Makrolon® 2405 and 2407

- **Polycarbonate (PC)**
- **General purpose grades**
- **Low viscosity**
- **Injection molding**

Short description

Makrolon® 2405:
Global grade; MVR 19 cm³/10 min; General purpose; Low viscosity; Easy release; Injection molding-Melt temperature 280-320 °C; Available in transparent, translucent and opaque colors

Makrolon® 2407:
Global grade; MVR 19 cm³/10 min; General purpose; Low viscosity; UV stabilized; Easy release; Injection molding-Melt temperature 280-320 °C; Available in transparent, translucent and opaque colors

Characterization

The Makrolon® 2405 and 2407 injection molding grades are transparent, easy flowing, linear polycarbonates based on bisphenol A.

These Makrolon® grades are noted for their very good melt flow properties and are thus suitable for the production of moldings with an unfavorable flow length/wall thickness ratio, i.e. for the production of large moldings with thin walls.
Compared with grades that have a high melt viscosity (Makrolon® 28.. and 3...), Makrolon® 2405 and 2407 have a lower level of toughness, but this is still perfectly adequate for a large number of applications.

Abbreviation to DIN EN ISO 1043-1: PC

Designation to DIN EN ISO 7391-1:

Makrolon® 2405:
Thermoplastics ISO 7391-PC,MR,(,,)-18-9

Makrolon® 2407:
Thermoplastics ISO 7391-PC,MLR,(,,)-18-9

These are amorphous thermoplastics which, when injection molded, provide a unique combination of strength, stiffness and hardness, together with toughness and breaking strength. The heat resistance of these Makrolon® grades extends up to 135 °C, depending on the type of stress placed on the component. This, together with the low-temperature impact strength that is sufficient for a large number of applications, means that these grades can be used over a broad temperature range (-100 to +135 °C).

New Makrolon® product nomenclature for food contact applications

When food contact applications are specified, we supply only Makrolon® grades with the final digits 06 or 56. The existing Makrolon® grades with 08 and 58 as the final digits are available only for applications involving medical devices.

Details on this can be found in our Technical Information Sheets.

"Makrolon® 2456"
"Makrolon® 2458"

Delivery form

Granules packed in 25-kg polyethylene sacks, FIBC (flexible intermediate bulk containers – big bags), large cartons with a polyethylene inliner or in bulk.

All Makrolon® batches are homogenized after production.

The injection molding grades Makrolon® 2405 and 2407 are supplied in transparent, translucent or opaque colors with excellent depth of color.

The production plants for Makrolon® have been certificated to DIN ISO by the appropriate quality organiza-

tions. The certificates can be found in the INTERNET at http://www.bayermaterialscience.com (Customer Services / Certificates).

Registered customers can access Safety Data Sheet on the Internet (bayerone.bayer.com). It can also be sent on request.
The Safety Data Sheet includes data on labeling, transport and storage, as well as information on handling, product safety and toxicological and ecological profiles.

Applications

Automotive engineering:
Interior components

Electrical/Electronics:
Switch covers, switch housings, electronic housings

Household articles/consumer goods:
Housings for electrical appliances

Lighting engineering:
Light diffusers, strip light reflectors, louvers, light conducting elements, starter bushings

Safety equipment:
Welders´goggles

Properties (see also table)

The key characteristic features of molded parts in Makrolon® 2405 and 2407 are:

- outstanding light transmission (transparent grades)
- high strength and impact strength
- dimensional stability, very low dimensional changes
- high heat resistance
- excellent electrical and dielectric properties

Mechanical properties

Molded parts made of Makrolon® 2405 and 2407 rank among the rigid materials on account of their strength and hardness, yet also amongst the elastic materials on account of their toughness. The low level of correlation between mechanical properties and temperature is striking; up to 140 °C, stress-free parts remain hard and rigid.
If parts are to be produced that will be exposed to dynamic loading, we recommend that model tests be conducted beforehand.
Stressing in excess of 20 MPa at 20 °C and in excess of 10 MPa at 60 °C can lead to surface cracking after a period of more than 10^4 hours. If the parts are employed in media other than air, then the permissible values may differ. Over and above this, allowance must be made for reduction factors as a function of the different influencing parameters (e.g. the molded part geometry, gate design and processing conditions). These reduction factors must be specified for each individual case.

