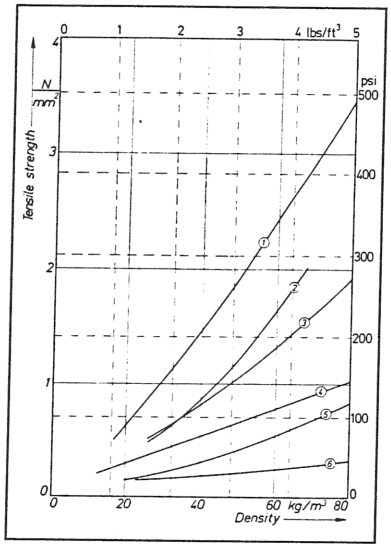
Fig. 32: Creep-compression test with ROHACELL 71 at 23 °C (73.4 °F)

The majority of the values for the following graphs are derived from our own measurements. However, comprehensive literature values were also included so as to be able to form the best possible averages for the different makes of the various foam plastics. Neither the composition nor the manufacture of the types of foam plastics included in the comparison is uniform. As a result, there may be differences from the given values, depending on the make. The properties are not rated. It is only intended to show where ROHACELL is to be classified.

Comparison with other foam plastics

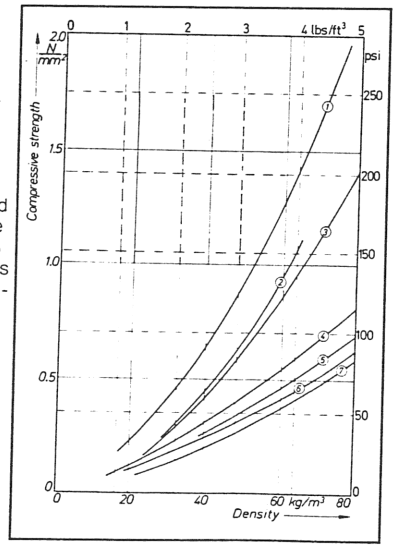
Explanation of the abbreviations
The foam plastics consist of:
PS = polystyrene
PVC = polyvinyl chloride
PU = polyurethane
PF = phenolformaldehyde

Fig. 33: Tensile strength according to ASTM D 638-68 of various rigid foams as a function of density at 20 °C (68 °F)



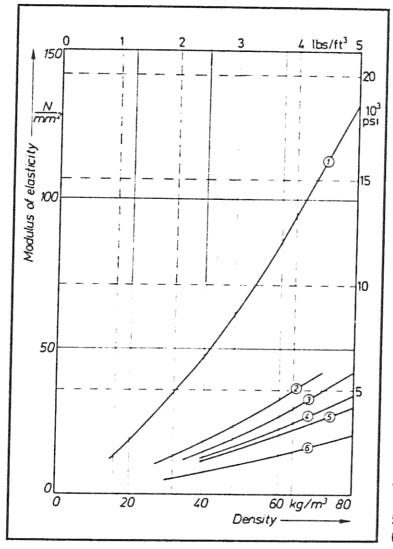
1 = ROHACELL
2 = PS (extrusion)
3 = PVC (cross-linked)
4 = PS (foamed in a mold)
5 = PUR
6 = PF

Fig. 34: Compressive strength according to ASTM D 1621-64 of various rigid foams as a function of density at 20 °C (68 °F). For PS foamed in a mold the compressive strength at 10 % compression was included for comparison's sake.



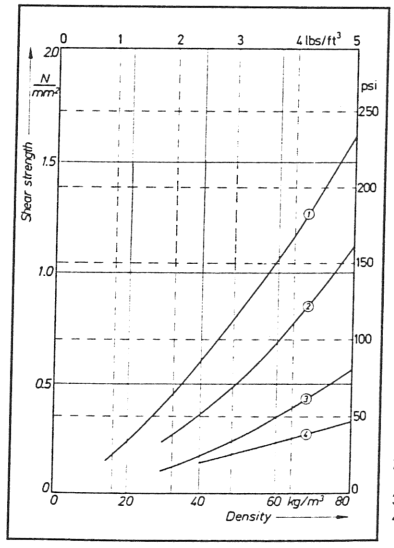
1 = ROHACELL
2 = PS (extrusion)
3 = PVC (cross-linked)
4 = PS (foamed in a mold)
5 = PVC (not cross-linked)
6 = PF
7 = PUR

Fig. 35: Modulus of elasticity according to ASTM D 638-68 of various rigid foams as a function of density at 20 °C (68 °F)



1 = ROHACELL
2 = PS (extrusion)
3 = PVC (cross-linked)
4 = PVC (not cross-linked)
5 = PF
6 = PUR

