

PLASKOLITE

TUFFAK Guidebook

EXTRUDED POLYCARBONATE (PC)
SHEETS



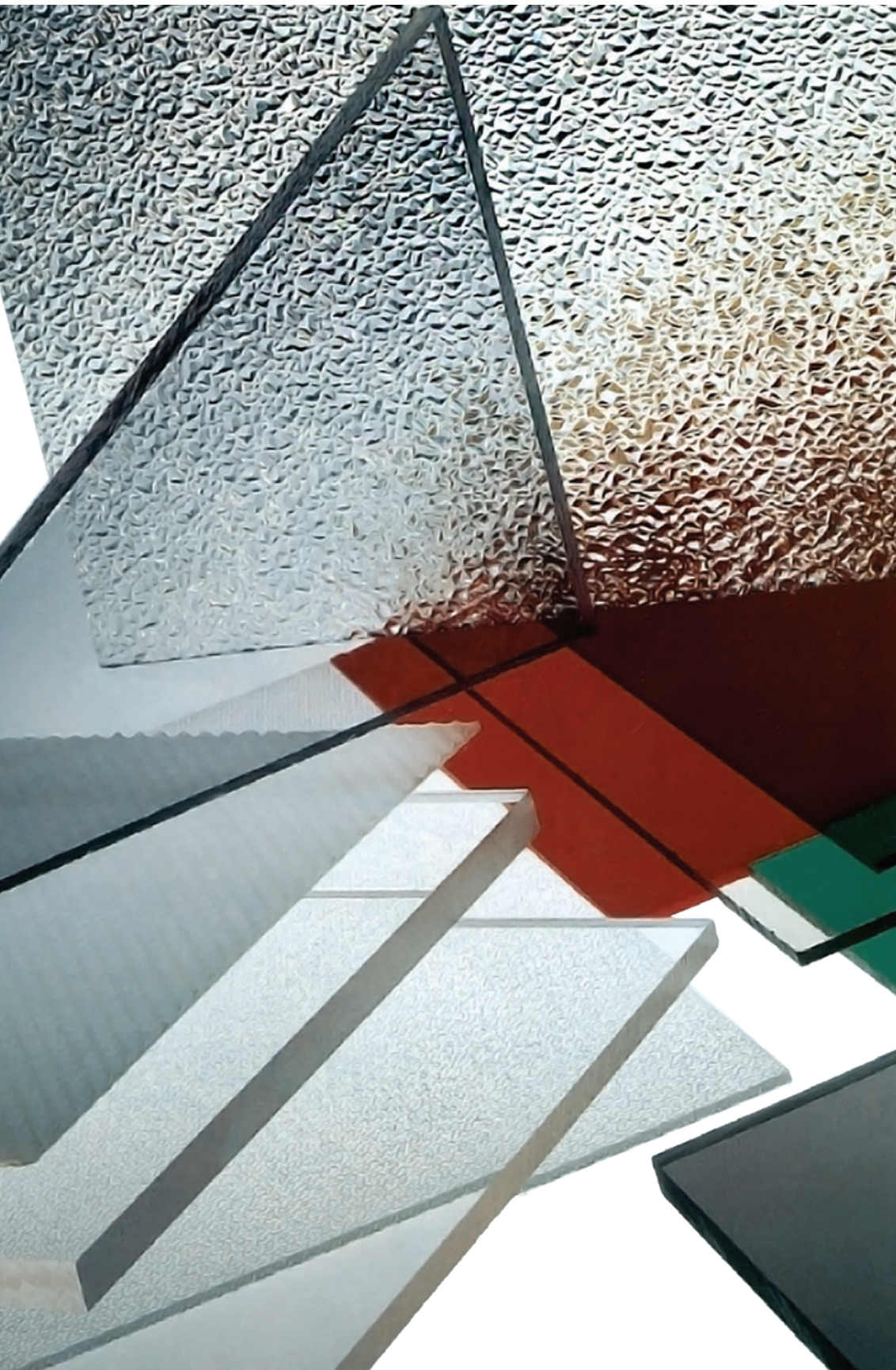


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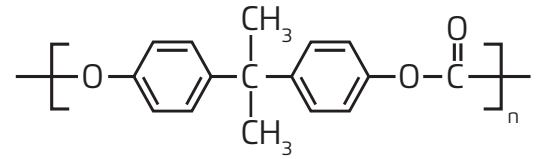
Introduction



1. Introduction

TUFFAK are the trade names of extruded solid polycarbonate (PC) sheets made by the PLASKOLITE.

PC was first produced in the late 1950s and initially used for electrical applications. Its unique combination of transparency, high impact and high heat resistance made it soon the preferred choice for many other applications.



Bisphenol A PC Molekül

PC is an outstanding plastic material, merging a unique combination of beneficial properties such as high transparency, high impact strength and toughness (virtually unbreakable) and high heat resistance. It can be stabilized and protected to have an excellent resistance to sunlight and environmental exposure for a long period of time. It also has excellent electrical properties and it is fire self-extinguishing. PC can be modified by different additives to perform specific applications: light reflection, light diffusion, IR blocking, etc.

With excellent transparency, safety and easy fabrication, TUFFAK extruded solid PC sheets provide long-life products for a wide range of applications. TUFFAK are available in a broad range of thicknesses, colors, textures and special effects.

TUFFAK sheets are produced in clean room environments using computerized state-of-the-art video technology in order to detect any imperfection in the sheets. A skilled team of engineers work 24 hours a day, 7 days a week, to improve materials and production processes and provide technical support to customers and help them to solve any technical challenge.



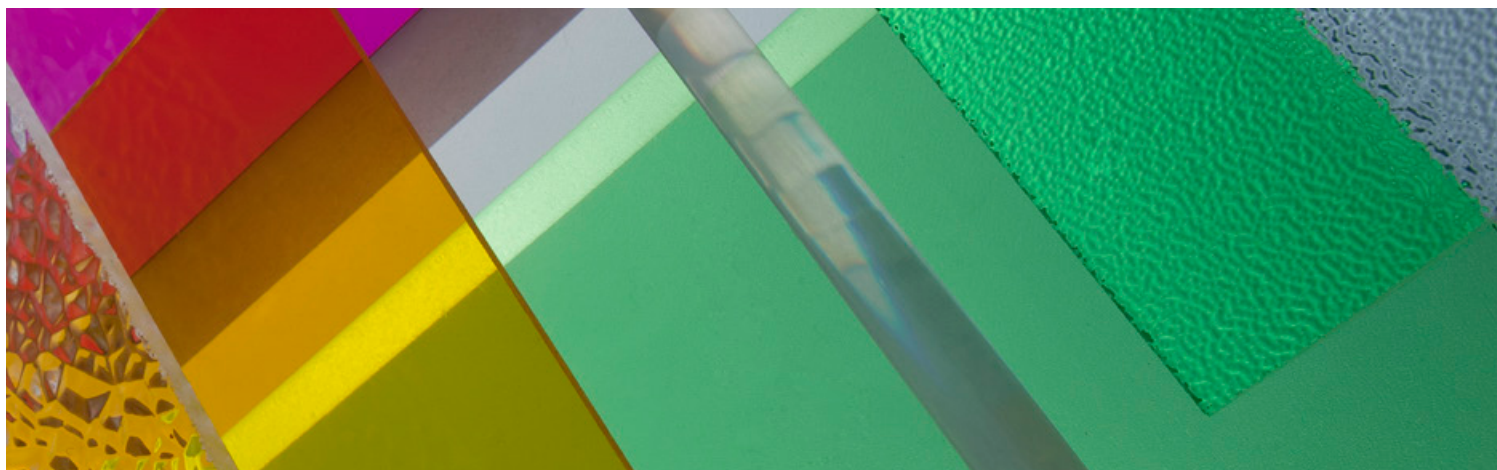
Characteristics



2. Characteristics of TUFFAK

2.1 Qualities

- High clarity and light transmission
- Low haze
- Bright surface
- Matte surface (anti-glare, anti-reflect) and special embossed patterns available
- Outstanding impact strength - virtually unbreakable
- High toughness
- Excellent heat resistance - continuous service temperature up to 100°C
- Lightweight. About half weight of glass
- UV protective layer, one or two sides, excellent weathering and ageing resistance. Ten years limited warranty
- Excellent color stability. A wide range of translucent and opaque colors available
- Excellent dimensional stability
- Easily machined and thermoformed by standard techniques
- Cold curving capability
- Can be glued and solvent bonded
- Good chemical resistance to a wide range of substances
- TUFFAK sheets and their polyethylene protective layers are fully recyclable
- Do not contain toxic materials or heavy metals, which may cause environmental damage or health risks
- REACH and RoSH declarations are available
- Good fire resistance, Self-extinguish. Fire retardant grades (TUFFAK F) available



2.2 Applications

TUFFAK extruded solid PC sheets are versatile and easy to fabricate and can be used in a wide range of applications. Their outstanding combination of properties make them the preferred choice for the most demanding applications in machinery, automotive, safety and construction. They can be used both indoor and outdoor for a wide variety of domestic and industrial purposes:

Building Industry:

- Glazing
- Walkways and shelters
- Skylights
- Greenhouses
- Swimming pools

Safety:

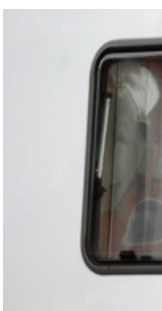
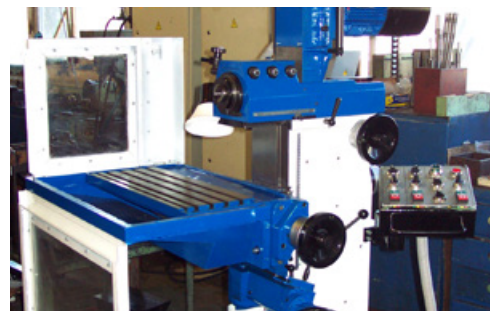
- Anti intrusion glazing and ceiling
- Safety secondary glazing
- Car window protection
- Machine safety, sliding windows and doors
- Protective visors and goggles
- Security protection gear

Automotive industry:

- Noise reduction barriers
- Wind shields
- Car sunroofs
- Motorcycle shields

Other:

- Signage
- Thermoformed, vacuumformed parts
- Light fittings, light diffusers
- Furniture
- Fabricated parts





Handling

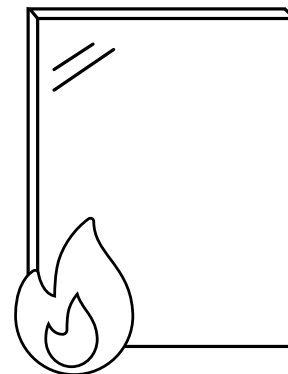


3. Handling TUFFAK Sheets

Handling TUFFAK must be done with care, always using protective gloves and shoes.

3.1 Burning Behavior

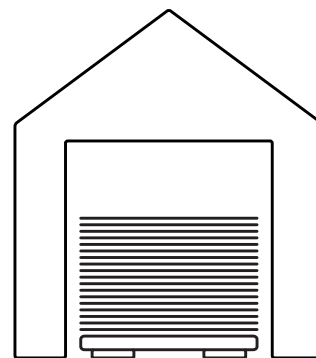
TUFFAK sheets have a good resistance to fire, however they will melt and burn under intense heat or fire. However, they do not promote flame propagation and once the source of fire is removed, the material will self-extinguish. TUFFAK sheets do not produce toxic fumes upon burning. Fire retardant grades are available for higher fire requirement applications. These grades are transparent and perform the same as the standard grades.



3.2 Sheets Storage

TUFFAK sheets must be stored with their original protective masking in a cool, dry and well-ventilated room, at a reasonable constant temperature, away from direct sunlight, excessive humidity or rain. Keep away TUFFAK sheets from environments containing chemical vapors. Failing to store TUFFAK in adequate conditions can compromise the performance of the product. Long term exposure to the sun or other heat sources can cause fusing of the protective polyethylene film to the sheet surface, impeding its removal.

TUFFAK sheets are best stored horizontally on their delivery pallets. Pay attention to avoid pressure on the unsupported areas. Do not leave uncovered sheets or pallets. If stored outdoors, cover the pallet with an opaque polyethylene film or cardboard.

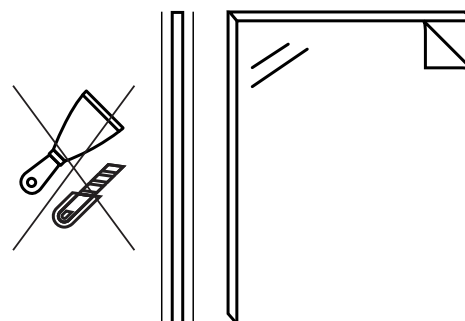


3.3 Protective Film

Both surfaces of TUFFAK sheet are protected by a fully recyclable polyethylene (PE) film. Keep this film in position as long as possible and remove only and immediately after installation.

Sharp objects, sharp particles or even small chips can penetrate the protective PE masking, and damage the surface, therefore always lay TUFFAK on a clean smooth surface.

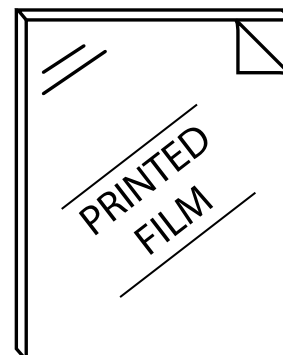
TUFFAK protective film is suitable for thermoforming.



3.4 Machining and Forming with PE Film

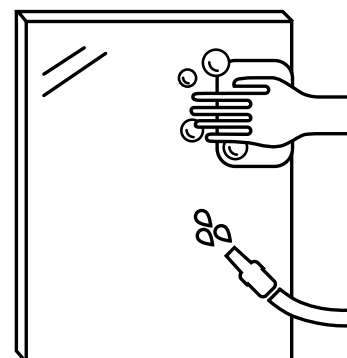
It is preferable to leave the protective film in position throughout machining to keep the sheet surface in perfect condition. Normal thermoforming temperatures do not affect the adhesive used for the film on TUFFAK sheets and can therefore be left in place during most heating and forming operations. However, care should be taken to ensure there are no defects in the film (holes, scratches, bubbles), which could mark the part during the forming process. High-heat deep-draw thermoforming applications can cause the PE film to adhere strongly. In these cases it is better to remove the PE film before thermoforming. Local overheating may cause fusing of the PE film to the sheet surface. Printed film must be removed before thermoforming, to avoid transfer of the printing ink to the sheet's surface.