Influence of coloring on thoughness

The majority of transparent colors do not cause any change in properties, or at least no major change. Opaque pigments affect toughness depending on the type and quantity of pigment employed.

The tough elastic properties of the low molecular Makrolon® 24.. grades are influenced to a greater extent by the coloring than those of the higher molecular Makrolon® 28.. and 3... grades.

Where particular requirements are placed on toughness, preference should be given to higher viscosity grades.

Thermal properties

Components made from the Makrolon® 24.. series of grades are noted for their high heat resistance. At low loading levels (e.g. inherent weight) the parts do not undergo any essential deformation at up to 135 °C. At above 145 °C (glass transition temperature), Makrolon® starts to soften and as from approximately 220 °C it assumes the molten state. Even higher temperatures are required, however, before it attains a flowability that will permit it to be processed on injection molding and extrusion machines. Lengthy periods of heating to temperatures in excess of 320 to 340 °C lead to thermal decomposition, with carbon dioxide being split off, and discoloration.

The coefficient of thermal expansion is lower than for many other thermoplastics. If the material is subject to temperatures in excess of about 80 °C for long periods of time, then a structural change will occur

as a function of the temperature and duration of the thermal treatment which is characterized by a slight increase in the tensile and flexural strength and a reduction in the notched impact strength. The maximum permitted service temperature for parts made of Makrolon® 24.. grades depends on the shape of the molded part, the type of loading and the specifications. The temperature indices to IEC 60216-1 and UL 746 B can be regarded as practical reference values for the permitted maximum temperatures during long-term service.

Where a component is subject to a high temperature and simultaneous mechanical loading, the creep behavior must be taken into account. Further details on this can be found in the CAMPUS® database.

Electrical properties

The favorable electric properties of molded parts in Makrolon® 24.. grades are not influenced notably by temperature fluctuations or by ambient humidity. The change in the measured values at higher frequencies must be taken into account when Makrolon® is used in the high-frequency sector. A further advantage is that no electrolytic corrosion is caused.

Optical properties

Makrolon® parts made from grades in the 24.. series have a high refractive index of 1.586. The virtually colorless, transparent grades possess a light transmission of up to 89 % in the visible range. Ultraviolet light, by contrast, is absorbed and leads to yellowing and a reduction in the impact strength in the course of time. In all cases where UV radiation is emitted, and particularly when it is emitted in conjunction with high temperatures, a UV-stabilized grade should be used (Makrolon® 2407). Finished parts, and particularly lamp diffusers, can be given subsequent UV protective treatment if required.

Behaviour towards moisture and water (hydrolysis resistance)

Molded parts in Makrolon® 24.. absorb only 0.10 to 0.17 % water at room temperature with 50 % relative humidity. The physical/technological properties remain virtually unaffected. The dimensional changes are similarly insignificant. With immersion in water and rising temperatures, values of only 0.5 % or so are achieved. The steam permeability, measured on 100 µm thick film, is 15 g/m² • d. A notable level of permeability also exists for other gases (hydrogen, carbon dioxide, sulfur dioxide, helium and ethylene oxide).

For applications requiring hydrolysis resistance Makrolon® 2456 should be used.

Chemical resistance

Makrolon® is resistant to mineral acids, including in high concentrations, to a large number of organic acids (e.g. carbonic acid, lactic acid, oleic acid and citric acid), to oxidation and reducing agents, neutral and acidic saline solutions, a range of greases and oils, saturated aliphatic and cycloaliphatic hydrocarbons, and also alcohols, with the exception of methyl alcohol. Makrolon® is destroyed by alkaline solutions, ammonia gas and its solution, and amines. Makrolon® dissolves in a number of industrial solvents. Other organic compounds, such as benzene, acetone and carbon tetrachloride, cause it to swell.