Fig. 36: Shear strength according to ASTM C 273-61 of various rigid foams as a function of density at 20 °C (68 °F)



1 = ROHACELL
2 = PVC (cross-linked)
3 = PUR
4 = PVC (not cross-linked)

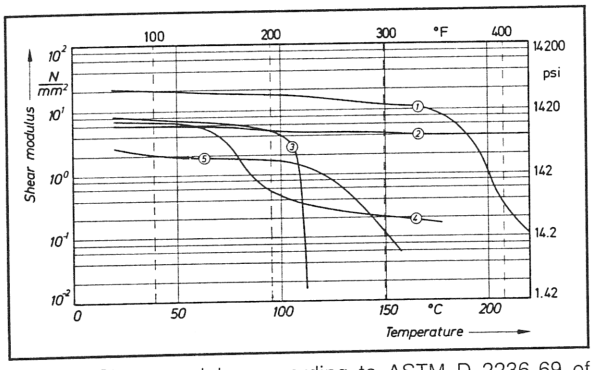


Fig. 37: Shear modulus according to ASTM D 2236-69 of various rigid foams with a density of 40 kg/m³ (2.5 lbs/ft.³) as a function of temperature

1 = ROHACELL
2 = PF
3 = PS (foamed in a mold)
4 = PVC (cross-linked)
5 = PUR

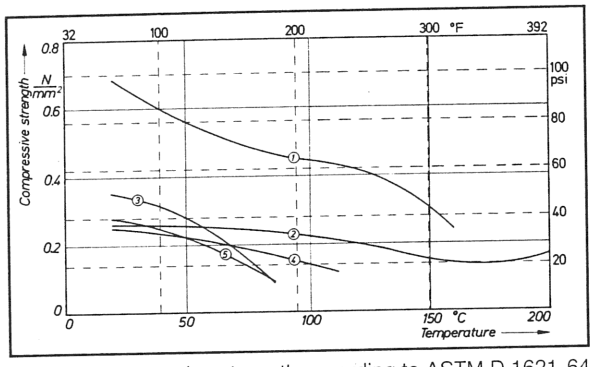


Fig. 38: Compressive strength according to ASTM D 1621-64 of various rigid foams with a density of 40 kg/m³ (2.5 lbs/ft³) as a function of temperature. For PS foamed in a mold the compressive strength at 10 % compression was included for the sake of comparison.

1 = ROHACELL
2 = PF
3 = PVC (cross-linked)
4 = PUR
5 = PS (foamed in a mold)

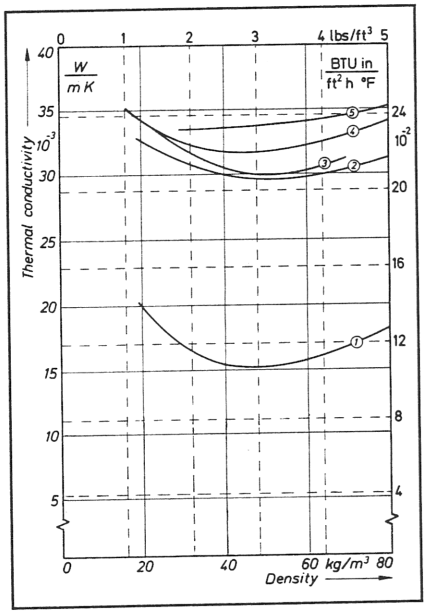
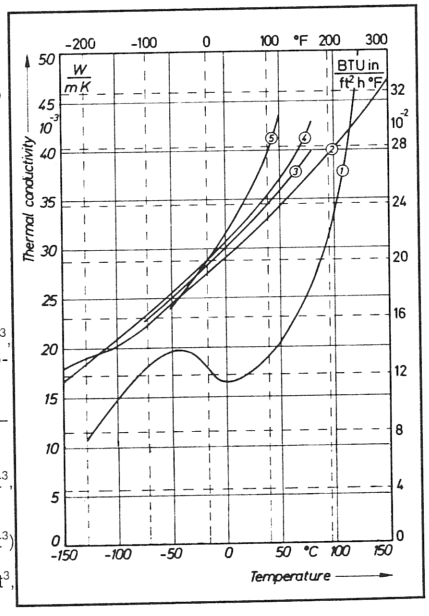


Fig. 40: Coefficient of thermal conductivity according to ASTM C 177-63 of various rigid foams as a function of density.

1 = PUR (foamed with Fluorotrichloromethane)
2 = PF
3 = ROHACELL
4 = PS (foamed in a mold)
5 = PUR (foamed with CO_2)

Fig. 39: Coefficient of thermal conductivity according to ASTM C 177-63 of various rigid foams as a function of temperature.