Remove Before
Thermoforming



3.5 Cleaning the Sheets

TUFFAK sheets are produced in clean room environment and do not need to be cleaned before use. However, cleaning may be needed after fabrication, before sensitive processes like vacuum metallization or printing or for maintenance during use. In the case that TUFFAK sheets need to be cleaned, wash the sheet surface with clean fresh water with a mild soap. Be sure that the soap you are using is compatible with PC. Test a hidden area before cleaning. Use a clean, soft cloth or sponge and rinse well. Do not scrub or use brushes. Dry with a soft cloth. Do not rub dry. The use of window cleaning fluids or solvents such as turpentine, acetone, etc., can cause damage to the sheet.



3.6 Environmental Advantages

TUFFAK sheets are environmental friendly.

The long-time resistance to aging and weathering of TUFFAK sheets often ensures a service time of decades. They do not need to be removed or replaced for many years reducing the environmental burden of plastics waste.

The sheets and their polyethylene protective layers are fully recyclable. They do not contain any toxic materials or heavy metals, which may cause environmental damage or health risks. Ozone Depleting Substances (ODP) are not used in the manufacture of TUFFAK sheets. TUFFAK do not release pollutant substances to the environment during manufacture.

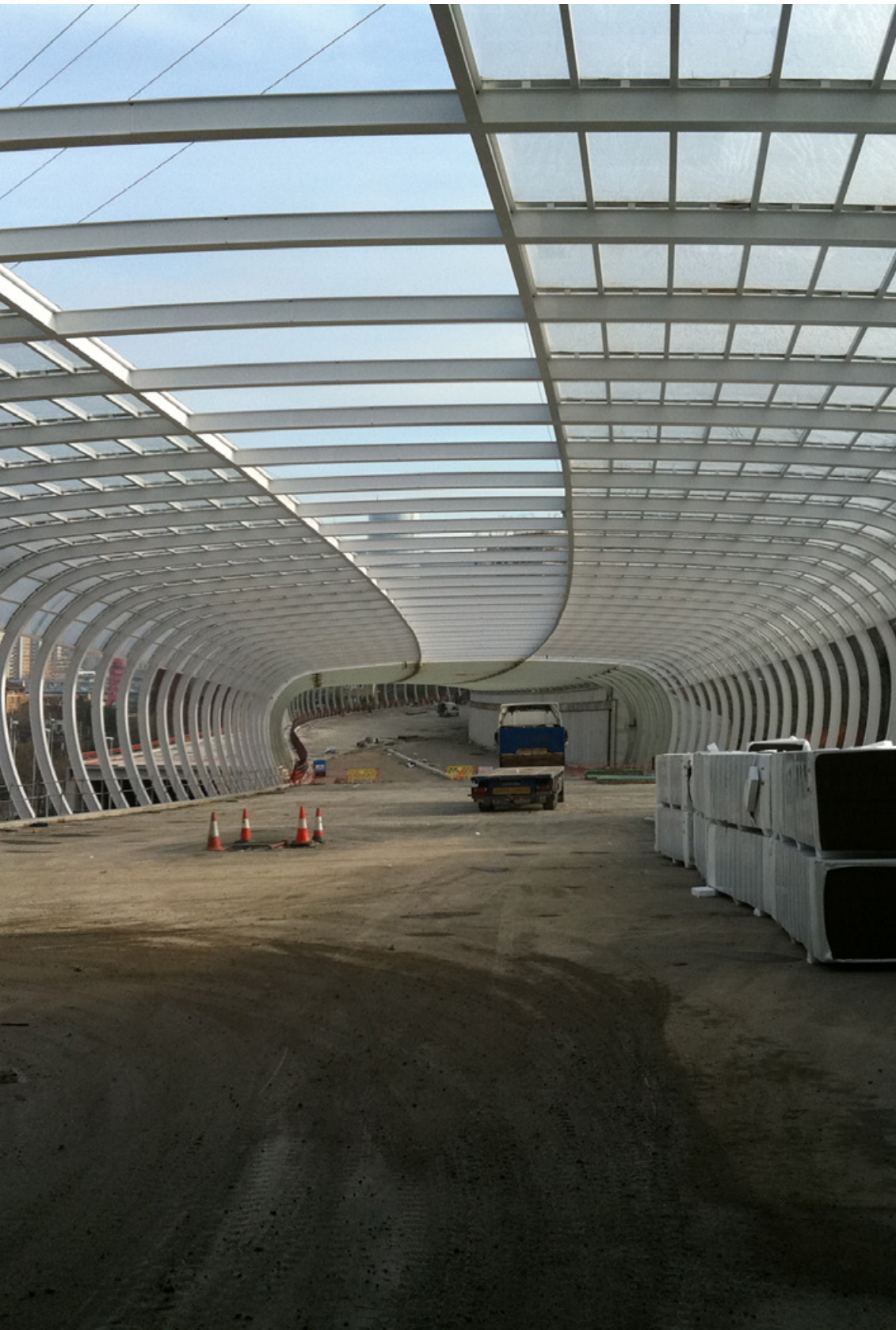
They do not produce toxic or corrosive gases upon burning.

Fires can be extinguished with water.

TUFFAK sheets can be used for energy recovery and chemical or mechanical recycling. TUFFAK scrap is not classified as hazardous waste. Small amounts can be disposed as household refuse. Large quantities should be disposed for recycling.



Technical Properties



4. Technical Properties

Sheets are produced according to ISO 22963:2012 and EN 16240:2013 standards.

Please note that technical values given in this guidebook are typical values for your guidance. They are not to be taken as specifications and are subject to certain variability.

4.1 Standard Sizes

Thickness	0.5 - 19.0 mm
Width	1000, 1220 and 2050 mm
Length	600 - 6000 mm

4.2 Light Transmission

The light transmission of clear TUFFAK sheets is thickness dependent and ranges between 81-90%, according to the following table:

Thickness	Light Transmission %
1	90
2	89
3	88
4	87
5	86
6	86
7	85
8	83
9	81

4.3 Colors

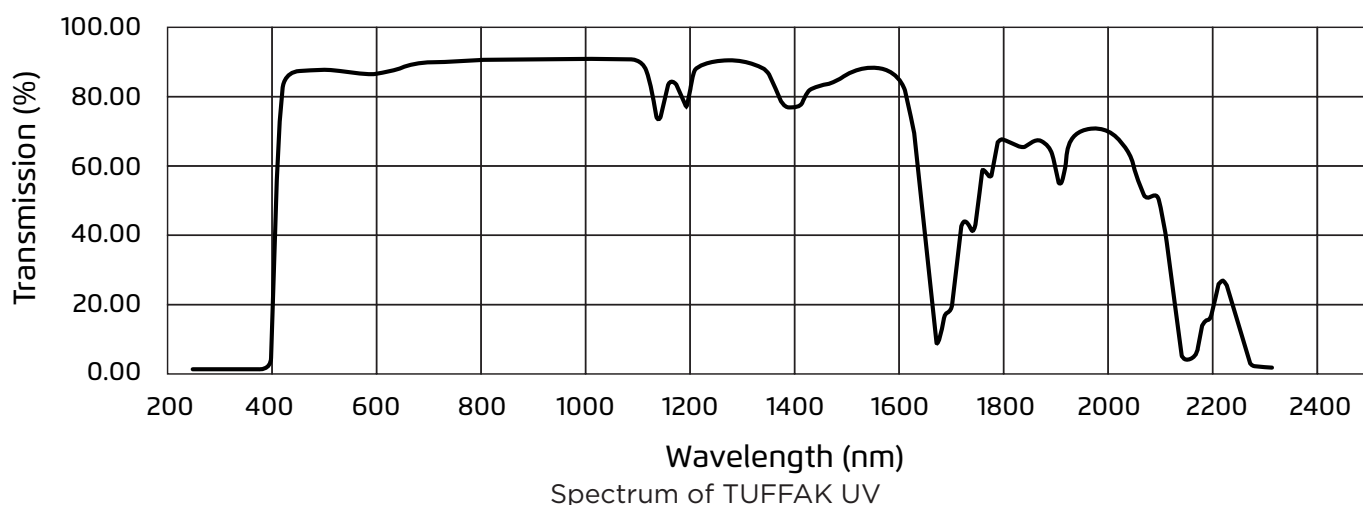
TUFFAK sheets are naturally colorless and exceptionally clear, however they can be pigmented to obtain a wide range of tints and colors. They are available transparent and in a wide range of translucent colors, opaque colors, opals and diffusers. The light transmission of TUFFAK colored sheets varies depending on thickness. For a list of updated colors please contact your regional supplier.

4.4 Typical Properties - TUFFAK - Extruded Polycarbonate Sheets

Properties	Method	Units	TUFFAK (R8000)
General			
Density	ISO 1183	g/cm ³	1.2
Water Absorption	ISO 62 (1)	%	0.15
Mechanical			
Tensile Strength at Yield	ISO 527-2	MPa	60
Elongation at Yield	ISO 527-2	%	6
Elongation at Break	ISO 527-2	%	> 100
Tensile Modulus	ISO 527-2	MPa	2300
Flexural Strength	ISO 178	MPa	90
Flexural Modulus	ISO 178	MPa	2300
Impact Resistance (Charpy unnotched)	ISO 179/1fu	kJ/m ²	No Break
Impact Resistance (Izod notched)	ISO 180/1A	kJ/m ²	> 65
Optica			
Refractive Index	ISO 489		1.585
Light Transmission (thickness dependent)	ASTM D1003	%	81-90
Haze (3 mm transparent sheet)	ASTM D1003	%	< 1
Thermal			
Vicat Softening Temp.(50N)	ISO 306	°C	144
Heat Deflection Temp. (1.82 MPa)	ISO 75-1	°C	130
Coeff. of Linear Thermal Expansion (0-50OC)		µm/m°C	6.5
Thermal Conductivity	ASTM C177	W/mK	0.2
Maximum Continuous Service Temp.		°C	100
Maximum Short Time Service Temp.		°C	120
Minimum Temp.		°C	-50
Electrical			
Dielectric Constant (50Hz)	DIN 53483		3.0
Dissipation Factor tanδ (100Hz)	DIN 53483		0.0006
Dissipation Factor tanδ (1 MHz)	DIN 53483		0.009
Volume Resistivity	IEC 60093	Ohm.cm	> 10 ¹⁴
Surface Resistivity	IEC 60093	Ohm	> 10 ¹⁵

4.5 Solare Transmission / UV Blocking

The sun spectrum that reaches the earth surface ranges roughly from about 250 nm to 2500 nm wavelength. This spectrum can be divided in three regions of increased wavelength. The ultra-violet (UV) region bellow 380 nm, the visible region between 380 and 700 nm and the infrared (IR) region above 700 nm. TUFFAK transparent sheets are an excellent filter for UV radiation. They completely block the harmful UV radiation while transmitting visible light and parts of the IR radiation. For special applications where more IR blocking is needed, special products that block the IR (TUFFAK IR Solar) have been developed.



4.6 Noise Reduction Properties

TUFFAK sheets are used widely as noise reduction barriers along roads and highways. TUFFAK sheets comply with the following standards:

EN-14388:2005 - Road Traffic Noise Reducing Device

EN-1793 - Road Traffic Noise Reducing Device - Acoustic Properties

EN-1794 - Road Traffic Noise Reducing Device - Non-Acoustic Properties

4.7 Chemical Properties

Some chemical substances do not produce any effect on TUFFAK, some cause staining, swelling, crazing, weakening or dissolve it completely. TUFFAK sheets have good resistance to mineral acids, many organic acids, neutral and acid salt solutions, oxidizing and reducing agents, aliphatic hydrocarbons, greases, waxes and oils and alcohols (except methanol). They have a good resistance to water up to 60°. A short contact with hot water will cause no effect, however, long exposition of PC to hot water or water vapor is not recommended.

Important Note:

Any substance that comes in contact with PC should be checked for compatibility. Even if the supplier confirms that the material is suitable for PC, please apply it first to a hidden area to see if there are any effects. However, this will cover you for short-time effects only. To assess long-term effects of substances on PC, laboratory testing is required.

Technical Properties

CHEMICAL	20 °C	50 °C	CHEMICAL	20 °C	50 °C
Acetaldehyde	S	N	Formic acid	E	S
Acetone	N	N	Gasoline	S	S
Acetic acid	E	B	Hexane	N	N
Aluminum hydroxide	S	N	Hydrochloric acid 35%	N	N
Ammonium chloride	E	E	Hydrofluoric acid	N	N
Ammonium hydroxide 5%	S	N	Hydrogen peroxide	E	E
Ammonium hydroxide 28%	N	N	Kerosene	B	S
Amyl chloride	N	N	Lactic acid	E	B
Aniline	S	N	Methyl alcohol	B	S
Benzaldehyde	S	N	Methyl ethyl ketone	N	N
Benzene	N	N	Methyl isobutyl ketone	N	N
Boric acid	E	E	Methylene chloride	N	N
Bromine	S	N	Mineral oil	E	B
Bromoform	N	N	Nitric acid 1-10%	E	B
Butadiene	N	N	Nitric acid 50%	B	S
Butyl acetate	N	N	Nitric acid 65%	S	N
Butyl Alcohol	B	S	Nitrobenzene	N	N
Butyric acid	S	N	Perchloric acid	N	N
Calcium hydroxide	N	N	Petroleum ether	S	N
Calcium hypochloride	S	N	Phenol	E	N
Carbon disulphide	N	N	Phosphoric acid 85%	E	B
Carbon tetrachloride	N	N	Potassium bichromate	E	B
Cellosolve	S	N	Potassium hydroxide conc.	N	N
Chlorine in air	E	B	Potassium permanganate	E	B
Chlorine (moist)	B	S	Propane	S	N
Chloroform	N	N	Propylene glycol	S	N
Citric add.	E	E	Silver nitrate	B	S
Cresol	N	N	Sodium hydroxide conc.	S	S
Cyclohexane	E	B	Sodium hypochloride	N	N
p-dichlorobenzene	N	N	Sulfuric acid 20%	B	S
Diethylene glycol	B	S	Sulfuric acid 98%	E	B
Diethylene formamide	N	N	Tetrahydrofuran	N	N
Dioxane	B	S	Thionil chloride	N	N
Ethyl acetate	N	N	Toluene	N	N
Ethyl alcohol	E	B	Trichloroacetic acid	S	N
Ethyl chloride	N	N	Trichloroethane	N	N
Ethylene chloride	N	N	Trichloroethylene	N	N
Ethylene oxide	S	N	Turpentine	S	N
Ethyl ether	N	N	Urea	N	N
Formaldehyde	E	B	Xylene	N	N

E - Excellent resistance. No etching.

B - Good resistance. Etching after 30 days of a exposure.

S - Fair resistance. Etching after 7 days of a exposure.

N - No resistant. Not recommended.