Weatherability

Weatherability is generally adequate for a large number of applications and particularly for indoor applications. For stringent requirements, use of the UV stabilized grade, Makrolon® 2407, is recommended. Maximum resistance can be attained in finished parts through the subsequent application of a UV protective coating.

Processing

Pre-treatment / drying[1)]

Makrolon® must be dried prior to processing. For injection molding no more than 0.02 % residual moisture may be present in the granules and, for extrusion, no more than 0.01 %. Moisture in the melt leads to surface defects as well as to an increased reduction in molecular weight.

Makrolon® should be dried in suitable driers at 120 °C.

The drying time for moist granules is largely a function of the nature and type of the drying unit and can amount 2 to 12 hours depending on the drying capacity. Drying times of 2 to 4 hours are sufficient in modern high-speed driers. One means of dispensing

with pre-drying is for the moisture to be removed during melting with the aid of a degassing unit, as has been standard practice in extrusion for a long time.

Injection molding[1)]

Makrolon® can be processed on all modern injection molding machines. Shut-off nozzles are suitable given sufficient, uniform heating. At high melt temperatures, melt can flow out of open nozzles. Molding shrinkage is more or less identical in all directions and amounts to between 0.5 to 0.7 %.

The melt temperatures generally employed during processing are between 280 and 320 °C.

Material damage has to be expected with excessively high processing temperatures or excessively long residence times in the cylinder and hot runner. This can lead to a reduction in toughness and/or to surface defects in the form of streaks.

It should be possible for the molds to be heated intensively and uniformly, and the mold temperature should be at least 80 °C to ensure parts with a low inherent stress and a good surface. No demolding difficulties are encountered at up to 120 °C. It will not generally be necessary to employ mold release agents when Makrolon® grades with easy mold release are used.

Under the recommended processing conditions small quantities of decomposition product may be given off during processing. To preclude any risk to the health and well-being of the machine operatives, tolerance limits for the work environment must be ensured by the provision of efficient exhaust ventilation and fresh air at the workplace in accordance with the Safety Data Sheet. In order to prevent the partial decomposition of the polymer and the release of volatile decomposition products, the prescribed processing temperatures should not be substantially exceeded.

1) Details on this can be found in the following Technical Information Sheets.

"Determining the dryness of Makrolon® by the TVI test"
"Processing data for the injection molder"
"The injection molding of high-quality molded parts"

Extrusion

Makrolon® 24.. grades can be processed on extruders in exceptional cases. As a general rule, the higher viscosity grades of the Makrolon® 3... series can be extruded more readily (higher melt stiffness).

Secondary finishing / post-treatment (molded parts)

The following processing methods can be employed:

- Forming:
  thermoforming, e.g. bending, embossing
  cold forming, e.g. high-pressure forming, folding

- Machining:
  sawing, drilling, milling, turning, planing, filing, thread cutting, punching, cutting

- Joining:
  screwing, adhesive bonding, welding

- Post-treatment:
  painting, printing, high vacuum metallization, laser inscription

Injection moldings made of Makrolon® 24.. grades can be machined without any difficulty. There is only a low tendency towards "smearing" on account of the high softening temperature. Only air or clean water can be employed as cooling agents. Makrolon® components can be readily polished to a high gloss. Only alkali-free polishing pastes may be used, however, in order to prevent any chemical damage to the surface.

The industry supplies products for painting, printing and embossing which are specially tailored to polycarbonate. Makrolon® components can be vacuum metallized.