1 = PUR (Density 40 kg/m³-2.5 lbs/ft³, foamed with Fluorotrichloromethane)
2 = ROHACELL (Density 35 kg/m³–2.2 lbs/ft³)
3 = PS (Density 40 kg/m³-2.5 lbs/ft³, foamed in a mold)
4 = PF (Density 40 kg/m³-2.5 lbs/ft³)
5 = PVC (Density 50 kg/m³-3.1 lbs/ft³, cross-linked)

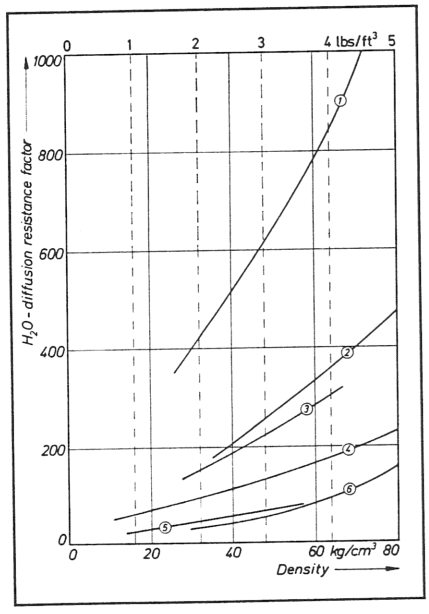


Fig. 41: H_2O diffusion resistance factor of various rigid foams as a function of density, measured in a 0–85 % R.H. humidity gradient.

1 = ROHACELL
2 = PVC (cross-linked)
3 = PS (extrusion)
4 = PS (foamed in a mold)
5 = PUR
6 = PF

Notes on some mechanical tests

1. Tensile strength and elongation at break ASTM D 638-68

If test specimens with small transition radii are used between the specimen holder and the measuring range, the fracture generally occurs at the transition of these radii to the measuring range and lower readings are obtained. The differences are less serious with foam plastics with a lower modulus of elasticity than ROHACELL. Similar considerations apply to the elongation at break.

2. Tensile strength at right angles to the skin

When such measurements are to be carried out, the specimens must be prepared with extreme care in order to get correct results, particularly when the skins of the specimens are hard and brittle or have been applied with hard and brittle adhesives. If the specimens are cut to size with a saw, the skins often tear off the core material at the corners of the specimens so that the real area under tensile stress is lower in the test than the external geometrical dimensions of the specimen. Through the crack that forms between the skin of the adhesive and the core material, an unduly low value is measured owing to the notched effect.

This point must particularly be noted with skins reinforced with a fibrous material. Sawing deflects the fibres and gives rise to many microcracks.

For these tests, round specimens prepared on a lathe are more suitable. For this purpose the circumferential speeds should be high and the feed rate of the turning tool low, particularly while machining the skins. To avoid damaging the specimens in the chuck, they should be held between two wooden panels bonded to abrasive paper for the sake of better force transmission.
The tensile strengths of such specimens with hard and brittle skins or adhesives can reach about 90 % of the tensile strength measured according to ASTM D 638-68, on ROHACELL without a skin. While sawing the specimens to size when the skins or adhesives are flexible, it is advisable to use a backing as an outer support which is sawn together with the specimen to avoid the skin being torn off at the saw slit in the saw bench.

3. Peel test

The peel test serves to determine the resistance of sandwiches to peeling forces which attack at right angles to the skin. During the test the skin is peeled off by reeling it up on a drum. The specific peel moment is measured.
For a comparison of such tests the following points should be observed:
High stresses occur at the peel line. The more flexible the skin, the core material or the adhesive, the more these stresses are relaxed through elastic and/or plastic deformation, and the specific peel moment becomes larger. Considering the high modulus of elasticity of ROHACELL and the skins, for example those made from glassfibre-reinforced epoxy resin prepregs of the kind used in the aircraft industry, lower peel moments are necessarily measured than with sandwich constructions which may, for instance, have core materials made of PVC foam which has a much lower modulus of elasticity. This is always assuming the densities are equal.
When ROHACELL sandwich constructions are compared with honeycomb cores, higher peel moments are again measured with the latter, provided the densities are the same. This is due to the grooves of adhesive or resin at the points of contact with the webs of the honeycomb. In addition, the entire loadbearing material, which is in tension in the peel line, lies in the direction of the load. Given the same density, the material substance of the foam must form the cell walls which go round on all sides. In the case of a honeycomb of the same mass of material, only the vertical walls need be formed which will then necessarily have larger loadbearing cross-sections.

Needling the ROHACELL surface gives an improvement in peel strength since adhesive resin is more deeply anchored in the foam. During peeling, the force is distributed over several cell walls so that higher peel strengths are obtained.
The peel strength can also be considerably raised by first priming the ROHACELL surface or putting in thin, flexible films as shims.