4.8 ESC (Environmental Stress Cracking)

ESC (Environmental Stress Cracking) is a well-known phenomenon in plastics including PC, and a common reason of product failure. ESC is a result of the combination of stress and chemical exposure. Under harsh chemical environment, stressed sheets will fail by cracking and crazing. The level of stress needed for ESC is lower than the normal failure mechanical stress of PC in a chemical-free environment. Stresses can be induced during forming and fabrication. These can be eliminated by an annealing process (see chapter 7).

Stresses can be induced also by improper installation (see chapter 8). Cold bended sheets under permanent induced stress or sheets under periodic stress (fatigue) are also susceptible to ESC.

4.9 Heat Transmission

The U-factor, or overall heat transmission coefficient, is the amount of heat which will pass through one square meter in one second for a specific thickness of material. Is an important factor to consider when choosing a glazing material, due to its influence on thermal efficiency and energy loss in winter (heating) or summer (air-conditioning). TUFFAK sheets insulate better than glass, contributing to substantial energy conservation for single glazing.

Thickness (mm)	TUFFAK	Glass
	U Factor (W/m²K) - EN16240:2013	
3	5.41	5.78
6	5.00	5.68
12	4.35	5.49

Total Heat Loss or Gain through a Window Due to Conduction/Convection:

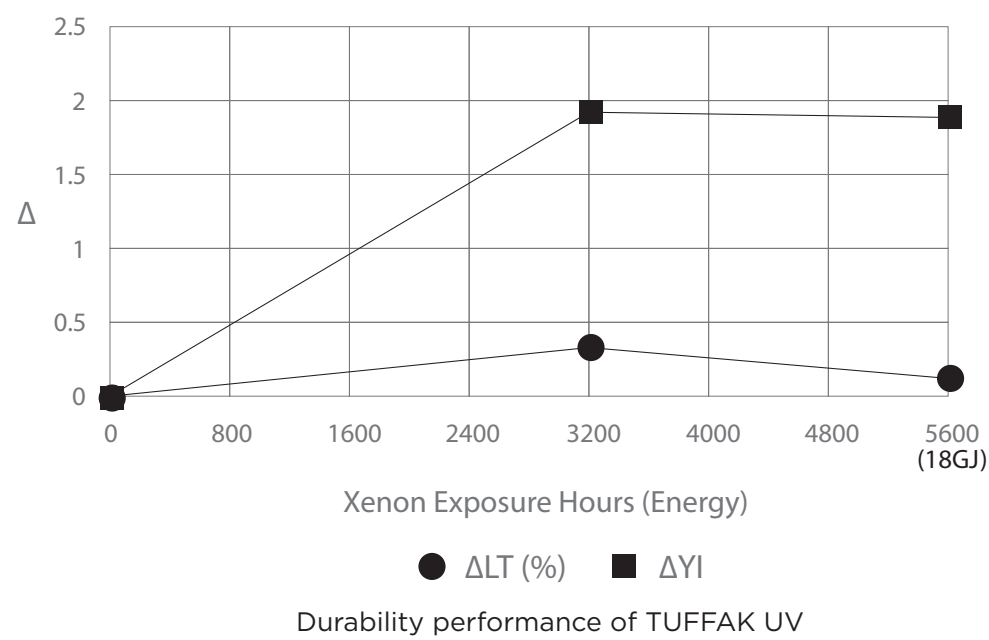
Heat Loss = Window Area X [Indoor Temp - Outdoor Temp] X U-Factor

4.10 Weathering Resistance

PC is not resistant to UV radiation and must be stabilized or protected using UV absorbing additives. TUFFAK sheets are UV stabilized and are suitable for indoor applications in areas where not in contact with UV radiation. TUFFAK UV sheets are protected with an additional UV-blocking co-extrusion layer from one side and are suitable for applications where in contact with UV radiation from one side only. TUFFAK 2UV sheets are protected with additional UV-blocking co-extrusion layers from both sides and are suitable for outdoor applications.

The UV protective co-extrusion layer, from one or two sides, provides excellent weathering and ageing resistance. It is an integral part of the sheet and does not detaches or delaminates. A ten-year limited warranty weathering resistance is available for TUFFAK UV protected sheets.

TUFFAK UV protected sheets durability performance rate ΔA , CuO, KuO according to EN 16240:2013 standard.



4.11 Fire Properties

PC is a thermoplastic; therefore, it will eventually melt and burn under the intense heat of fire. However, PC is considered a self-extinguish material meaning it will stop burning when the fire source is taken away. TUFFAK sheets, unlike other materials do not produce toxic or corrosive gases when burning.

TUFFAK extruded PC sheets classify:

- HB according to UL94 for thin gauge sheets
- V2 according to UL94 for higher gauge sheets
- V0 for fire retardant “F” grades
- B, s1, do according to EN ISO 13501 (specific thicknesses)

4.12 CE Marking

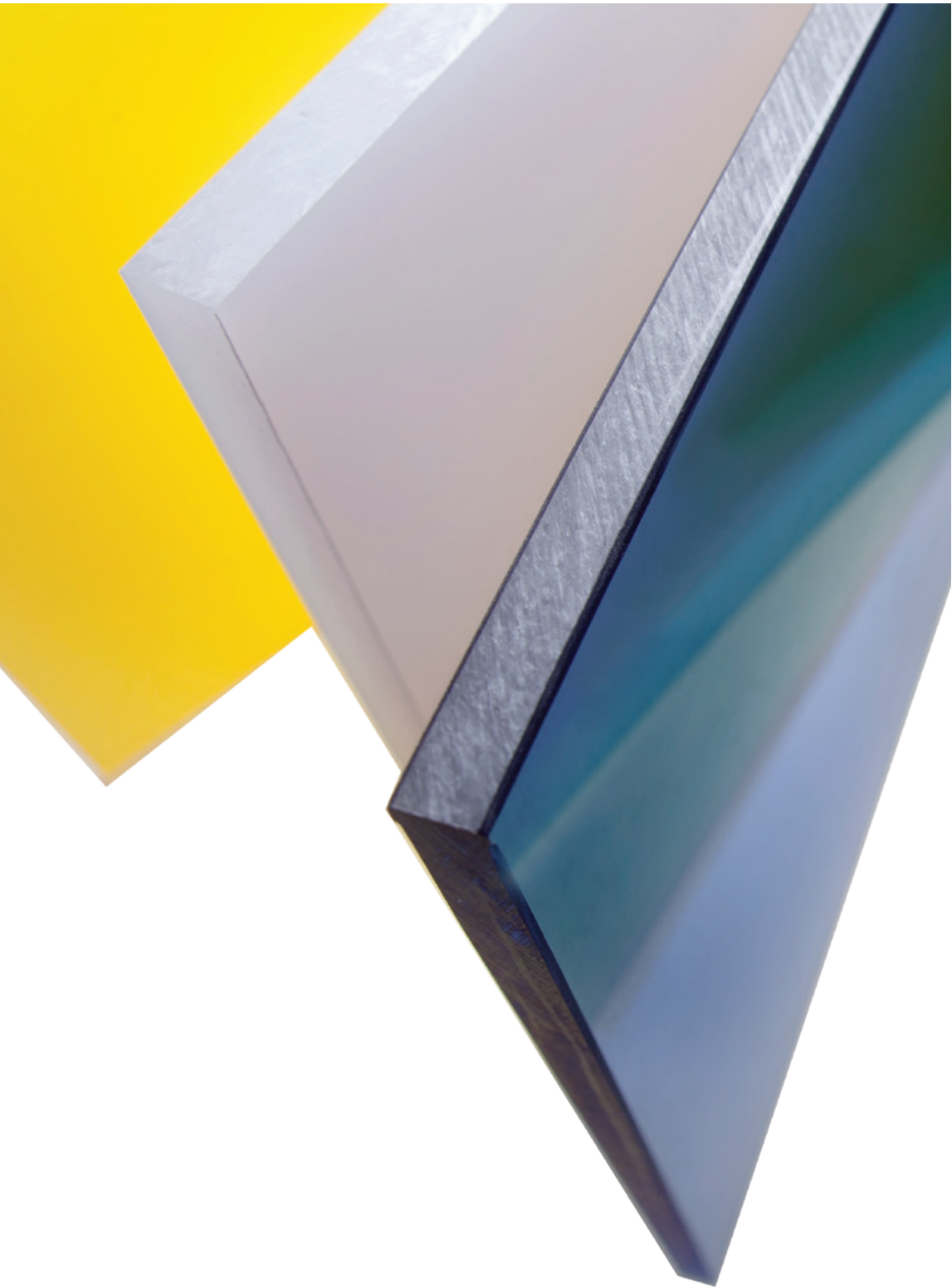
CE Markings for TUFFAK sheets are available according to:

EN 16240:2013 - “Light trasmitting flat solid polycarbonate (PC) sheets for internal and external use in roofs, walls and ceillings - requirements and test methods.

EN-14388:2005 - “Road Traffic Nosie Reducing Device” (specific thicknesses)



Special Grades

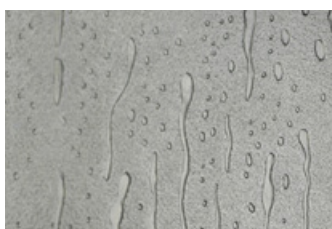


5. TUFFAK Special Grades

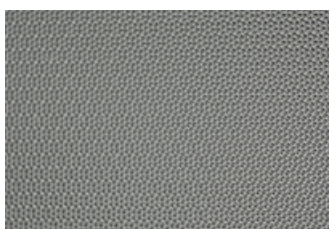
5.1 TUFFAK Embossed Sheets

TUFFAK sheets are available in a wide range of embossed patterns. Beside their beautiful esthetic appearance, the embossed patterns diffuse light by physical action providing an excellent solution for lighting applications. Embossing patterns include:

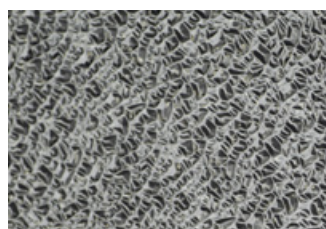
Pattern type	Maximum width (mm)	Maximum length (mm)	Thickness range (mm)
Pinspot	1500	up to 6000	1.5 to 5
Aqua	1400	up to 6000	1.2 to 5
Geometric	1400	up to 6000	1.5 to 5
Lizard	2050	up to 6000	1.5 to 5
Cracked Ice	1500	up to 6000	2.5 to 5
Prismatic K-12	1500	up to 6000	2.8 to 5
G-Tech	2050	up to 6000	1.5 to 5
Non reflect	1250	up to 6000	1.2 to 3
K-10	1400	up to 6000	2.8 to 5



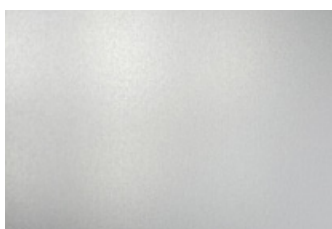
Aqua



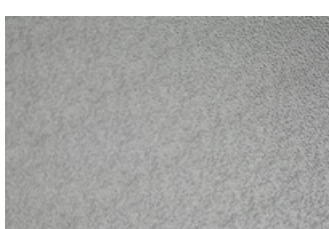
Pinspot



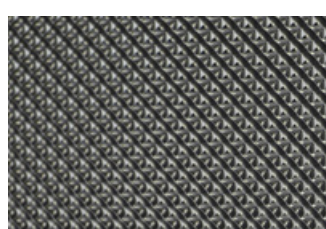
Cracked Ice



Non Reflective



G-Tech



K-12

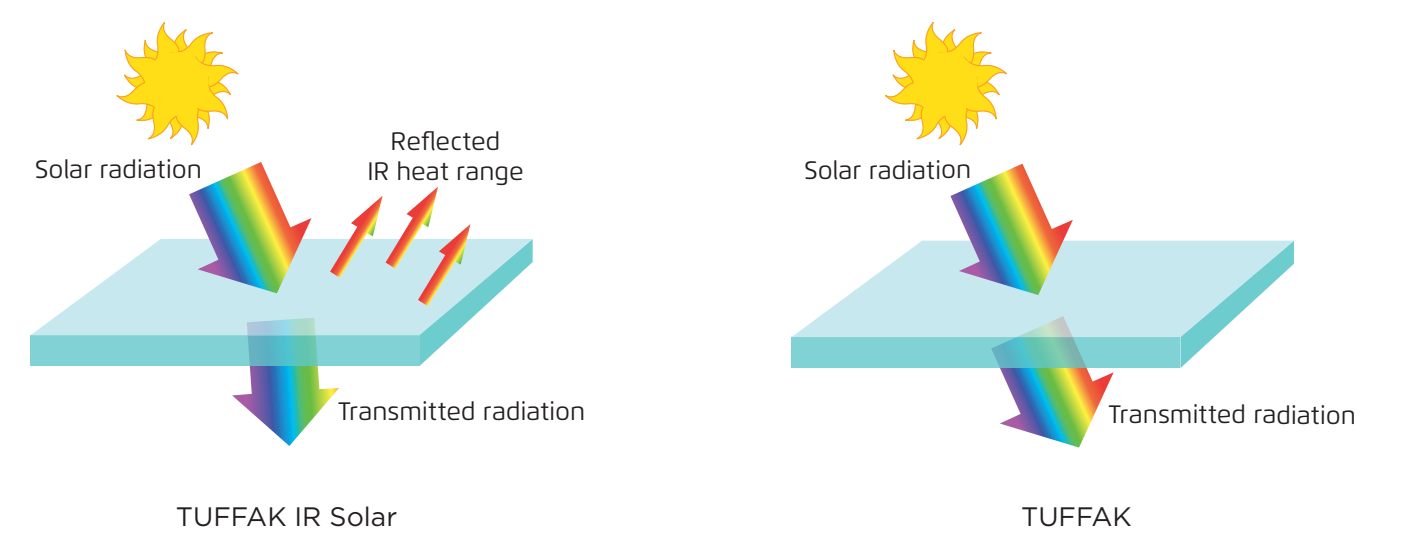
5.2 TUFFAK F - Fire Retardant PC Sheetsn

TUFFAK sheets have a good resistance to fire, they do not promote flame propagation and once the source of fire is removed, the material will self-extinguish. However, when additional fire retardancy is required for special applications, fire retardant grades are available. These grades are transparent and perform the same as the standard grades.

TUFFAK F grades rate V0 in the UL94 burning test (limited to specific thicknesses).

5.3 TUFFAK IR-Solar

TUFFAK IR-Solar helps to preserve energy, reduce cooling and heating costs. The solar near infrared (IR) radiation ranges from 700 to 2500 nanometers. These longer wavelengths are invisible to the eye, yet they contain about half of the solar energy. IR radiation builds up heat. The special formulation of TUFFAK IR-Solar reflects the undesirable hot IR radiation while allowing visible light to pass through.