If parts in Makrolon® are to be glued together[2)], solvents such as methylene chloride (dichloromethane), 1,2-dichloroethane and 1,3-dioxolane (1,3 dioxetane) are particularly suitable. These can be used to partially dissolve the contact surfaces prior to gluing (see Safety Advice).

Two-pack adhesives, such as those based on epoxy resin, silicone (with an amine-free hardening agent) or polyurethane are suitable both for gluing together parts made of Makrolon® and for gluing parts in Makrolon® to other materials. A condition for the use of adhesives based on epoxy resin, silicone and polyurethane is that these must not contain any components that are incompatible with Makrolon® .

Makrolon® parts can be welded by means of vibration, friction, heated tool or hot gas welding. Ultrasonic welding and riveting are the preferred processes.

2) Details on this can be found in our Technical Information Sheet.

"The adhesive bonding of Makrolon®"

Safety Notice

When handling the recommended adhesives and solvents, it is essential for the advice contained in the Safety Data Sheets for these products to be observed. The Safety Data Sheets can be obtained from the individual suppliers. Further up-to-date information on individual solvents is available on the Internet in the GESTIS database on substances at www.hvbg.de/d/bia/gestis/stoffdb/index.html.

Recycling

Rejects and production waste can be reground, observing the drying and processing advice for virgin material, and made into new moldings. It is essential to check the property level and the color of molding compounds that contain regrind in respect of the envisaged application. The permissible regrind content must be established on a case-by-case basis.

When using regrind, it should be borne in mind that the granule geometry, which differs from that of extrusion granules, will influence the feed and plastication behavior. For this same reason, physical mixtures of regrind and granules tend to segregate on account of the movement they experience during transport, conveying and metering operations.

When Makrolon® is reprocessed, care should be taken to ensure that no foreign materials and no dirt is incorporated. Waste that contains pollutants and mixed waste can be chemically recycled or incinerated with energy recovery.

Non-recyclable Makrolon® waste can be disposed of in an environmentally compatible manner through the correct form of incineration and subsequent dumping of the slag.

Parts should be identified in accordance with DIN EN ISO 11469; the marking to be applied to parts in Makrolon® 2405 and 2407 is as follows:

>PC<

Details on this can be found in our Technical Information Sheet "Part identification of thermoplastics for recycling".