The properties of ROHACELL P 170 and P 190

These ROHACELL grades have very high specific strengths. The cell structure has been oriented by a special method which produces a difference in the strength in the plane of the sheet and at right angles to it. In this way, and depending on the situation in which the ROHACELL sheets are installed, excellent sandwich constructions can be obtained.

For a number of uses in sandwich construction it is therefore reasonable to allow the direction of the principal stress to coincide with the direction of the highest material strength, i.e. to use the sandwich with an upright cell structure.

Here is an example of this technique:

The compacted ROHACELL rigid foams are supplied as sheets. Normally they are bonded with two-component adhesives to a height corresponding to the width of the required sandwich core. Out of the resultant block the cores are sawn at right angles to the glue lines so that their cell structure is vertical when the core is in a horizontal position.

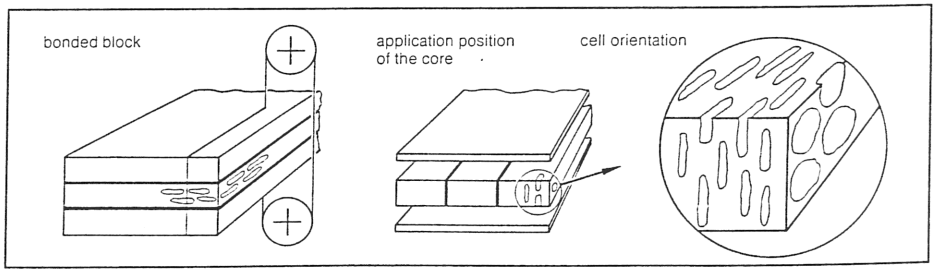
It is not necessary for this technique to be used in every case. If the strength values measured in the molding direction satisfy a certain purpose, the ROHACELL sheets may be used flat.

[1] Test conditions: 23 °C (73.4 °F) and 50 % relative humidity
[2] Measured normally to the plane of the sheet
[3] At elevated temperatures the cell structure begins to lose its orientation

For information on X-ray transmission see, under the appropriate heading, b12. For information on chemical resistance see, under the appropriate heading, b13. Fig. 42 ↓

Physical properties of ROHACELL P 170 and P 190

Properties[1]	Units	ROHACELL P 170	ROHACELL P 190	Standard
Gross density	kg/m³ (lbs/ft³)	170 (10.6)	190 (11.9)	ASTM D 1622-63
Tensile strength	N/mm² (psi)	7.5 (1070)	8.5 (1210)	ASTM D 638-68
Compressive strength	N/mm² (psi)	6.5 (924) (2.8)[2] (398)[2]	7.8 (1110) (3.2)[2] (455)[2]	ASTM D 1621-64
Flexural strength	N/mm² (psi)	10.5 (1490) (10.0)[2] (1420)[2]	12.5 (1780) (12.0)[2] (1710)[2]	ASTM D 790-66
Shear strength	N/mm² (psi)	4.5 (640) (3.0)[2] (427)[2]	5.5 (782) (3.0)[2] (427)[2]	ASTM C 273-61
Modulus of elasticity	N/mm² (psi)	320 (45500)	380 (54000)	ASTM D 638-68
Shear modulus	N/mm² (psi)	120 (17000)	185 (26300)	ASTM D 2236-69
Shear modulus	N/mm² (psi)	88 (12500)	100 (14200)	ASTM C 273-53
Elongation at break	%	5	6	ASTM D 638-68
Deflection temperature under load	°C (°F)	130[3] (266)[3]	130[3] (266)[3]	DIN 53424



C 2

40 months water permeation tests with ROHACELL P 170 in a sandwich structure

For boat building and similar uses, the water penetration behavior into GRP structural sandwich parts is of particular interest when the skin has been damaged, as in a collision.

ROHACELL P 170 with the dimensions 400 x 400 x 28 mm (15.7 x 15.7 x 1.1 in.) was laminated on all sides with glassfibre reinforced polyester resin. The skin system consisted of: mat (450 g/m^2/.09 lbs/ft^2) woven rovings (500 g/m^2/.1 lbs/ft^2), mat (450 g/m^2/.09 lbs/ft^2), woven rovings (500 g/m^2/.1 lbs/ft^2) and mat (450 g/m^2/.09 lbs/ft^2). The laminating resin was a polyester (PALATAL® P 51). The skins were applied manually and cold-cured. Their final thickness was about 5 mm (.2 in.).