Typical solar properties of TUFFAK IR-Solar grades:

	LT (%)	Tsol (%)	SHGC	SC
TUFFAK Clear Standard (R8000, 3 mm)	89	87.4	0.87	1
TUFFAK Reflective Silver (R8397, 3 mm)	17-20	20	0.37	0.43
TUFFAK IR-Solar Pearl (R8362, 3 mm)	48-52	38	0.49	0.56
TUFFAK IR-Solar Green (R8329, 3 mm)	53-57	28	0.50	0.57

LT: Light Transmission
Tsol: Solar Transmittance

SHGC: Solar Heat Gain Coefficient - the ratio of solar heat gain through the sheet and the incident solar radiation. It takes into account all conduction, convection and radiation effects involved. The SHGC of a 3 mm clear glass at normal (90°) incidence is 0.87.

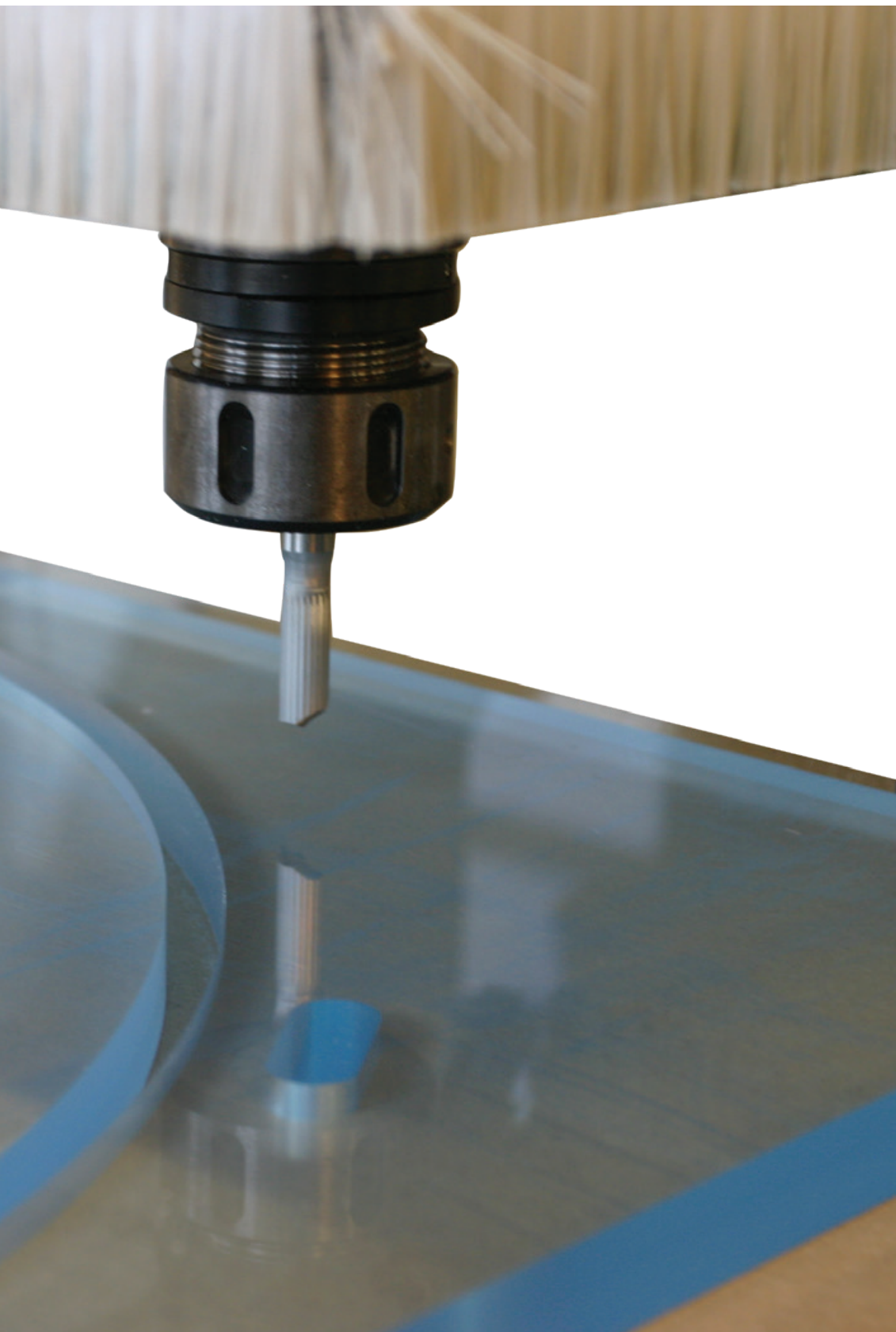
SC: Shading Coefficient is the ratio of SHGC of the sheet and the SHGC of a 3mm clear glass at normal (90°) incidence.

Measurements were performed according to ASTM E903 and ASTM E308 using a double-beam spectrophotometer with a 100 mm integrating sphere.

5.4 TUFFAK LED

LEDs are the most economical device in the field of illumination. They do not contain harmful elements like mercury, which is present in other illumination devices. LEDs are gaining popularity and are now replacing older illumination technologies. Unlike fluorescent or neon tubes, which have an angle of dispersion of 360°, LED's have a much narrower angle (from 40° to 140° for example) and appear as tiny spots of light. TUFFAK LED sheets from PLASKOLITE avoid this phenomenon known as "hot spots" and optimize uniform diffusion without compromising light transmission. TUFFAK LED sheet enables sign makers and designers to enjoy the benefits of LEDs and create elegant solutions that are cost and eco-efficient, whilst enhancing intensity and color.

Machining



6. Machining TUFFAK Sheets

TUFFAK sheets can be cut, sawn, drilled, milled and bent easily using standard workshop equipment for wood or metal. However, it is always recommended to use specific tools specially designed for plastics. TUFFAK are ideal for fabricating for a wide range of indoor and outdoor applications. It is preferable to leave the protective film in position throughout machining to keep the sheet surface in perfect condition.

6.1 Basic Rules for Machining TUFFAK

All methods of machining cause local overheating, generating internal stress, which can result in crazing (very fine cracks) later evolving into larger cracks, during forming or in the presence of solvents (for example during bonding or painting).

Crazing can be significantly reduced if the following general instructions are applied.

1. Proper cooling: Keep the working tools cooled with compressed air. Beware from using coolants that can chemically attack PC.
2. Swarf removal: Ensure efficient removal of swarf. Machining without suction requires frequent stops for manually cleaning the swarf.
3. Sharpened tools: Use only adequate tools and keep them perfectly sharp.
4. Material support: Support the sheet firmly during machining, especially close to the machined area, to avoid vibration of the sheet.
5. Feed rate: The faster the feed rate is, the better the cut, but when the tool exceeds a certain speed overheating leading to stress generation may happen. Maintain a constant feed rate as much as possible.
6. Rotation plane: Keep the rotation plane of the working tool exactly parallel or perpendicular (depending on the machine used) to the feed direction.
7. Annealing: Cold fabrication may generate internal stresses. Anneal the sheets before exposure to solvents or adhesives.

6.2 Cutting

When choosing the equipment for cutting TUFFAK sheets, a few factors must be taken into account:

1. The complexity of the cut.
2. The accuracy needed.
3. The quantities needed (cost efficiency).
4. The process following the cutting operation.

Hand Cutting

Thin TUFFAK sheets (up to 2 mm thickness) can be cut using a scoring knife. Draw the scoring knife along a ruler held firmly in place. Score several times applying very light pressure, at least 1/3 way through TUFFAK sheets thickness. Align the cut with a straight edge (for example, a table edge) and apply gentle pressure on both sides of the cut, starting at one end of the sheet, working your way slowly along the cut until full breakage is achieved.



Jigsaw

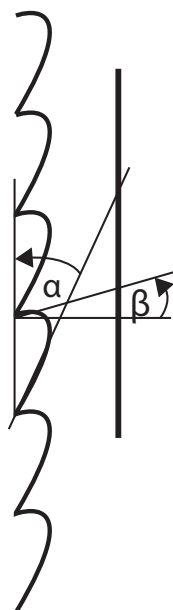
TUFFAK sheets up to 6 mm thickness can be cut by jigsaw, but results may be poor. Cutting TUFFAK with jigsaw results in inaccurate cuts and very rough edges. This type of cutting also causes high internal stress and will often cause melting and welding of the cut.

Band Saw

Although nice clean edges can never be achieved with a band saw, these types of saws are very easy to operate and are the most cost-efficient method for cutting irregular shapes, and trimming excess material from thermoformed parts before final machining. Band saws can be used to cut most thicknesses. For thin sheets, better results are obtained when sheets are stacked to a height of about 10 mm and cut together.

It is recommended to take note of the following guidelines to obtain best results:

1. The thickness of the blade should be 0.5-1.2 mm.
2. The width of the blade will range from 10 to 20 mm. A narrow blade will allow a curved cut with a smaller radius but with a poorer quality.
3. Tooth spacing 2 - 3 mm.
4. Clearance angle $\alpha = 20 - 30^\circ$.
5. Rake angle $\beta = 0 - 5^\circ$.
6. Band speed 600-1300 m/min (slower range for thicker sheets).
7. Feed speed 20 - 25 m/min.
8. Always firmly clamp TUFFAK sheets to prevent vibrations that may induce cracks.

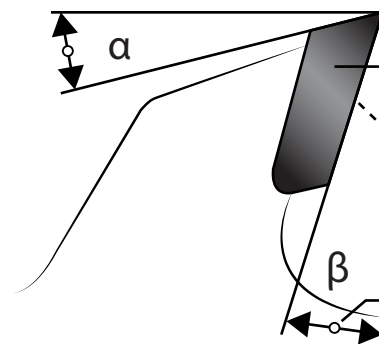
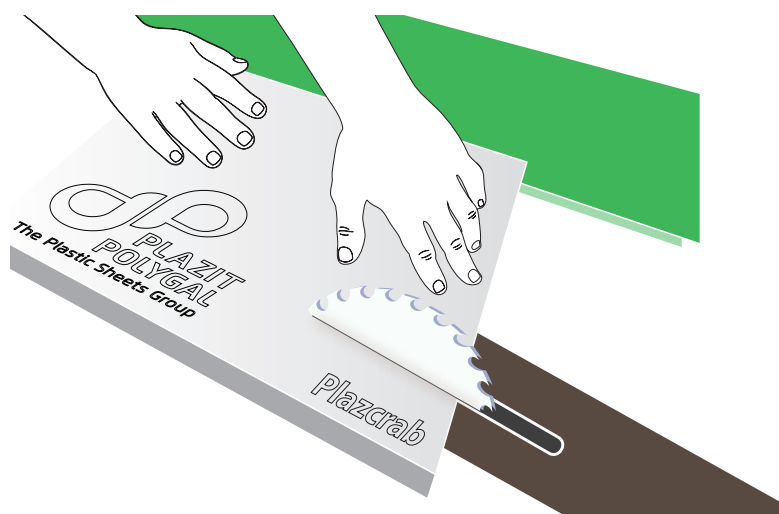


Circular saw

Using this saw, it is possible to achieve a straight accurate cut with a clean edge. Fixed table and moving cutting head machines are far more accurate and easy to handle and therefore perform better than stationary motor /moving table saws.

It is recommended to take note of the following guidelines to obtain best results:

1. Use carbide type saws.
2. Tooth spacing: steel teeth = 2 - 5mm, tungsten carbide teeth: 10 - 12 mm.
3. Clearance angle $\alpha = 20 - 30^\circ$.
4. Rake angle $\beta = 12 - 15^\circ$.
5. Cutting speed 1800 - 3000 m/min (slower for thicker sheets).
6. Feed speed 15 - 25 m/min .
7. Always firmly clamp TUFFAK sheets to prevent vibrations that may induce cracks.



Cutting - Troubleshooting

Problem	Possible cause	Possible solution
Sheet breakage	Excessive vibration	Support the sheet properly, especially close to the cut
	Blunt blade	Replace blade with a sharp blade
Chipping	Wrong blade type	Use a blade with characteristics according to the instruction in this guide
		Use a blade with more teeth per cm
	Blade too thin	Use a wider blade
	Feed speed too high	Decrease the feed speed
	Poor clamping	Check sheets are firmly clamped
Melting	Blunt blade	Replace blade with a sharp blade
	Blade not straight	Check blade alignment
	Wrong blade type	Use a blade with characteristics according to the instruction in this guide
		Use a blade with less teeth per cm
	Feed speed too low	Increase the feed speed
	Cutting speed too high	Decrease the cutting speed
	Saw overheating	Use air to cool saw
Sheets welding	Melting when cutting more than one sheet at a time	See melting problems and solutions
Crazing	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area

6.3 Laser Cutting

While not the most suitable method for cutting TUFFAK sheets, they may be laser cut up to 5 mm. Laser cut may need pre-drying of the sheet to avoid the development of bubbles caused by moisture entrapped within the sheet (see drying instructions). Laser cut results in high internal stresses, which must subsequently be relieved by annealing (see annealing instructions). Also, laser cutting may produce scorching and discoloration on the edge.



IMPORTANT NOTE:

When laser cutting TUFFAK, provide adequate ventilation at the cutting head to remove any trace of unpleasant combustion vapor.

6.4 Shear Cutting

Guillotine

PC is a ductile material, and as such can be shear cut with a guillotine for thicknesses up to 3 mm. Guillotine cut is fast and easy to perform however renders slightly rough edges, but it can still be suitable for many applications. Only one sheet at the time should be cut with this system. The guillotine blade should be very sharp to prevent cut stresses and cracks.

Punching

A shear cut similar to guillotine used to cut holes or other openings across the sheets. As before it is recommended for single sheets up to 3 mm thickness.

6.5 Drilling

As in the case of saws blades, working with drills and bits that were designed for plastics will have the best results. It is recommended to take note of the following guidelines to obtain best results:

1. Use carbide - tipped drills.
2. Drill speed 250-1800 rpm.
3. Reduce drill speed for larger sheet thicknesses or larger diameter holes.
4. Do not drill holes too close to the sheet's edge. Keep at least 10 mm from the edge.
5. Do not use cooling liquids that may cause chemical attack on PC. Use compressed air for cooling if needed.
6. Always firmly clamp TUFFAK sheets to prevent vibrations that may induce cracks.
7. Ensure efficient removal of swarf to reduce overheating and internal stresses in the hole area.
8. The drill bit must be kept vertical to the sheet.
9. Make the hole larger than the intended fixing element through it, to allow for thermal expansion and contraction.