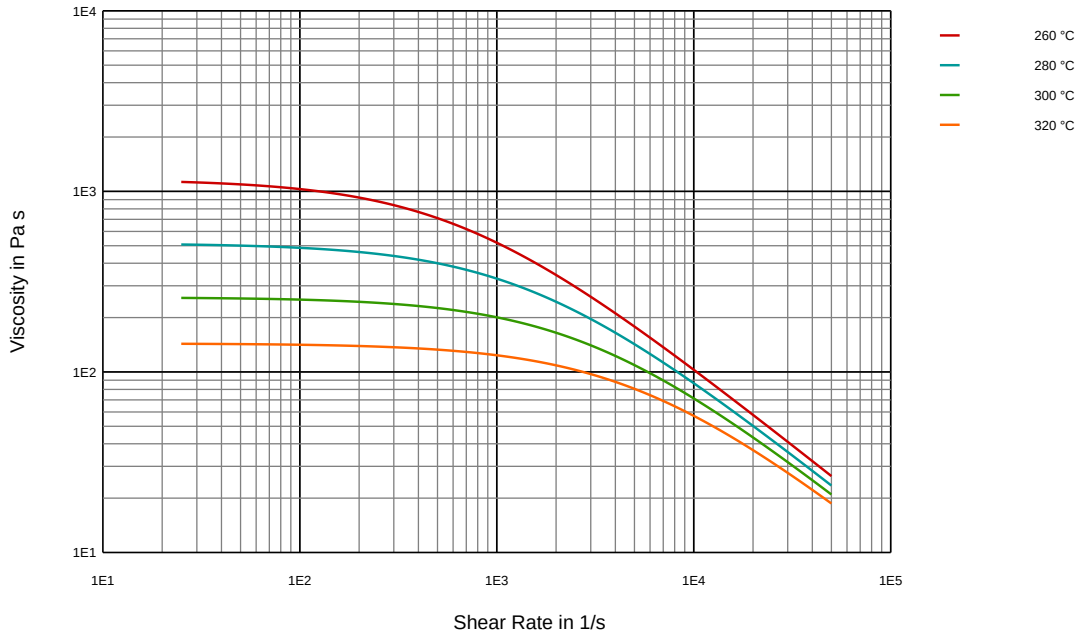

Fig. 1: Melt viscosity as a function of shear rate (Makrolon® 2405, 2407)

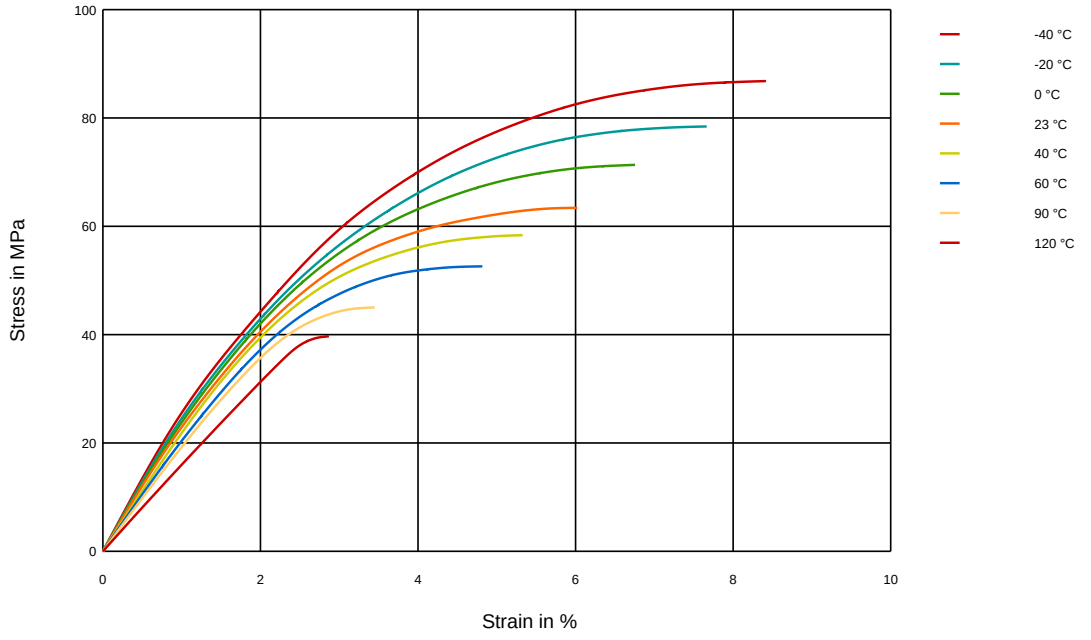

Fig. 2: Isothermal stress-strain curves from the short-time tensile test to ISO 527-1, -2 (Makrolon® 2405, 2407)