In the middle of one of the surfaces a part of the skin with a diameter of 70 mm (2.8 in.) was removed. A tube was placed into this opening and sealed with silicone against the remaining skin. The tube was filled with water to a height of 300 mm (11.8 in.). Since ROHACELL is a foam with closed cells, the penetration of water is purely due to diffusion, a fact which was confirmed by preliminary tests.

After 40 months, the skins were removed and the ROHACELL core examined for water absorption. The places from which the samples were taken are shown in the illustration. The specimens were dried in a vacuum oven at 70 °C (158 °F) and this is how the water content in per cent by weight was determined. The size of each sample was 50 x 50 x 28 mm^3 (2 x 2 x 1.1 in.^{3}). The water content drops very quickly from the center outwards, i.e. even after being kept for 40 months the specimen was not soaked. At a distance of about 150 mm (5.9 in.) from the center of the water tube the material was practically dry.

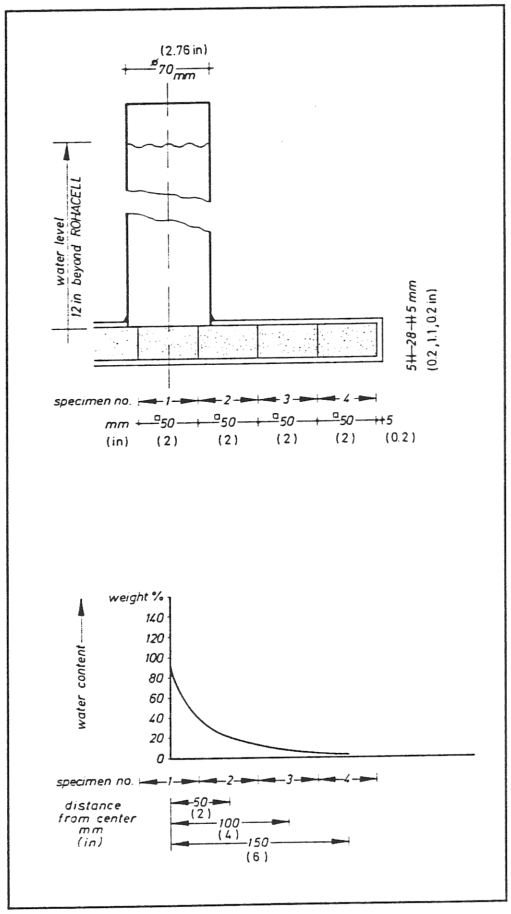


Fig. 43: Sandwich with ROHACELL P 170 stored 40 months

have a symmetrical cross ruled on it consisting of seven horizontal parallel fine lines spaced 12.7 mm (0.5 in.) apart and seven vertical parallel fine lines spaced 12.7 mm (0.5 in.) apart. These lines shall be as fine as it is possible to make them and still have them distinctly visible at a distance of 7.62 m (25 ft). A width of about 1.6 mm (1/16 in.) is suggested.

NOTE 1—An alternative form of target may be preferred, consisting of concentric circles having radii increasing by 25.4 mm (1 in.) from a 25.4-mm (1-in.) radius for the innermost circle, ruled in the center of a piece of white cardboard 0.3 m (1 ft) square. It is suggested that the first circle be ruled with a line thickness of 3.2 mm (⅛ in.), the second with a line thickness of 1.6 mm (1/16 in.), the third with a line thickness of 3.2 mm (⅛ in.), and so on.

5.4 *Supports*—A suitable means of rigidly supporting the projector and the screen.

5.5 *Dark Room*—A slightly darkened or dark room of sufficient length to accommodate the test setup. It has been found that an illumination level of not over 10 footcandles in the room will be satisfactorily dark when an ordinary lantern slide projector is being used.

6. Assembly of Apparatus

6.1 The screen shall be placed 7.62 m (25 ft) from the front lens of the projector and perpendicular to the direction of projection.

6.2 The cross-ruled slide shall be placed in the projector and the projector and its lens system adjusted to throw a sharply defined image of the cross directly on top of the center cross rules on the screen. The light source in the projector shall be adjusted to insure complete filling of the aperture in the projection lens.

NOTE 2—If the alternative form of target is used, the projector shall be adjusted so that the center of the image of the cross falls on the center of the circles.

7. Test Specimen

7.1 The test specimen shall consist of any flat sheet of a transparent plastic.

8. Conditioning

8.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

8.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreements, the tolerances shall be ± 1°C (±1.8°F) and ±2 % relative humidity.

9. Procedure

9.1 Hold the test specimen with its plane perpendicular to the direction of projection and in front of the projector at a distance of approximately 0 to 30 m (12 in.) from the front lens and move so that the entire area inside of a 25.4-mm (1-in.) border around the sheet is surveyed by the beam of light from the projector system. While the specimen is being moved about, observe the screen for movement of the projected image of the cross. Note the maximum amount and nature or frequency of movement of the image.