Drilling-Troubleshooting

Problem	Possible cause	Possible solution
Sheet breakage	Excessive vibration	Support the sheet properly, especially close to the drill
	High pressure application	Apply very light pressure
	Wrong bit withdrawn	Withdraw the drill bit slowly and stop the rotation only after full withdrawal
	Blunt drill bit	Replace the drill bit with a sharp drill bit
	Curved drill bit	Replace the drill bit
	Advance speed too high	Decrease the advance speed
	Rotation speed too low	Increase the rpm
	Bit diameter too big	Drill a pilot hole

Problem	Possible cause	Possible solution
Melting	Blunt bit	Replace the drill bit with a sharp drill bit
	Curved drill bit	Replace the drill bit
	Advance speed too low	Increase the advance speed
	Rotation speed too high	Decrease the rpm
	Insufficient swarf removal	Clear the hole frequently and remove swarf
	Insufficient cooling	Cool with air and back feed the bit more frequently
Crazing	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area

6.6 Routing

Routing TUFFAK sheets is possible with Standard CNC, table or even hand routers. Bits designed especially for routing plastics will have the better results. It is recommended to take note of the following guidelines to obtain best results:

1. Use carbide - tipped drills
2. Router speed 20,000 -25,000 rpm.
3. Use two or three flutes cutters.
4. Best results are obtained with 6-12 mm diameter bits.
5. Feed rate should be reduced to avoid excessive heating
6. Always firmly clamp TUFFAK sheets to prevent vibrations that may induce cracks.
7. Do not use cooling liquids that may cause chemical attack on PC. Use compressed air for cooling if needed.

Cutting - Troubleshooting

Problem	Possible cause	Possible solution
Chipping	Blunt bit	Replace the bit with a sharp bit
	Excessive tool vibration	Check the collets, the bearing and the bit's shaft. Replace the defected part
	Excessive sheet vibration	Support the sheet properly
	Advance speed too high	Decrease the advance speed
	Rotation speed too low	Increase the rpm
	Advance speed too high	Decrease the advance speed
Tool breakage	Bit not properly installed	Fix the bit in collets and close it tight
	Heavy chip load	Increase number of flutes Ensure proper swarf removal
	Excessive tool vibration	Check the collets, the bearing and the bit's shaft. Replace the defected part

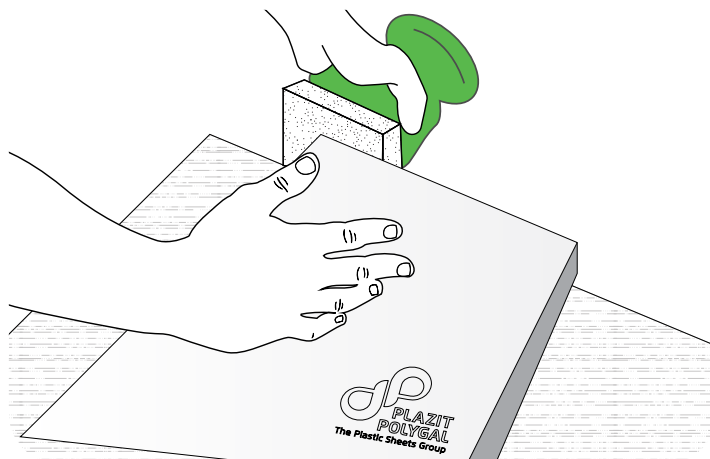
Problem	Possible cause	Possible solution
Melting	Blunt bit	Replace the bit with a sharp bit
	Advance speed too low	Increase the advance speed
	Rotation speed too high	Decrease the rpm
	Insufficient cooling	Cool with air and back feed the bit more frequently
Crazing	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area

6.7 Sanding and Polishing

All cutting methods described above may render saw marks, rough edges and corners, which apart of being a cosmetic deficiency may be a source of sheet weakness leading to crazing and cracking under end-use. It is recommended to smooth edges and corners by sanding and polishing.

Sanding

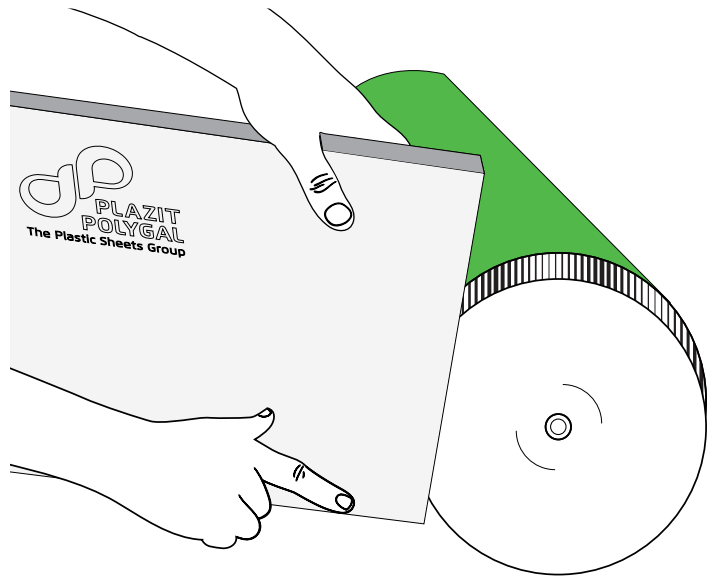
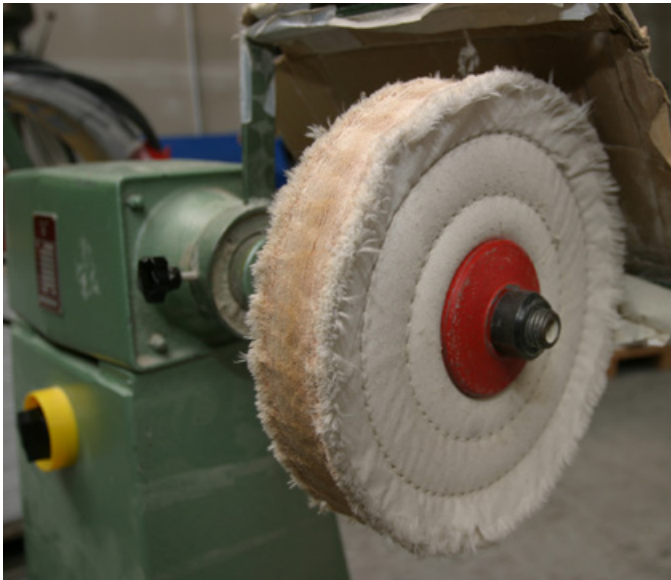
Sanding is used to remove machine marks or saw cut marks from the edges and corners. Standard woodworking belt or portable sanders may be used to sand TUFFAK sheets. Sandpaper with 400-500 grit is recommended. If TUFFAK sheets are very deeply scratched a 3-stage sanding process might be needed. First, the deep scratches should be sanded using 80-100 grit paper, then a 400 grit paper should be used to remove the scratches from the coarse paper and eventually a 600 grit paper should be used to prepare the surface for polishing. To prevent softening or melting of the surface, apply very light pressure and keep either part or sander in constant circular motion. Sanding with sandpapers 150 grit or finer, should be done wet.



Hand sanding is possible for sanding small areas or when power sanding is not possible, due to lack of equipment or inaccessible surface. Use a wooden or rubber sanding block. If the surface that is to be sanded is not flat, the sanding block must have its mirror shape enabling to apply even pressure on all the sanded surfaces. Apply the 3 sanding method as described before.

Polishing

When polishing TUFFAK sheets edges, machine marks must be first removed by sanding as described in the previous section. Stationary and portable machines with rotating calico mops, muslin or felt can be used to polish TUFFAK sheets. Apply mild abrasive buffing compound with light pressure to prevent overheating.



Problem	Possible cause	Possible solution
No polish is achieved	Insufficient rubbing	Apply more pressure Increase the speed of the wheel
	Insufficient buffing compound	Apply more buffing compound
	Surface not sanded	Sand the surface according to the instructions
Optical distortion	Too small area	Polish a wider area and feather its edges



Forming



7. Forming TUFFAK Sheets

7.1 Cold Bending (Line Bending)

TUFFAK sheets are ductile and can be cold-bent in a straight line, up to an angle of 90° or more. When cold bending TUFFAK sheets, a plastic permanent deformation is induced in the bending line. This deformation causes a reduction of the mechanical properties in the bent area.

If the sheet is UV protected, the UV coextrusion layer will stretch and the UV resistance in the bent area will be decreased. Also, plastic deformation causes frozen-in internal stresses that reduce the chemical resistance of the sheet in the bent area and increase the susceptibility to ESC attack. Annealing may cause a partial improvement of the mechanical and chemical resistance.

It is recommended to sand and polish the edges of the sheet before bending. The small cracks of a rough edge can cause the cracking of the sheet during bending.

The sheets should be bent with an excess angle of about 30 degrees over the desired final angle, due to relaxation. It is recommended to relax the sheet for 24-48 hours after bending to let the sheet settle to its final form.

It is recommended to use equipment designed for plastics. Metal working equipment may not be the best suitable for this task. Particularly the blade radius should be about 4-6 mm. The thicker the sheet the larger the blade radius. Both, blades and anvil, should be smooth and polished and deprived from sharp angles and corners.

For TUFFAK sheets up to 6 mm, the recommended minimum bent angle is 90°.

For higher thicknesses, up to 12 mm, the recommended minimum bent angle is 135°.

Hard coated sheets cannot be bent.

7.2 Thermoforming

TUFFAK softens with temperature allowing for easy thermoforming.

Thermoforming involves four stages:

1. Pre-Drying - TUFFAK sheets absorb moisture from the environment and must be pre-dried for quality thermoforming.
2. Heating - softening TUFFAK until its plastic/soft phase.
3. Forming - forcing TUFFAK into the desired form.
4. Cooling - restoring TUFFAK its initial rigidity.

Forming with PE film

PLASKOLITE has developed a special PE masking film that can be left in position during heating and forming. However, when deep thermoforming is needed it is recommended to remove the film before forming. Local overheating may cause fusing of the PE film to the sheet surface, impeding its removal. When introducing the TUFFAK sheet to the thermoforming machine avoid scratching and indenting the sheet. Small hardly visible scratches and indentations in the sheet will expand and may become visible after thermoforming.

Ghosting problems when forming with PE film

When TUFFAK sheets are intended for forming applications, it is recommended to order the sheets with plain PE protective film (i.e. without any printed logos). Printed logos in the PE films can cause “ghosting”, i.e. a “watermark-like” defects on the formed sheet. Printed film must be removed before thermoforming, to avoid ghosting.

Safety note

While TUFFAK sheets have a good resistance to fire, they will melt and burn under intense heat or fire. Before heating TUFFAK, the necessary fire precautions must be considered, based on regional regulations and good judgment, considering the burning behavior of TUFFAK. When heating TUFFAK horizontally, extra care should be taken to prevent sagging on the heater causing damage and a possible risk of fire.

Co-extrusion layer

Most thermoforming techniques include a significant amount of stretching. Stretching the sheet will cause a reduction in the overall thickness of the sheet including in the thickness of the co-extrusion UV protection layer. The TUFFAK UV and 2UV co-extruded, UV protected sheets have co-extrusion layers specifically designed for long term UV protection. Stretching the coextrusion layer to a lower thickness will reduce or even stop completely the UV protection of the sheet in the highly-stretched areas.

Pre-drying

TUFFAK sheets absorb moisture from the environment and must be pre-dried for quality thermoforming. The appearance of small bubbles in the sheet, after the heating process, is an indication that moisture is present in the sheet. Apart from the cosmetic deficiency of the part, moisture in TUFFAK sheets during thermoforming can cause degradation of the material reducing the mechanical properties of the part.

Remove the protective film and pre-dry in a dehumidifying air circulating oven at controlled temperature of 120oC for a recommended period of time according to the following table. The final drying time will depend on the quality of the drying oven and it may be increased if results are not satisfactory. However, care should be taken not to dry longer than needed, which may result in thermal aging of the material. Final moisture of the sheets should be less than 0.04%. The sheets will start absorbing moisture as soon as they are removed from the drying oven, so it is necessary to thermoform the sheet as soon as possible.

Recommended Drying Time at 120°C	
Sheet Thickness (mm)	Drying Time (h)
1	1
1.5	1.5
2	3
3	6
4	10
5	16
6	23
8	32
10	36
12	48

Heating

If TUFFAK is formed before it is soft, stress is generated and reduction of mechanical properties leading to mechanical failure may occur. On the other hand, too much energy will melt the material, making it impossible to work with, or might even cause surface blisters. Hot spots may even cause local material degradation and reduction of mechanical properties. PC has a narrow high-temperature forming range. Good temperature control is required to produce high quality thermoformed parts. Care should be taken to ensure that TUFFAK is uniformly heated: temperature differences exceeding 5°C across the sheet may lead to internal stresses. Internal stresses are invisible but may cause significant reduction of the part performance. The working area must be sealed from drafts. Wind will badly influence the results. Certain TUFFAK colors can change slightly during the heating process, specially is the sheet is overheated. Moreover, since the sheet is stretched due to drawing, there will be an inevitable thinning of the sheet, giving rise to a decrease of opacity (in opaque sheets) or an increase in light transmission (in translucent sheets) through the thinner area.

Hot-air circulation oven

This technique is characterized by the uniformity of heating and by its mass production capabilities. More than one sheet can be in the oven in different stages of heating, therefore it is the obvious choice of high volume producers. Temperature should be accurately controlled. For optical quality products sheets should be hung vertically to avoid any contact with a surface. Hang the sheets along their longest dimensions using suitable clamps.

Infrared heating

Infra-red inline heating machines (all three thermoforming stages done on the same machine) are the preferred option for heating TUFFAK. These machines have a heating head, which can be moved freely when the heating process is done, making room for the forming and cooling process. Although heating time is very short, the possibility to heat only one sheet at a time makes this method cost efficient only for low volume / high versatility production. TUFFAK of 5 mm thickness and above must be heated by a two-sides heating device. Two-sided infrared heating machines are preferable in all cases because they will cause a more uniform heating through the sheet thickness.

Forming

Heating conditions

The following factors should be taken into consideration when determining the temperature and time of the heating process:

1. The sort of heating source (infrared or hot air circulation).
2. The distance between the sheet and the heating source.
3. The uniformity of the heating (on all three dimensions of the sheet).
4. The material thickness.
5. The type of mold.
6. The depth and complexity of the required shape.
7. Degree of stretching required.

Heating temperatures

Minimum temperature (°C)	150
Maximum temperature (°C)	190
Recommended range (°C)	170-190

Shrinkage

After heating, TUFFAK extruded sheets will shrink during the cooling process. The shrinkage is higher in the extrusion direction (MD - machine direction) than in the direction perpendicular to the extrusion (TD - transverse direction). When final part dimensions are critical, forms must be sufficiently oversized to allow for shrinkage when the part cools from ejection temperature to room temperature.