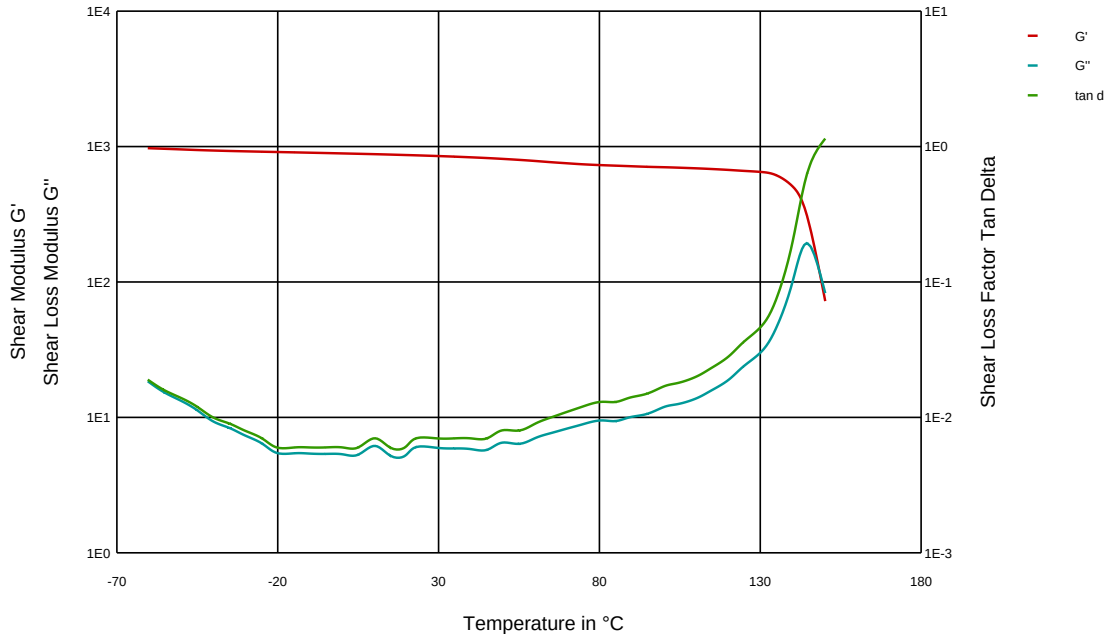

Fig. 3: Shear modulus as a function of temperature to ISO 6721-1, -2 (Makrolon® 2405, 2407)

Typical Values

	Property	Test Condition	Unit	Standard	Makrolon® 2405	Makrolon® 2407
Rheological properties						
C	Melt volume-flow rate	300 °C; 1.2 kg	cm³/10 min	ISO 1133	19	19
C	Molding shrinkage, parallel	60x60x2 mm; 500 bar	%	ISO 294-4	0.65	0.65
C	Molding shrinkage, normal	60x60x2 mm; 500 bar	%	ISO 294-4	0.65	0.65
	Molding shrinkage, parallel/normal	Value range based on general practical experience	%	b.o. ISO 2577	0.5 - 0.7	0.5 - 0.7
	Melt mass-flow rate	300 °C; 1.2 kg	g/10 min	ISO 1133	20	20
Mechanical properties (23 °C/50 % r. h.)						
C	Tensile modulus	1 mm/min	MPa	ISO 527-1,-2	2400	2400
C	Yield stress	50 mm/min	MPa	ISO 527-1,-2	65	66
C	Yield strain	50 mm/min	%	ISO 527-1,-2	6.0	6.0
C	Nominal strain at break	50 mm/min	%	ISO 527-1,-2	> 50	> 50
	Stress at break	50 mm/min	MPa	ISO 527-1,-2	65	65
	Strain at break	50 mm/min	%	b.o. ISO 527-1,-2	120	120
C	Tensile creep modulus	1 h	MPa	ISO 899-1	2200	2200
C	Tensile creep modulus	1000 h	MPa	ISO 899-1	1900	1900
	Flexural modulus	2 mm/min	MPa	ISO 178	2350	2350
	Flexural strength	2 mm/min	MPa	ISO 178	97	98
	Flexural strain at flexural strength	2 mm/min	%	ISO 178	7.1	7.0
	Flexural stress at 3.5 % strain	2 mm/min	MPa	ISO 178	73	74
C	Charpy impact strength	23 °C	kJ/m²	ISO 179-1eU	N	N
C	Charpy impact strength	-30 °C	kJ/m²	ISO 179-1eU	N	N
	Charpy impact strength	-60 °C	kJ/m²	ISO 179-1eU	N	N
	Charpy notched impact strength	23 °C; 3 mm	kJ/m²	ISO 7391/b.o. ISO 179-1eA	65P	65P(C)
	Charpy notched impact strength	-30 °C; 3 mm	kJ/m²	ISO 7391/b.o. ISO 179-1eA	14C	14C
	Izod notched impact strength	23 °C; 3.2 mm	kJ/m²	b.o. ISO 180-A	75P(C)	75P(C)
	Izod notched impact strength	-30 °C; 3.2 mm	kJ/m²	b.o. ISO 180-A	12C	12C
C	Puncture maximum force	23 °C	N	ISO 6603-2	5100	5100
C	Puncture maximum force	-30 °C	N	ISO 6603-2	6000	6000
C	Puncture energy	23 °C	J	ISO 6603-2	55	55
C	Puncture energy	-30 °C	J	ISO 6603-2	65	65
	Ball indentation hardness		N/mm²	ISO 2039-1	115	116

Typical Values

	Property	Test Condition	Unit	Standard	Makrolon® 2405	Makrolon® 2407
Thermal properties						
C	Glass transition temperature	10 °C/min	°C	ISO 11357-1,-2	145	144
C	Temperature of deflection under load	1.80 MPa	°C	ISO 75-1,-2	125	124
C	Temperature of deflection under load	0.45 MPa	°C	ISO 75-1,-2	137	136
C	Vicat softening temperature	50 N; 50 °C/h	°C	ISO 306	145	144
	Vicat softening temperature	50 N; 120 °C/h	°C	ISO 306	146	145
C	Coefficient of linear thermal expansion, parallel	23 to 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65
C	Coefficient of linear thermal expansion, transverse	23 to 55 °C	10^{-4}/K	ISO 11359-1,-2	0.65	0.65
C	Burning behavior UL 94	0.75 mm	Class	UL 94	V-2	V-2
	Burning behavior UL 94	0.36 mm	Class	UL 94	V-2	
	Burning behavior UL 94	2.7 mm	Class	UL 94	HB	HB
C	Oxygen index	Method A	%	ISO 4589-2	27	27
	Thermal conductivity	23 °C	W/(m·K)	ISO 8302	0.20	0.20
	Resistance to heat (ball pressure test)		°C	IEC 60695-10-2	136	135
	Relative temperature index (Tensile strength)	1.5 mm	°C	UL 746B	125	125
	Relative temperature index (Tensile impact strength)	1.5 mm	°C	UL 746B	115	115
	Relative temperature index (Electric strength)	1.5 mm	°C	UL 746B	125	125
	Glow wire test (GWFI)	1.0 mm	°C	IEC 60695-2-12	850	850
	Glow wire test (GWFI)	1.5 mm	°C	IEC 60695-2-12	850	850
	Glow wire test (GWFI)	2.0 mm	°C	IEC 60695-2-12	850	850
	Glow wire test (GWFI)	3.0 mm	°C	IEC 60695-2-12	930	930
	Glow wire test (GWFI)	4.0 mm	°C	IEC 60695-2-12	960	960
	Glow wire test (GWIT)	1.0 mm	°C	IEC 60695-2-13	875	875
	Glow wire test (GWIT)	1.5 mm	°C	IEC 60695-2-13	875	875
	Glow wire test (GWIT)	2.0 mm	°C	IEC 60695-2-13	875	875
	Glow wire test (GWIT)	3.0 mm	°C	IEC 60695-2-13	875	875
	Glow wire test (GWIT)	4.0 mm	°C	IEC 60695-2-13	875	875
	Application of flame from small burner	Method K and F; 2.0 mm	Class	DIN 53438-1,-3	K1, F1	K1, F1
	Needle flame test	Method K; 1.5 mm	s	IEC 60695-11-5	5	5
	Needle flame test	Method K; 2.0 mm	s	IEC 60695-11-5	5	5
	Needle flame test	Method K; 3.0 mm	s	IEC 60695-11-5	10	10
	Needle flame test	Method F; 1.5 mm	s	IEC 60695-11-5	60	60
	Needle flame test	Method F; 2.0 mm	s	IEC 60695-11-5	120	120
	Needle flame test	Method F; 3.0 mm	s	IEC 60695-11-5	120	120
	Burning rate (US-FMVSS)	>=1.0 mm	mm/min	ISO 3795	passed	passed
	Flash ignition temperature		°C	ASTM D1929	480	480
	Self ignition temperature		°C	ASTM D1929	550	550
Electrical properties (23 °C/50 % r. h.)						
C	Relative permittivity	100 Hz	-	IEC 60250	3.1	3.1
C	Relative permittivity	1 MHz	-	IEC 60250	3.0	3.0
C	Dissipation factor	100 Hz	10^{-4}	IEC 60250	5	5
C	Dissipation factor	1 MHz	10^{-4}	IEC 60250	90	90
C	Volume resistivity		Ohm·m	IEC 60093	1E14	1E14
C	Surface resistivity		Ohm	IEC 60093	1E16	1E16
C	Electrical strength	1 mm	kV/mm	IEC 60243-1	34	34
C	Comparative tracking index CTI	Solution A	Rating	IEC 60112	250	250
	Comparative tracking index CTI M	Solution B	Rating	IEC 60112	125M	125M
	Electrolytic corrosion		Rating	IEC 60426	A1	A1

Typical Values

	Property	Test Condition	Unit	Standard	Makrolon® 2405	Makrolon® 2407
Other properties (23 °C)						
C	Water absorption (saturation value)	Water at 23 °C	%	ISO 62	0.30	0.30
C	Water absorption (equilibrium value)	23 °C; 50 % r. h.	%	ISO 62	0.12	0.12
C	Density		kg/m³	ISO 1183-1	1200	1200
	Water vapor permeability	23 °C; 85 % RH; 100 µm film	g/(m²·24 h)	ISO 15106-1	15	15
	Gas permeation	Oxygen; 100 µm film	cm³/(m²·24 h*bar)	b.o. ISO 2556	800	800
	Gas permeation	Oxygen; 25.4 µm (1 mil) film	cm³/(m²·24 h*bar)	b.o. ISO 2556	3150	3150
	Gas permeation	Nitrogen; 100 µm film	cm³/(m²·24 h*bar)	b.o. ISO 2556	160	160
	Gas permeation	Nitrogen; 25.4 µm (1 mil) film	cm³/(m²·24 h*bar)	b.o. ISO 2556	630	630
	Gas permeation	Carbon dioxide; 100 µm film	cm³/(m²·24 h*bar)	b.o. ISO 2556	4800	4800
	Gas permeation	Carbon dioxide; 25.4 µm (1 mil) film	cm³/(m²·24 h*bar)	b.o. ISO 2556	18900	18900
	Bulk density	Pellets	kg/m³	ISO 60	660	660
Material specific properties						
	Refractive index	Procedure A	-	ISO 489	1.586	1.586
	Haze for transparent materials	3 mm	%	ISO 14782	< 0.8	< 0.8
	Luminous transmittance (clear transparent materials)	1 mm	%	ISO 13468-2	89	89
C	Luminous transmittance (clear transparent materials)	2 mm	%	ISO 13468-2	89	89
	Luminous transmittance (clear transparent materials)	3 mm	%	ISO 13468-2	88	88
	Luminous transmittance (clear transparent materials)	4 mm	%	ISO 13468-2	87	87
Processing conditions for test specimens						
C	Injection molding-Melt temperature		°C	ISO 294	280	280
C	Injection molding-Mold temperature		°C	ISO 294	80	80
C	Injection molding-Injection velocity		mm/s	ISO 294	200	200

C These property characteristics are taken from the CAMPUS plastics data bank and are based on the international catalogue of basic data for plastics according to ISO 10350.

Impact properties: N = non-break, P = partial break, C = complete break

colored fields = UL recognition

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