9.2 After the specimen has been completely surveyed in the position near the projector, move it parallel to and at a distance of 127 mm (5 in.) from the screen. Move the specimen back and forth parallel to the screen and observe any projected images of minor irregularities that are visible on the screen. Then move the specimen to positions 254, 381, or 508 mm (10, 15, or 20 in.) (integer multiples of 127 mm (5 in.)) from the screen until a pattern is observed. Note the maximum distance from the screen at which the specimen can be held without producing a pattern of its minor surface irregularities.

10. Report

10.1 The report shall include the following:

10.1.1 The displacement factor,

10.1.2 The frequency and nature of the shift of the image, and

10.1.3 The pattern distance in an integer multiple of 127 mm (5 in.).

Designation: D 638 – 84

Creep Deflection Standard

Standard Test Method for TENSILE PROPERTIES OF PLASTICS[1]

This standard is issued under the fixed designation D 638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This test method covers the determination of the tensile properties of plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Method D 882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

NOTE 1—A complete metric companion to Test Method D 638 has been developed—D 638 M.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant-rate-of-crosshead-movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with ASTM Method D 229, Testing Rigid Sheet and Plate Materials Used for Electrical Insulation,[2,3] and ASTM Method D 651, Test for Tensile Strength of Molded Electrical Insulating Materials.[3]

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

D 374 Test Methods for Thickness of Solid Electrical Insulation[2,4]

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[2]

D 883 Definitions of Terms Relating to Plastics[2]

D 4066 Specification for Nylon Injection and Extrusion Materials (PA)[5]

E 4 Methods of Load Verification of Testing Machines[5,6]

E 83 Method of Verification and Classification of Extensometers[6]

3. Significance and Use

3.1 This test method is designed to produce

[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D 20.10 on Mechanical Properties.

Current edition approved July 27, 1984. Published September 1984. Originally published as D 638 – 41 T. Last previous edition D 638 – 82a.

[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 10.02.

[5] *Annual Book of ASTM Standards*, Vol 08.03.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development.

3.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

3.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

3.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 4—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

4. Definitions

4.1 Definitions of terms applying to this test method appear in Definitions D 883 and Annex A1.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member. The grips shall be self-aligning, that is, they shall be attached to the fixed and movable member, respectively, in such a manner that they will move freely into alignment as soon as any load is applied, so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.1 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (3/32 in.) apart and about 1.6 mm (1/16 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, this velocity to be regulated as specified in Section 9.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Methods E 4.

NOTE 5—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Methods E 4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.2 *Extension Indicator*—A suitable instrument for determining the distance between two designated points located within the gage length of the test specimen as the specimen is stretched. It is desirable, but not essential, that this instrument automatically record this distance (or any change in it) as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia lag at the specified speed of testing and shall be accurate to ±1 % of strain or better.

NOTE 6—Reference is made to Method E 83.

5.3 *Micrometers*—Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: *(1)* a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), *(2)* a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter, and *(3)* a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.0002 in.) over the entire foot area. Flatness of foot and anvil shall conform to Test Methods D 374, 5.1.3. An optional instrument equipped with a circular contact foot 15.88 ± 0.08 mm (0.625 ± 0.003 in.) in diameter is recommended for thickness measuring of process samples or larger specimens at least 15.88 mm (0.625 in.) in minimum width.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.)

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.)

6.1.3 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

NOTE 7—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2¼ in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

6.3 The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2¼ in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Methods D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C (1.8°F) and ±2 % relative humidity.

7.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreements, the tolerances shall be ± 1°C (1.8°F) and ±2 % relative humidity.

NOTE 8—The tensile properties of some plastics change rapidly with small changes in temperature. Since heat may be generated as a result of straining the specimen at high rates, conduct tests without forced cooling to ensure uniformity of test conditions. Measure the temperature in the reduced section of the specimen and record it for materials where self-heating is suspected.

8. Number of Test Specimens

8.1 Test at least five specimens for each sample in the case of isotropic materials.

8.2 Test ten specimens, five normal to, and five parallel with the principal axis of anisotropy, for each sample in the case of anisotropic materials.

8.3 Discard specimens that break at some obvious fortuitous flaw, or that do not break between the predetermined gage marks, and make retests, unless such flaws constitute a variable to be studied.

NOTE 9—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

9. Speed of Testing

9.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. Rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

9.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5 min testing time.

9.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

10. Procedure

10.1 Measure the width and thickness of rigid flat specimens (Fig. 1) with a suitable micrometer to the nearest 0.025 mm (0.001 in.) at several points along their narrow sections. Measure the thickness of nonrigid specimens (produced by a Type IV die) in the same manner with the required dial micrometer. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Figs. 2 and 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extension indicator.