The table below shows typical shrinking percentage of TUFFAK sheets:

Sheet Thickness (mm)	Shrinkage M.D*	Shrinkage T.D*
1.80 - 2.30	6% - 7%	0.5%
2.30 - 3.50	5% - 6%	0.5%
3.50 - 4.00	3% - 4%	0.5%
4.00 - 6.00	2% - 3%	0.5%
6.00 ++	2%	0.5%

*M.D - Machine (extrusion) direction

*T.D - Transverse (perpendicular to extrusion) direction

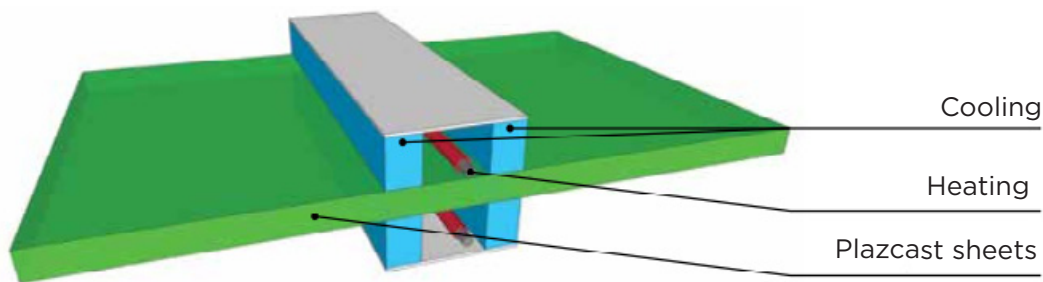
Forming

While in its soft phase, TUFFAK can be formed to almost any shape, by different methods and equipment. Home-made machines as well as sophisticated commercial machines can be used depending on the product requirements (complexity, quality and volume).

Line bending

Most common line bending simple equipment will give excellent results. Double side heating machines with cooling strips are recommended if a very accurate bend and high quality surface near the bend is needed. Ceramic and quartz tubes or even metal rod heaters equipped with a thermoregulator and installed with parallel support on both sides are most commonly used. For thinner sheets (< 3 mm) it may be possible to bend without pre-drying, however inspect the quality of the bend to reach the final conclusion about pre-drying or not. The supports should keep TUFFAK at least 0.5 cm away from the heater. First, remove the PE Film from the bend area facing the heater then, lay TUFFAK on the supports with the bend line above the strip heater. The recommended material temperature range when line bending is 155°C-165°C. Bend immediately as PC has a fast cooling rate. Remove the sheet from the heater, place it in a fixture with the desired angle, clamp it and leave it to cool naturally. Overbending may be necessary to achieve the final desired angle. Line heating and bending of PC (as any other thermoplastic) induces stress into the material. Design and processing good practices will reduce the level of stress; however, the properties of the material in the bent area will be unavoidable lower. Bent areas should be kept away from adhesives and chemicals that can produce ESC.

Please note the following points:



1. Avoid direct contact of TUFFAK with the hot strip heater.
2. Sheets of more than 3 mm thickness should be heated from both sides.
3. If this is not possible heat the sheet several times from each side.
4. For thick sheets (> 3 mm) it is recommended to make a 2 mm radius groove on the inner side of the bend prior to the heating.
5. A bend line longer than 1000 mm might bow across the bend. This can be improved if TUFFAK is bended perpendicularly to the machine direction.
6. The greater the diameter of the rod heater and the more the rod heater is distant from TUFFAK, the wider the heating zone, enabling formation of a bend with a larger radius.
7. The width of the heating zone should be:
Bending TUFFAK up to 900 - 3 times the thickness.
Bending TUFFAK more than 900 - 5 times the thickness.
8. Avoid contact of the heated TUFFAK with hard rough surfaces. Felt, flannel or aluminum can be used to cover the surface of the fixture, to help prevent stamping.
9. Anneal the bent part before exposure to solvents or excessive temperature changes.

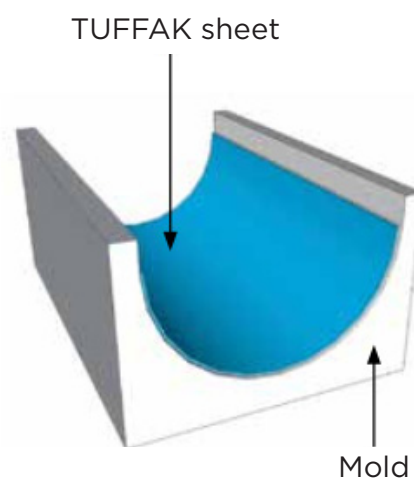
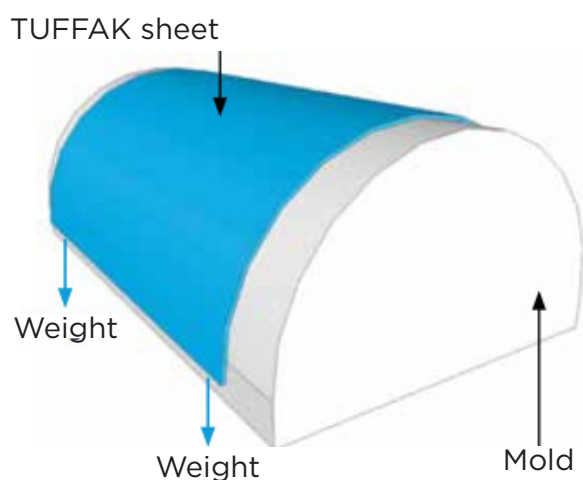
Hot line bending - Troubleshooting

Problem	Possible cause	Possible solution
Blisters on the surface of the sheet	Overheating	Shorten the heating time
		Lower the heaters temperature
		Increase distance between sheet and heater
Bubbles in the sheet	Moisture in the sheet	Pre-dry the sheet before hot bending
Radius of bend too wide	Heated zone too wide	Use a heater rod with smaller diameter
		Lay the sheet closer to the heater
	Heated zone too narrow	Use a heater rod with bigger diameter
Crazing	Excessive stress	Increase distance between sheet and heating source
		Anneal the bent part
	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area
Crossbow bend	The sheet is too wide	Bend the sheet perpendicularly to machine direction

Drape forming

This method of forming is restricted to two dimensional or very simple three dimensional shapes, which require no stretching for forming. When drape forming, pre-drying may not be necessary; however, inspect the quality of the product to reach the final conclusion about pre-drying or not.

Heat TUFFAK properly between 1500C and 1550C and without delay, drape it over the mold. In drape forming it is crucial that TUFFAK is placed on the mold at the right temperature. If not hot enough, TUFFAK will not obtain its shape but if too hot, it will curl and twist. TUFFAK will often obtain its form by the force of its own weight but in some cases the help of some forcing is needed. The hot edges of TUFFAK tend to curl and therefore clamping or heavy covering should force the edges to the mold.



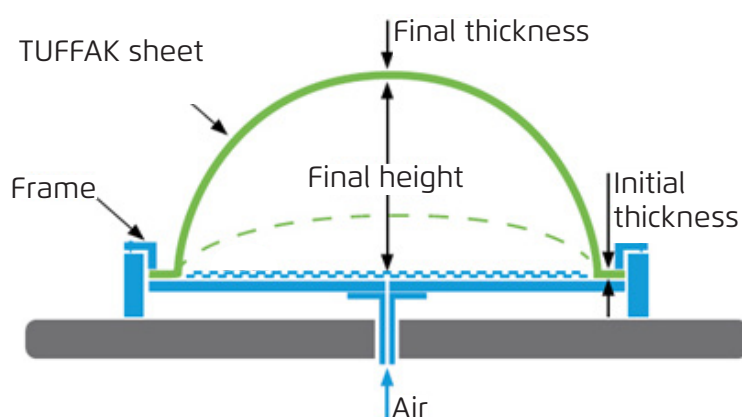
Free blown forming

This method is suitable for high optical quality and limited bubble-like part shapes. Requiring low cost equipment and short production cycles. This method is the most cost efficient for sky dome production. The free blowing equipment is composed of a plywood board attached to a compressed air source with a pressure control device. It is recommended to preheat the clamps and tool to about 100-120°C. Frame the pre-dried sheet tightly and heat it until it sags uniformly (170-190°). Gradually increase the air pressure (or vacuum) to the desired point. Maintaining the pressure at the desired point. Let TUFFAK cool. Dismantle after regaining rigidity.

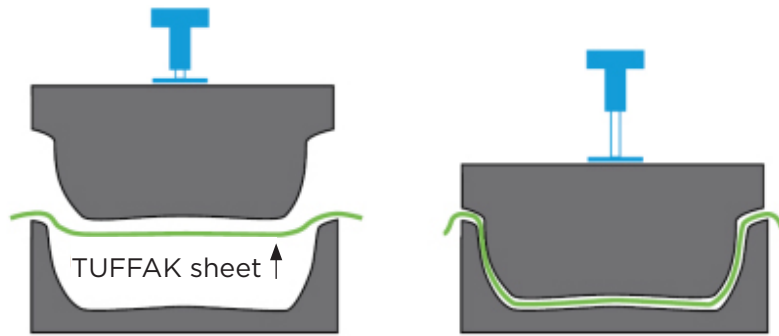
Please note:

1. The air pressure controls the height of the dome.
2. The shape of the dome can be altered by an imprint and by using a different frame shape.
3. The top part of the dome will be thinner than the part close to the base. This includes the coextrusion UV protective layer.
4. Since vacuum is restricted to 1 atmosphere, the use of vacuum free forming will limit the height of the dome.
5. Commonly used air pressure is 3 - 4.5 atmospheres.
6. Use clean filtered air. Contaminations will impress in the part.
7. Disperse the incoming air, using a protective plate felt or cotton wool. Cold air jet, directed onto the hot TUFFAK will cause rapid local cooling and as a result high stress and non-uniform expansion of the sheet and may induce frozen-in stresses.
8. Forming big domes is better performed when blowing with hot air.

Press forming



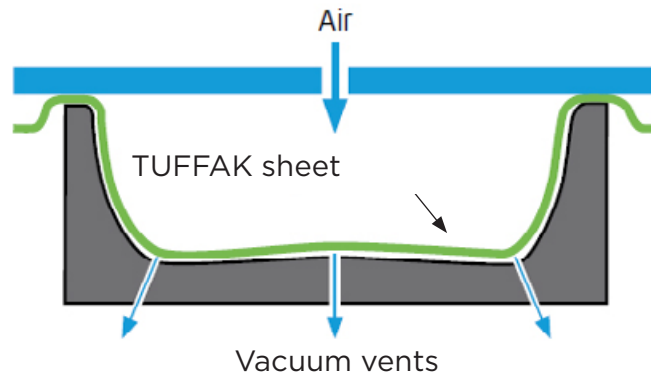
The pre-dried, pre-heated TUFFAK is clamped over the cavity, and then pressured into it, up to a fixed depth, by the plug. Pressing can be done by a manual drill press, air cylinder or pneumatic cylinder. The plug and cavity must match in a way that enough space will be left for the sheet. Air pockets can be vented by vacuum through holes in the mold. Accurate dimensions of the mold are needed to achieve good tolerances.



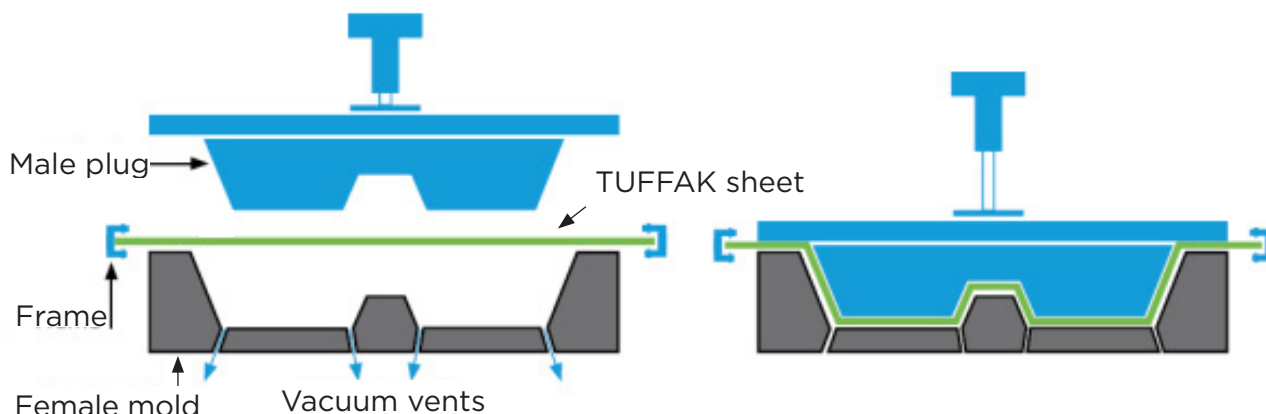
Straight vacuum (pressure) forming

This is a very simple method with fairly good results. The quality of the surface is good and the wall thickness for shallow drawn parts is quite even. Both female and male molds can be used. The pre-dried, pre-heated TUFFAK is clamped over the mold. The air, trapped between the sheet and the mold, is then sucked through vacuum forcing the sheet to form against the mold. When using air pressure instead of vacuum it is essential to make vent holes in the mold to enable evacuation of the trapped air to form its final shape. Since vacuum is restricted to 1 bar, straight vacuum is limited to forming shallow simple parts. Using high pressure (up to 5 bar) the straight forming method can be used for more complex parts.

Plug-assisted forming



This is a more demanding process. Better control of forming rate and temperature are required, and only experienced workers will be able to achieve the needed results. Plug-assisted is used for forming deep drawn parts that require a better wall thickness uniformity. The pre-dried, pre-heated TUFFAK is clamped over the cavity and the plug is then lowered to stretch the sheet. When the plug is in its final course, applied vacuum from the cavity or pressure from the plug forces the sheet against the cavity to form its final shape. For even better wall thickness uniformity, vacuum is first used to create a maximal bubble and only then the plug is lowered. When the plug is in its final course, pressure from the plug forces sheet against the cavity to form its final shape. The plug will be 80% - 90% of the volume of the cavity. The shape of the plug will influence the distribution of wall thickness. The plug should be heated or at least made of low thermal conductivity material to prevent mark-off.



Cooling

After shaping, TUFFAK must be left on the mold, with the applied pressure to cool. TUFFAK sheets cool quickly compared to other materials and can be removed from the mold relatively fast.

TUFFAK can be removed from the mold even at when at 1250C. However, if too hot TUFFAK might not retain its shape, but if left for too long, TUFFAK might cool and shrink too much on the mold, causing excessive stress and making it hard to release it from the mold. Avoid drafts and when working in a cold environment cover TUFFAK with felt or flannel. Covering is also very important for cooling uniformly through the bulk of thick wall final parts. A heated mold helps with the gradual cooling process. Slow uniform cooling is essential to prevent stress. Cooling too fast will induce internal stresses in the part reducing its properties and making it more susceptible to ESC. A better part quality comes at the expense of a lower output rate.

Molds

Used in different forming methods and for production of different products, molds can be made of a variety of materials such as hard wood, aluminum, steel, gypsum, reinforced polyester or epoxy resins. Laminating and finishing of molds made of other materials than metal, should produce a surface which will resist wear and will prevent distortion by moisture. Aluminum made molds with temperature control will achieve best results for large quantity production. Faults in the finished mold will leave imprints on the molded part. When making a mold, the shrinking properties of TUFFAK, must be taken into account. Allow for shrinkage, to make sure that the finished part is not smaller than required (see shrinkage instructions). Mold clearance angle, must be a 30-60 for convex parts and 0.50- 10 for concave parts (TUFFAK tends to shrink on convex parts and away from concave parts). A heated mold will result in better part shaping and will cause a more gradual cooling, reducing induced stress. When molding TUFFAK the mold temperature range should be 100°C-120°C. Uniform mold heating is necessary to obtain the highest surface detail and optical quality. Keep the mold clean. Dirt and dust in the mold will imprint on the molded part. Surface embossing is sometimes used to produce patterned surfaces in TUFFAK sheets for applications such as lightning fixtures. Surface embossing is produced by pressing the hot sheet against a mold having a textured surface.

Thermoforming - Troubleshooting

Problem	Possible cause	Possible solution
Blisters on the surface of the sheet	Overheating	Reduce the temperature or shorten the heating time Prevent hot spots Increase distance between sheet and heating source
	Moisture in the sheet	Pre-dry the sheet before thermoforming
Bubbles in the sheet	Overheating	Reduce temperature
	Uneven heating of the sheet	Fix malfunctioning heaters Eliminate drafts
Uneven form	Bad clamping	Ensure firm clamping of the sheet
	Sheet is too hot or too cold during forming	Adjust temperatures or time
	Mold too cold	Increase the mold temperature
	Use controlled heat mold	
Surface defects	Defect in the mold	Replace the mold
	Dirt on the mold	Clean mold thoroughly before heating
	Dirt on the sheet	Clean sheet thoroughly before heating
	Scratches or indentations on the sheet before forming	Keep the sheet from scratching or indenting while handling before thermoforming. Small scratches and indentations will amplify during forming
Water marks on the surface of the sheet (ghosting)	Defects on the PE protective film	Thermoform sheets either with perfect PE film or without PE film
	Printed PE logos imprinting on the sheet	Use plain PE film or remove PE film before thermoforming
	Low pressure	Increase the pressure applied
	Defect in the mold	Replace the mold
Imperfect form	Cooling time too short	Ensure sheet is sufficiently rigid before removing from mold
	Heating elements	Heating elements malfunctioning or not calibrated
	Sheet is too hot or too cold during forming.	Adjust temperatures or time
	Drawing is done too quickly.	Reduce drawing speed
	Mold too cold	Increase the mold temperature Use controlled heat mold
	Uneven heating of the sheet	Fix malfunctioning heaters Eliminate drafts
Crazing	Cooling time too long	Do not allow the sheet to shrink too much on the mold
	Internal stress	Anneal the part
	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area
	Sheet is too hot or too cold during forming	Adjust temperatures or time
	Drawing is done too quickly	Reduce drawing speed
	Mold too cold	Increase the mold temperature Use controlled heat mold
Cracks or broken areas	Mold angles are too sharp	Round angles and corners in the mold
	Internal stress	Anneal the part

7.3 Annealing

Internal stress in TUFFAK, as a consequence of machining and forming can result in crazing (very fine cracks) which will later evolve into larger cracks, especially in the presence of chemicals (for example during bonding or painting) or exposure to harsh environmental conditions (industrial and agricultural areas, motorways, repeated cleaning, etc).

Internal stress can be a result of:

1. Machining - All methods of machining cause local overheating, thus resulting in internal stress.
2. Forming - Forming too cold, overheating or cooling too fast or unevenly after thermoforming, will cause internal stress. It is strongly recommended to anneal TUFFAK sheets before any bonding, painting or printing operations.

Annealing time and temperatures

TUFFAK should be annealed at 120°C - 130°C for 1 hour up to 3 mm. Above 3 mm anneal for 20 minutes more for each additional mm (e.g. a 5mm sheet will need 1 hour and 40 minutes annealing):

- Insert the sheet in the annealing oven only when the oven has reached the target temperature
- Beware that the oven temperature does not drop significantly during sheet insertion
- It is recommended to anneal without the PE protection film
- After the annealing, turn off the oven and let the sheet cool inside it

It is important to allow the annealed parts to cool slowly in the oven, as stated above, to avoid the development of new stresses due to thermal shock during the annealing process.

Do not overanneal. Higher temperatures or extended annealing time may cause heat aging and degradation of the sheet.

Assembling



8. Assembling TUFFAK

When choosing the assembling method for TUFFAK sheets, a few factors should be regarded:

1. The strength of the joint needed.
2. The transparency needed.
3. The material assembled to TUFFAK.
4. End use environment.
5. Required durability.
6. Is disassembling needed?

8.1 Assembling with screws

When assembling TUFFAK to a different material (wood, metal, other plastics) or to rough and inaccurately fit surfaces, screwing may be the preferred solution. Like all other machining operations, cutting screw threads in TUFFAK is done in the same manner and with the same standard tools as cutting screw threads in wood. Drill a hole of the required size in TUFFAK, then use a screw-tap to cut the screw threads. It is recommended to cut threads only in one of the parts being assembled, leaving the other part with a smooth drill hole. The great advantage of assembling by screwing is that it is a reversible process, which allows for repeated assembling and disassembling.

When screwing TUFFAK sheets a few factors should be considered:

1. Use sharpened screw-taps.
2. Be careful to use only compatible lubricants to reduce the friction.
3. When tapping a hole three times deeper than the diameter, back feed the drill, at regular intervals, to ensure removal of swarf.
4. Metal fixings are recommended especially if dismantling is likely.
5. Anneal the cut areas if glue is to be used.
6. When TUFFAK will be exposed to fluctuating temperatures, allowances for thermal expansion and contraction must be provided. Drill oversize holes and slots, use compatible spacers and washers and do not overtight the screws.
7. Use wide EPDM washers to distribute and reduce the stress levels arising for the screws.
8. TUFFAK should not be placed in contact with incompatible materials such as soft PVC washers or silicone sealing compounds containing unknown additives. Use only neutral silicone.
9. Assure that oil and greases are removed from the screws before use. Some oil and greases may attack chemically the PC.
10. Special care must be taken when assembling TUFFAK sheets to other materials. Different materials have different coefficients of thermal expansion. When screwing TUFFAK to other materials allow for thermal expansion clearance.
11. The space between the screw hole and the sheet's edge should be 1.5 times the hole diameter.

Problem	Possible cause	Possible solution
Crazing while tapping	Bad drill holes	See drilling troubleshooting
	Excessive stress	Use lubricants (compatible with PC) Ensure proper swarf removal
	Chemicals	Remove any chemicals close to the working area
Crazing while screwing		Use a screw with smaller diameter
	Excessive stress	Use only reasonable force to fasten screws Use rough threaded taps and screws
	Contact with chemicals, even in vapor form	Remove any chemicals close to the working area
Threaded wearing	Glue presence	Anneal the part if glue is to be used
	Excessive disassembling and assembling	Use metal fixing

8.2 Riveting

Riveting can be used to assemble TUFFAK sheets. Care should be taken when using this assembling method since it can produce local stresses on the sheets. Use appropriate rubber washers from both sides of the rivet. Use a metal back-up washer with laminated rubber from bottom side of the rivet. When riveting the plastic sheet to metal, install the rivet head with a rubber washer from the plastic side. Make the hole 1.5 times the diameter of the rivet.

8.3 Bonding

TUFFAK sheets can be bonded using different methods.

A wide range of adhesives is available in the market. Polyurethane, epoxy and silicone adhesives maybe used however, the choice of the right type of adhesive depends on the application and should be done carefully. Adhesion technology is a very technical field by its own. Apart from properties such as flexibility, mechanical strength, durability (indoor-outdoor), etc. of the bond, the compatibility of the adhesive to PC must be assessed. Any substance that comes with contact with PC should be checked for compatibility. Even if the supplier confirms that the material is suitable for PC, apply first to a hidden area to see if there are any effects. However; this will cover for short-time effects only. To assess long-term effects of substances on PC, laboratory testing is required.

It is essential to anneal the parts previously to bonding, to prevent crazing. The surfaces to be bonded must be kept clean and free from oil, dust and contaminants of any type. Cleaning the surfaces prior to bonding is recommended. Bonding techniques are considered generally to be irreversible and are used in applications where disassembling is not required.

Safety Measures

Most types of solvents and adhesives are highly volatile, flammable and toxic.

1. Always follow the adhesive manufacturer's instructions and safety instructions according with the adhesive's Material Safety Data Sheet (MSDS).
2. Always work in a well-ventilated area.
3. Keep open flames from the area. Do not smoke in the area.
4. Use respiratory protection as described in the adhesive's MSDS.
5. Protect skin and eyes from contact with solvents as described in the adhesive's MSDS

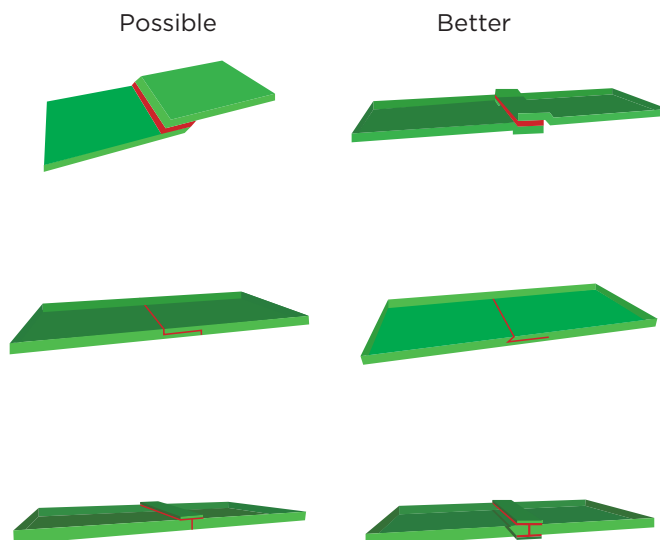
Solvent Bonding

Solvent bonding is a popular method used to bond TUFFAK. The solvent dissolves and softens the surfaces. Upon pressure application, a complete fusion can be achieved at the interface of the joint which then hardens by solvent evaporation. Dichloromethane (DCM, Methylene chloride) is recommended for solvent bonding PC.

Design of Adhesive Joints:

WARNING! Solvents are harmful if swallowed, inhaled or absorbed through skin. Always work according solvent's MSDS instructions.

The design of the adhesive joint has an influence on the final strength of the bond. Joints should be designed in a way that transform tensile or compressive stress to shear stress. The larger the bonding area, the stronger the bonding. Anneal parts after machining the designed joint and before bonding.



8.4 Welding

TUFFAK can be welded by different methods: ultrasonic, radio frequency, spin welding etc. Welding is most useful when attaching TUFFAK to itself. For assembling TUFFAK to other materials, screwing or bonding may be a better option. The different welding methods generate heat energy by different ways that soften the edges and thus weld the joint. This process leaves great stress in the material, which must be relieved later by annealing. This method results in weak joints, 10% to 40% of the original strength. Welding techniques are considered generally to be irreversible and are used in applications where disassembling is not required.

Printing



9. Printing TUFFAK

TUFFAK can be decorated by screen, digital and spray-painting. Inks and paints formulated for PC must be used. Beware of using inks and paints that can chemically attack PC (e.g. contain toluene, xylene or other solvents). Usually, no surface treatment is required on clean PC sheets before decorating.

Preparing TUFFAK

When decorating TUFFAK, it is important to keep its surface clean. Smallest particles, surface stains and even static charges will cause uneven spread or adherence failure of the paint. Remove the protective PE film as close as possible to the beginning of the decorating process. It is recommended to use an ionizing gun to remove dust and neutralize static charges before decorating operations. Keep the surface from being stained and if necessary clean TUFFAK with a damp rug or isopropyl alcohol.

UV co-extrusion

TUFFAK UV and 2UV carry a co-extrusion UV protection layer (one or two sides respectively). While this layer is basically made from PC, the adhesion of the ink may be a little different than for the non-protected layer. Ink and process adjustments may be needed when decorating on the UV co-extrusion side.

Ghosting problems when printing

When TUFFAK sheets are intended for printing applications it is recommended to order the sheets with plain PE protective film (i.e. without any printed logos). Printed logos in the PE films can cause “ghosting”, i.e. a “watermark-like” defect on the printed sheet. If some logo is required in the PE protective sheet, printing should be performed in the reverse side of the sheet. Electrostatic charges on the sheet surface can also cause ghosting. They should be dissipated before printing.

Installation



10. Installing TUFFAK

10.1 Installation - General guides

Light weight, high transparency and outstanding weather performance makes TUFFAK an excellent glazing and signage material for both exterior as well as interior uses. The excellent toughness of PC makes it the first choice for vandalism exposed applications.

After the general desired dimensions of the sign/window are chosen, the exact dimensions of TUFFAK and frame are determined according to the following stages.

1. Determining the maximum wind load.
2. Determining thickness of the TUFFAK sheet.
3. Determining the expansion clearance.
4. Determining the groove dimensions and the exact dimensions of the TUFFAK sheet.

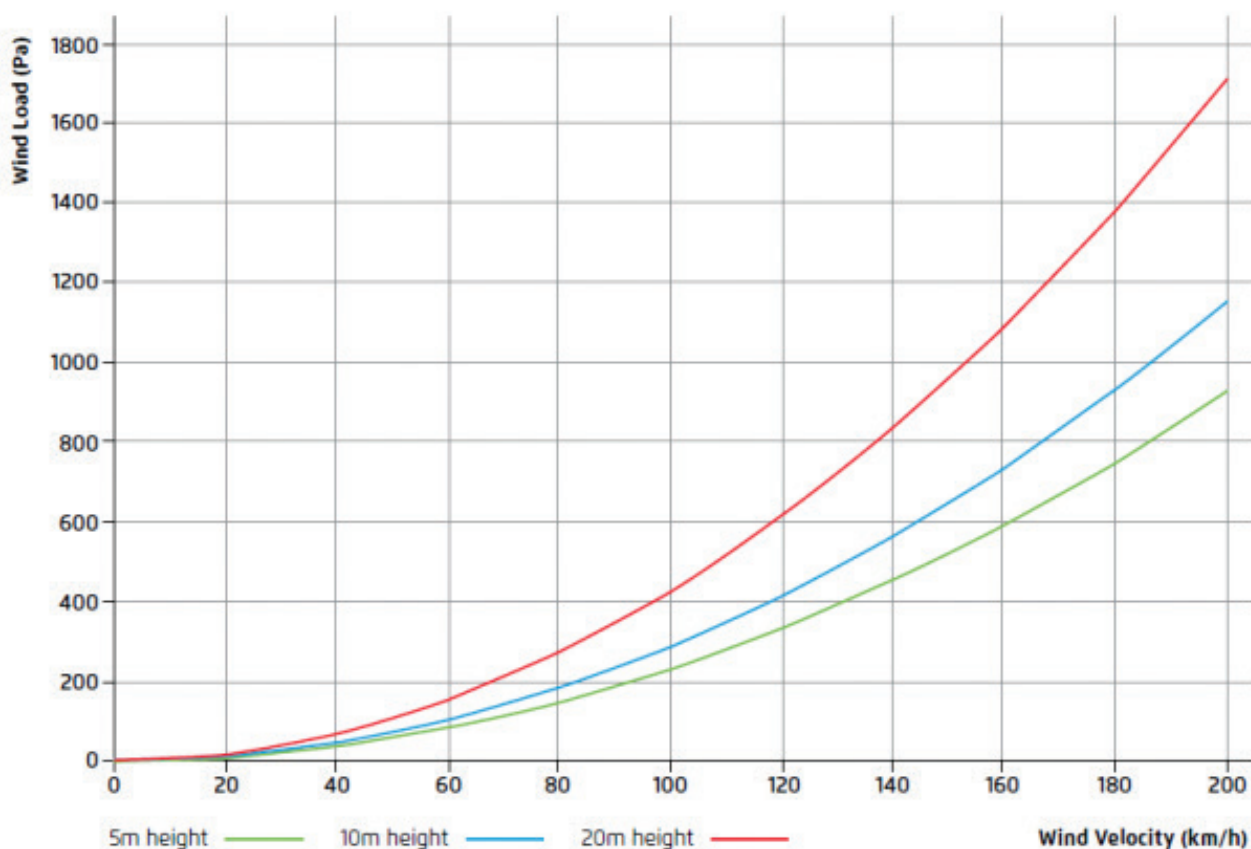
*** The following data is intended as a basic guideline for simple signs/windows applications. When TUFFAK sheets are to be mounted in construction projects (full roofs, acoustic walls, etc.) under complicated load fields, curved designs, complicated supporting systems and/or extreme temperature and environmental conditions, accurate engineering analysis is required. Seek advice from a construction engineer.**

Maximum wind load

Determine the maximum wind load, which will be applied on the mounted sheet according to Figure 1. The maximum wind velocity, in the area and the height of the mounted TUFFAK determines the wind load.

Note: The graph refers to a vertically placed, straight sheet (not curved) - The load does not take into consideration the self-weight of the sheet and snow weight load

FIGURE 1 – WIND VELOCITY – LOAD CONVERSION



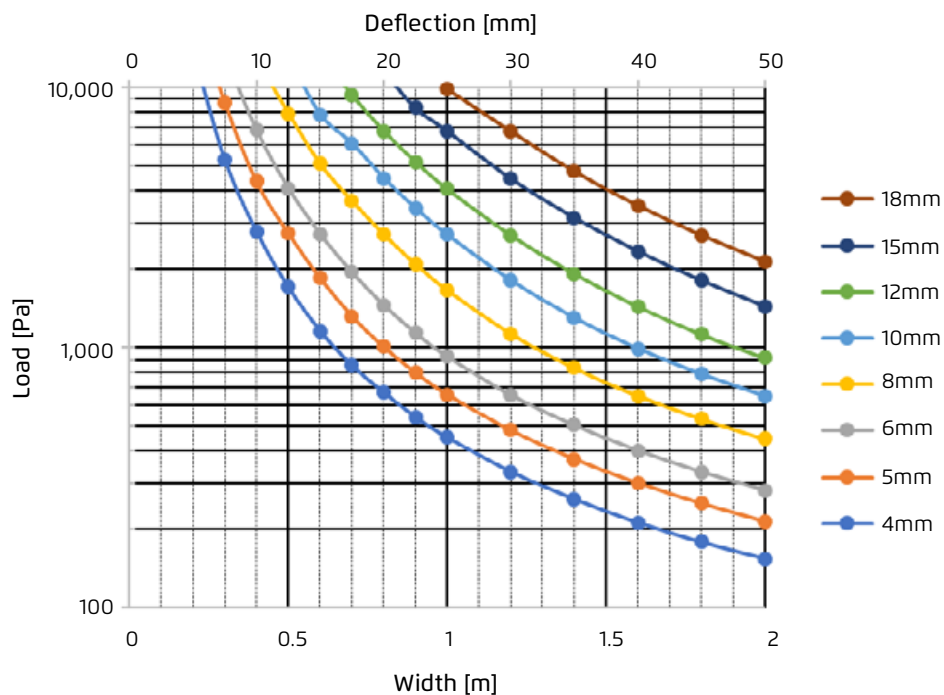
Sheet thickness

Once the load is established, determine the recommended sheets thickness according to the following graphs.

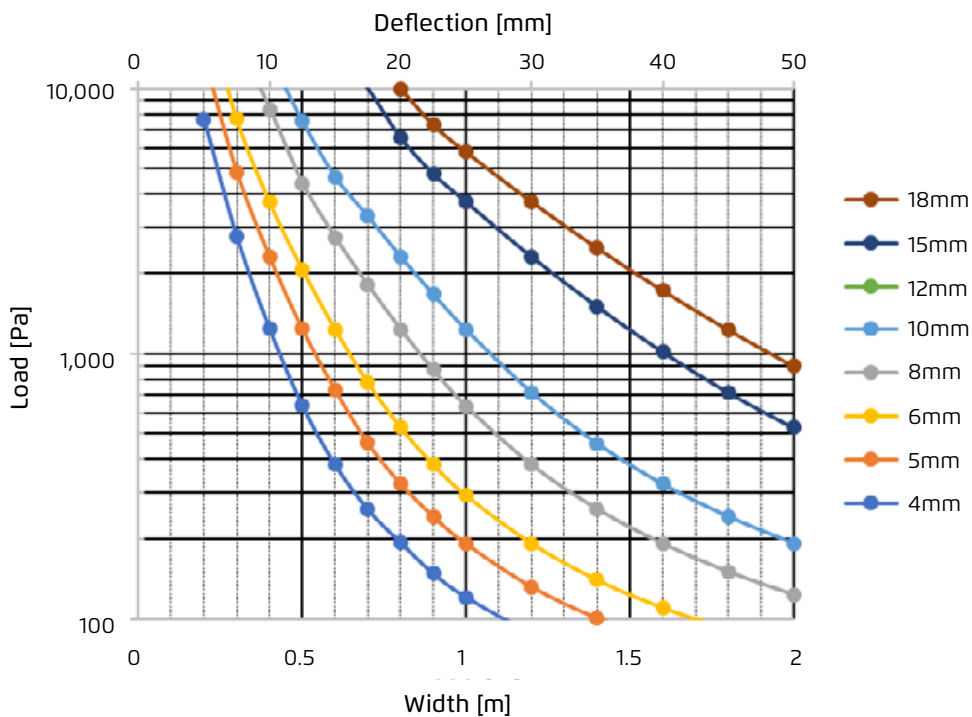
The data in the graphs is subject to the following remarks:

1. The sheet is simple supported on all four edges (worst case scenario).
2. AR = Aspect Ratio = Sheet length/sheet width.
3. The percent 2.5% deflection limit refers to percent of the width (shorter side) (for example for a 1 m width sheet a 2.5% deflection means, 25 mm. For a sheet supported from the 4 sides (as in the graphs) this maximum deflection will occur at the center of the sheet.
4. PLASKOLITE recommends a 2.5% maximum center deflection.
5. The following graphs are based on mathematical simulations and should be used only as a reference. Simulations do not predict the exact real behavior of the sheet.

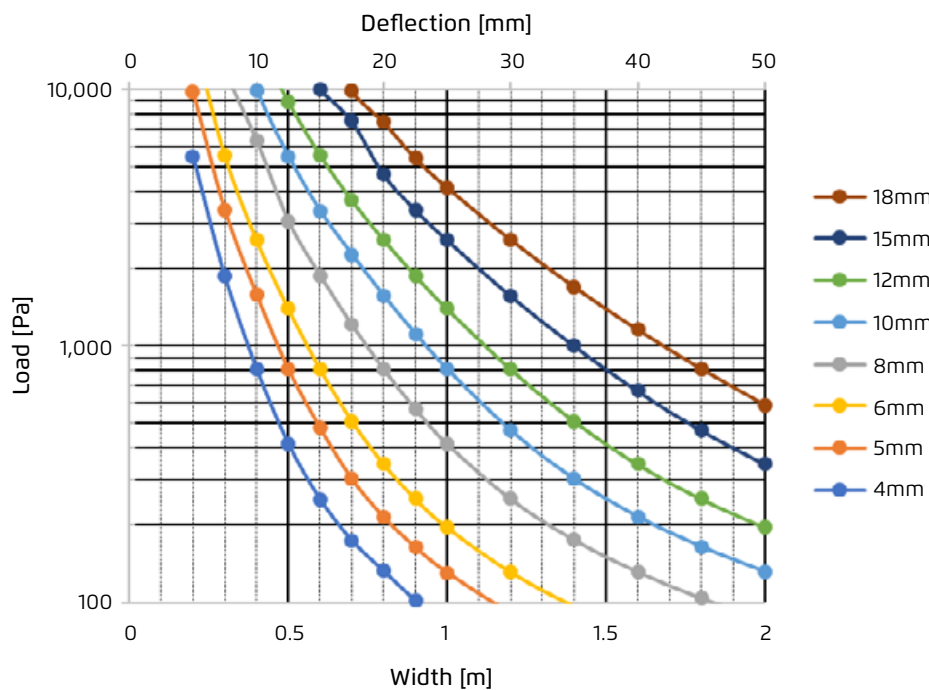
Square Plate AR = 1.0 - 2.5% Center Deflection



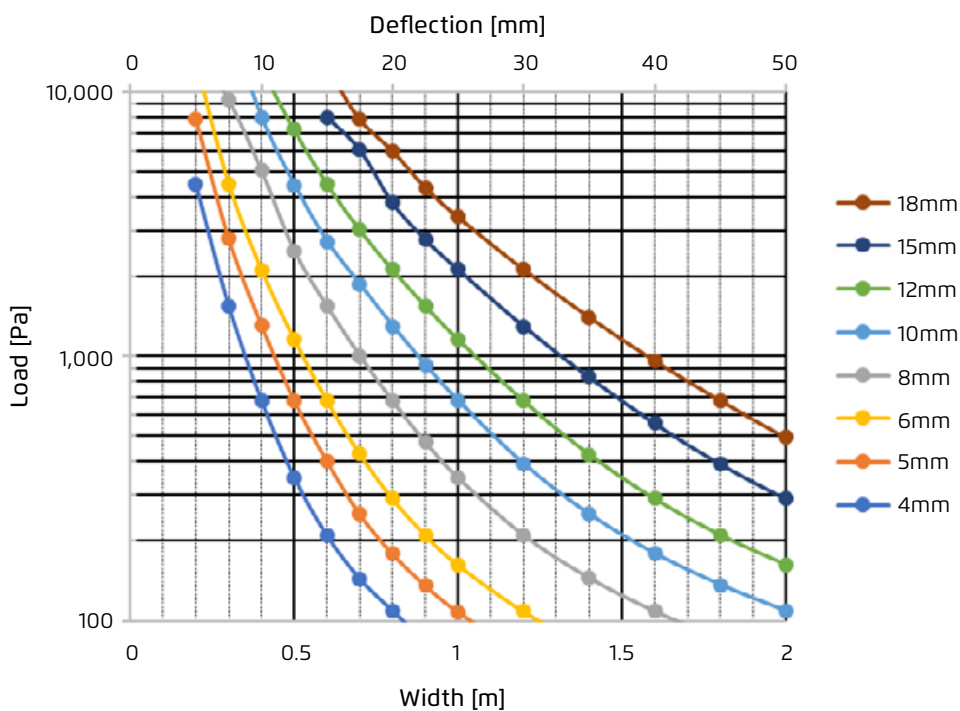
Square Plate AR = 1.5 - 2.5% Center Deflection



Rectangular Plate AR= 2 - 2.5% Center Deflection



Rectangular Plate AR= 2 - 2.5% Center Deflection



Expansion clearance

PC, like most plastics, has a coefficient of thermal expansion higher than all other non-plastics materials used for framing. A sufficient clearance must be given allowing the sheet to expand freely. PC sheets have a linear thermal expansion of about 0.065 mm/m°C. Humidity is also an expansion parameter. PC sheets expand when humidity rises to about 0.3%. The maximum expected value of linear expansion depends on the final sheets application temperature and humidity. Design the sheet's final dimensions and the frame considering the expansion clearance. Insufficient expansion clearance will cause stresses in the sheets, causing distortions and eventually cracking and breakage of the sheets.

Use only sealing agents compatible with PC. Non-rigid PVC and PUR foams are incompatible due to migration of plasticizers. So are silicone sealing compounds containing certain additives. Use only neutral silicones.

10.2 Cold Curving TUFFAK Sheets

Unlike in the case of thermoforming, cold bended (curved) TUFFAK will not keep its form unless installed into a frame. The sheet must be with perfect edges to avoid breakage during curving. The length between the two edges of the bend should not exceed the minimum length in order to avoid high permanent stress, which would eventually cause small cracks or even break the sheet.

Minimum recommended bend radius of 175 times the thickness of the sheet.

Cold curved sheets are at stress and special attention must be paid not to install them in environments with chemicals. The combination of high stress and chemical attack (ESC - Environmental Stress Cracking) may cause cracks and cloudiness.

All information, recommendations or technical advice given in this manual, is given in good faith, to the best of our knowledge and based on our present experience and procedures. However, no liability or other legal responsibility is assumed for the full adequacy, accuracy or completeness of this information. We reserve the right to make any changes, according to technological progress and further developments. The customer is not released from the obligation to conduct careful inspection and testing of incoming goods.

Product design using TUFFAK sheets must be carried out only by qualified experts in the sole responsibility of a customer. Performance should be verified by testing, carried out only by qualified experts in the sole responsibility of a customer.

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Our Mission: to deliver superior thermoplastic sheet, coatings and polymers to the world, through long-lasting customer relationships and hands-on customer service.

MANUFACTURING LOCATIONS



These suggestions and data are based on information we believe to be reliable. They are offered in good faith, but without guarantee, as conditions and methods of use are beyond our control. We recommend that the prospective user determines the suitability of our materials and suggestions before adopting them on a commercial scale.

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