10.4 Set the speed of testing at the proper rate as required in Section 9, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 10—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad range incremental extensometer or hand rule technique may be needed when such materials are taken to rupture.

11. Calculations

11.1 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (or pounds-force) by the original minimum cross-sectional area of the specimen in square metres (or square inches). Express the result in pascals (or pounds-force per square inch) and report it to three significant figures as "Tensile Strength at Yield" or "Tensile Strength at Break," whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding "Tensile Stress at Yield" or "Tensile Stress at Break" and report it to three significant figures (Annex Note A1.1).

11.2 *Percent Elongation*—If the specimen gives a yield load that is larger than the load at break, calculate "Percent Elongation at Yield." Otherwise, calculate "Percent Elongation at Break." Do this by reading the extension (change in gage length) at the moment the applicable load is reached. Divide that extension by the original gage length and multiply by 100. Report "Percent

Elongation at Yield" or "Percent Elongation at Break" to two significant figures. When a yield or breaking load less than the maximum is present and of interest, it is desirable to calculate and report both "Percent Elongation at Yield" and "Percent Elongation at Break" (Annex Note A1.2).

11.3 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average initial cross-sectional area of the test specimens in the calculations. The result shall be expressed in pascals (or pounds-force per square inch) and reported to three significant figures.

11.4 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.5 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)}$$

where:

s = estimated standard deviation,

X = value of single observation,

n = number of observations, and

$\bar{X}$ = arithmetic mean of the set of observations.

11.6 See Appendix X1 for information on toe compensation.

12. Report

12.1 The report shall include the following:

12.1.1 Complete identifications of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Tensile strength at yield or break, average value, and standard deviation,

12.1.9 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.10 Percentage elongation at yield or break (or both, as applicable), average value, and standard deviation,

12.1.11 Modulus of elasticity, average value, and standard deviation, and

12.1.12 Date of test.

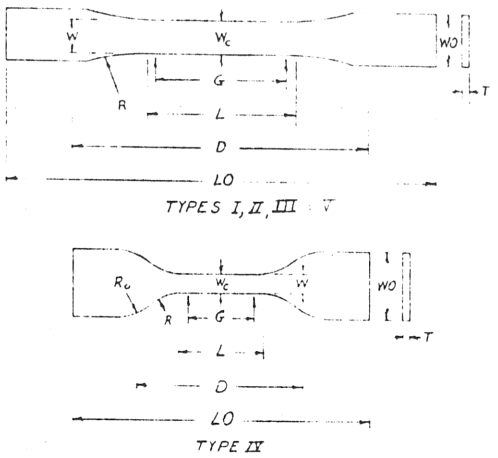
TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min (in./min)		Nominal Strain[C] Rate at Start of Test, mm/mm·min
Rigid and Semirigid	I, II, III rods and tubes	5	(0.2) ± 25 %	0.1
		50	(2) ± 10 %	1
		500	(20) ± 10 %	10
	IV	5	(0.2) ± 25 %	0.15
		50	(2) ± 10 %	1.5
		500	(20) ± 10 %	15
	V	1	(0.05) ± 25 %	0.1
		10	(0.5) ± 25 %	1
		100	(5) ± 25 %	10
Nonrigid	III	50	(2) ± 10 %	1
		500	(20) ± 10 %	10
	IV	50	(2) ± 10 %	1.5
		500	(20) ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 9.2).

[B] See Definitions D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.



Specimen Dimensions for Thickness, T, mm[D]

Dimensions (see drawings)	7 or under		Over 7 to 14 incl.	4 or under		Tolerances
	Type I	Type II	Type III	Type IV[G]	Type V[I]	
W—Width of narrow section[A,B]	13	6	19	6	3.18	±0.5[G,I]
L—Length of narrow section	57	57	57	33	9.53	±0.5[I]
WO—Width over-all, min[E]	19	19	29	19	...	+6.4
WO—Width over-all, min[E]	...	...	...	...	9.53	+3.18
LO—Length over-all, min[F]	165	183	246	115	63.5	no max
G—Gage length[C]	50	50	50	...	7.62	±0.25[I]
G—Gage length[C]	...	...	...	25	...	±0.13
D—Distance between grips	115	135	115	64[H]	25.4	±5
R—Radius of fillet	76	76	76	14	12.7	±1[I]
RO—Outer radius (Type IV)	...	...	...	25	...	±1

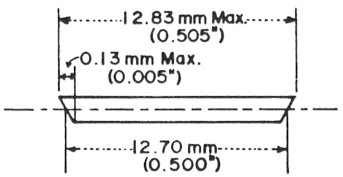
Specimen Dimensions for Thickness, T, in.[D]

Dimensions (see drawings)	0.28 or under		Over 0.28 to 0.55 incl.	0.16 or under		Tolerances
	Type I	Type II	Type III	Type IV[G]	Type V[I]	
W—Width of narrow section[A,B]	0.50	0.25	0.75	0.25	0.125	±0.02[G,I]
L—Length of narrow section	2.25	2.25	2.25	1.30	0.375	±0.02[I]
WO—Width over-all, min[E]	0.75	0.75	1.13	0.75	...	+0.25
WO—Width over-all, min[E]	...	...	...	...	0.375	+0.125
LO—Length over-all, min[F]	6.5	7.2	9.7	4.5	2.5	no max
G—Gage length[C]	2.00	2.00	2.00	...	0.300	±0.010[I]
G—Gage length[C]	...	...	...	1.00	...	±0.005
D—Distance between grips	4.5	5.3	4.5	2.5[H]	1.0	±0.2
R—Radius of fillet	3.00	3.00	3.00	0.56	0.5	±0.04[I]
RO—Outer radius (Type IV)	...	...	...	1.00	...	±0.04

FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

[A] The width at the center W_c shall be plus 0.00 mm, minus 0.10 mm (+0.000 in., −0.004 in.) compared with width W at other parts of the reduced section. Any reduction in W at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[B] For molded specimens, a draft of not over 0.13 mm (0.005 in.) may be allowed for either Type I or II specimens 3.2 mm (0.13 in.) in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:



[C] Test marks or initial extensometer span.

[D] Thickness, *T*, shall be 3.2 ± 0.4 mm (0.13 ± 0.02 in.) for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm (0.55 in.) the specimens shall be machined to 14 ± 0.4 mm (0.55 ± 0.02 in.) in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm (0.55 and 2 in.) approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined and the location of the specimen with reference to the original thickness of the sheet, shall be noted. Tolerances on thickness less than 14 mm (0.55 in.) shall be those standard for the grade of material tested.

[E] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

[F] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[G] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm (0.250 ± 0.002 in.). The dimensions are essentially those of Die C in ASTM Test Method D 412, for Rubber Properties in Tension (*Annual Book of ASTM Standards*, Vols 08.01 and 09.01).

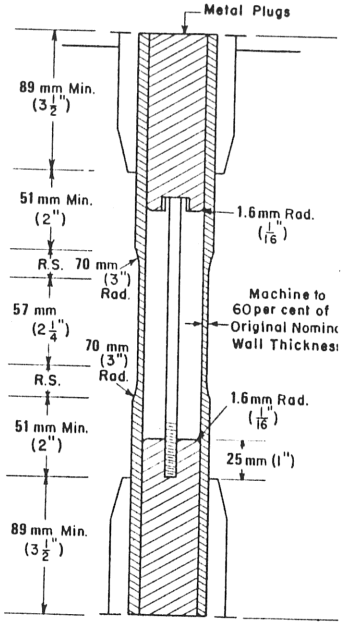
[H] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

[I] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:

W = 3.18 ± 0.03 mm (0.125 ± 0.001 in.),
L = 9.53 ± 0.08 mm (0.375 ± 0.003 in.),
G = 7.62 ± 0.02 mm (0.300 ± 0.001 in.), and
R = 12.7 ± 0.08 mm (0.500 ± 0.003 in.).

The other tolerances are those in the table. Supporting data on the introduction of the L specimen of Test Method D 1822 as the Type V specimen may be obtained from ASTM Headquarters, 1916 Race St., Philadelphia, PA 19103, by requesting RR:D-20-1038.

FIG. 1 *Continued.*



DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, 2R.S.	Total Calculated Min Length of Specim
mm(in.)	mm(in.)	mm(in.)
0.79(1/32)	13.9(0.547)	350(13.80)
1.2(3/64)	17.0(0.670)	354(13.92)
1.6(1/16)	19.6(0.773)	356(14.02)
2.4(3/32)	24.0(0.946)	361(14.20)
3.2(1/8)	27.7(1.091)	364(14.34)
4.8(3/16)	33.9(1.333)	370(14.58)
6.4(1/4)	39.0(1.536)	376(14.79)
7.9(5/16)	43.5(1.714)	380(14.96)
9.5(3/8)	47.6(1.873)	384(15.12)
11.1(7/16)	51.3(2.019)	388(15.27)
12.7(1/2)	54.7(2.154)	391(15.40)

[A] For other jaws greater than 89 mm (3½ in.), the standard length shall be increased by mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (¼ t maximum length of jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens i