TECHNICAL MANUAL

NUDECPET®

NUDEC®

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2. INTRODUCTION

Background

NudecPET® is an amorphous, solid plastic sheet, which can be manufactured in transparent, translucent or coloured form. It is made of Polyethylene Terephthalate (PET), a thermoplastic polyester. This plastic is widely known from its use in food packaging (PET-soft drink bottles), as fibres used in clothing and as video- and audio- tape.

Process innovation has now made it possible to extrude this material into sheets of thickness between 1 to 8mm that combine good mechanical and optical properties. The unique combination of properties of NudecPET® include excellent fire and impact resistance, compliance with FDA/BGA requirements for contact with foodstuffs, and the ability of any waste sheet to be used in existing recycling facilities for PET.

This technical handbook describes the different properties of NudecPET®, provides details of the test methods, and explains the results. In general, the tests are performed according to ISO methods, but reference is made to the corresponding DIN, ASTM or BS test standard where appropriate. In addition, various methods are suggested to form and fabricate articles using NudecPET®.

The Product

Since its discovery in 1941, the properties of PET polymers have become well established within the Fibres, Packaging, and Engineering Plastics Industries due to their high performance characteristics. NudecPET® sheet products are manufactured from a high specification crystallisable thermoplastic PET polymer which provides an outstanding range of properties suited to the production of a wide variety of transparent or coloured, fast-forming, heat-resistant, precision engineering components and high quality commercial products.

Since its introduction to the market, NudecPET® sheet has been successfully evaluated in applications as diverse as security glazing, point-of-sale displays, automotive parts, telephone kiosks, bus shelters, illuminated signs, roof lighting and machine guards.

Product Range

NudecPET® sheet is available in an extensive range of gauges, sizes, and both translucent and opaque colours. Due to the versatility of its production process customised products can be manufactured to suit particular customer requirements.

For further details of the full NudecPET® product range together with information on your nearest stockist please contact Nudec S.A. at:-

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3. FEATURES OF NUDECPET®

Technical:-

- Excellent impact strength and rigidity.
- Ultra-fast forming cycle times and good deep-draw behaviour with uniform wall thickness.
- Suitable for external use; NudecPETuv® 10 year limited guarantee against weathering effects.
- No sheet drying required prior to forming.
- Wide service temperature range, (-20°C to +60°C).
- Very good scratch and scuff resistance.
- Can be cold formed into bends and hinges.
- Inertness; excellent resistance to chemicals, solvents, detergents, oil and greases, etc.
- High resistance to stress cracking and crazing.
- Suitable for food contact and medical applications (except UV stabilised products).
- Suitable for gamma radiation sterilisation.

Commercial:-

- Cost effective; downgauging often possible.
- Fast cycling ensures high productivity in forming operations.
- Aesthetically pleasing; high gloss, high transparency or colour uniformity and easy printing and decoration without pre-treatment.
- Versatile technical performance.
- Fully recyclable.

Environmental:-

- Good fire resistance; does not support combustion; B1 (Germany), 1Y (United Kingdom), M2 (France), Classe 1 (Italy); non-burning drips without flame inhibiting additives.
- Combustion products are only CO_2 and H_2O; no toxic emissions.
- Any sheet manufacturing waste can be fully recycled in-house and any customer waste can be 100% recycled using existing recycling schemes.

4. PRODUCT RANGE

Grade Range

There are three basic grades of NudecPET® sheet - NudecPET® 00 for flat sheet applications, simple thermoforming or fabrication. NudecPET® 01 which has been developed in response to customer requests for a more forgiving product which can be processed on some of the less advanced thermoforming equipment. NudecPET® 01 should also be of use in more difficult forming applications requiring a material which is easier to process. NudecPET® 02 should be use in the most critical and difficult thermoforming applications.

All these, NudecPET® 00, NudecPET® 01 and PET® 02 are available in UV stabilised forms. Contact Nudec S.A. for further details.

Standard Sheet Sizes

NudecPET® 01 grade sheet is available in gauges from 4mm to 6mm and in the following range of standard sheet sizes. NudecPET® 00 is available in the same sheet sizes but only up to 3.0mm gauge.

NudecPET® 02 is available only in the largest size of the standard sheet in 8mm.

All these products can be supplied in custom sheet gauges and sizes to order.

	SHEET SIZE (mm)	SHEET GAUGE							
		1.0mm	1.5mm	2.0mm	3.0mm	4.0mm	5.0mm	6.0mm	8.0mm
NudecPET® 00	3050 x 2050	✓	✓	✓	✓				
NudecPET® 01	3050 x 2050					✓	✓	✓	
NudecPET® 02	3050 x 2050								✓

Dimension tolerances

NudecPET® sheet products are supplied to the following dimensional tolerances:

Sheet thickness:	±10% of nominal thickness for sheet of thickness 2.5mm and below ±5% of nominal thickness for sheet thickness above 2.5mm
Sheet length:	±2mm
Sheet width:	±1mm

Tints and Colours

NudecPET® is available in a white standard opaque (solid) and translucent (tinted) colours including opal, and bronze. Other colours can be produced to order. Please contact Nudec S.A. for further information.

NudecPET® Enhanced Performance Products

The NudecPET® product range also includes UV stabilised, patterned surface and anti-reflection sheet products. For further information on the availability of these products please contact Nudec S.A.

Product Stockists

For details of your nearest NudecPET® Stockist please contact Nudec S.A.

5. TYPICAL CHARACTERISTICS

PROPERTY	TEST STANDARD	UNITS	VALUE
Melt Temperature (T_m)		^oC	245-249
Glass/Rubber Transition Temp (T_g)		^oC	80
Density		$g.cc^{-1}$	1.34
Light Transmission	ASTM D1003	%	89
Rockwell Hardness	ISO 2039-2	R Scale	115
Typical Thermoforming Temperature		^oC	135
Vicat Softening Temperature	BS 2782 Method 120A	^oC	75
Heat Deflection Temperature	ISO 75:1987 @ 1.80 MPa	^oC	69
	ISO 75: 1987 @ 0.45 MPa	^oC	73
Flammability Rating	UL94		V2
	DIN 4102-1	Germany	B1
	BS 476: Part 7	UK	1Y
	NFP 92-501	France	M2
	UNI 9177	Italy	1
Oxygen Index		%	24
Tensile Strength @ Fracture	ISO R527	MPa	25
Tensile Strength @ Yield	ISO R527	MPa	57
Elongation @ Yield	ASTM D638 @ 2"/min	%	4.5
Elongation @ Fracture	ASTM D638	%	No break
Flexural Modulus	ISO 178	MPa	2400
Flexural Strength	ISO 178	MPa	88
Notched Izod	ISO 180 @ 23^oC	KJ/M^2	4.7
Unnotched Izod	ISO 180 @ 23^oC	KJ/M^2	No Break
Refractive Index			1.576
Coefficient of Linear Thermal Expansion	-40^oC to 60^oC	$^oK^{-1}$	$<6 \times 10^{-5}$

NOTE:- The above is only an indication of the performance of NudecPET® sheet as supplied to the customer and should in no way be regarded as a guarantee of performance or used for design calculation purposes. Some of the above property values have not been measured by Nudec S.A. and have been obtained from polymer suppliers. In addition, the properties of a fabricated or thermoformed article may be significantly changed depending on the part design, the process conditions used and the level of any crystallinity developed in the material. The physical properties and chemical resistance may be considerably improved when the sheet is stretched (orientated) as in a typical thermoforming process.

6. THERMOFORMING (1)

Introduction

NudecPET® sheet is manufactured from a crystallisable polyester, i.e., the molecular structure of the sheet within its typical service temperature range can be either amorphous or semi-crystalline depending on its thermal processing history. Since the properties of the sheet will depend greatly on the level of crystallinity, it is important to understand the sheet processing parameters that may affect its development.

Crystallinity may be developed in NudecPET® sheet if it is held within the temperature range from 80°C to 250°C. (see Figure 1). The maximum rate of crystalline development will occur at a temperature of about 160°C.

CRYSTALLISATION RATE vs **TEMPERATURE**

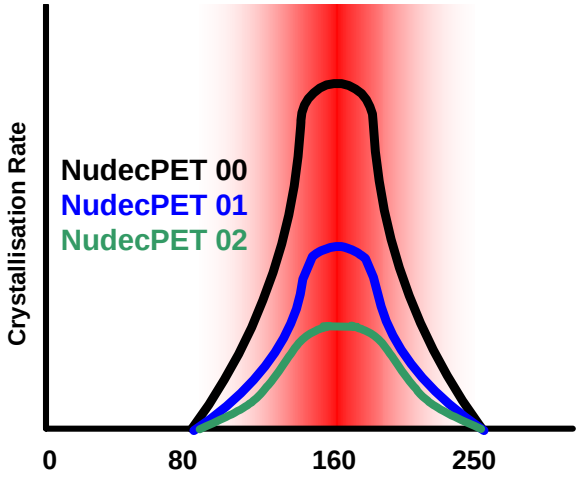


Figure 1

Since the typical thermoforming temperature for NudecPET® sheet is around 135°C., i.e., within the crystallisation temperature range, it is important for the sheet to spend a minimum time at this temperature to prevent the development of any unacceptable crystallisation before the forming process takes place.

Once the sheet has been formed to the desired shape it can then either be cooled to maintain its amorphous state or heat treated to develop the required level of crystallinity for high temperature stability.

Amorphous Products

- can be transparent,
- heat stable to 60°C,
- high impact strength,
- good chemical resistance,

Crystalline Products

- are always opaque,
- stable to + 200°C,
- medium impact strength,
- excellent chemical resistance,

General Information

NudecPET® sheet possesses outstanding thermoforming properties and is capable of reproducing the most complicated mould surfaces even in extreme deep-drawing applications.

As the sheet is stretched its molecular structure becomes orientated and the already-high mechanical performance is substantially improved. In addition, as the sheet is stretched, its unique strain-hardening characteristics will result in a much more uniform wall thickness.

Thermoforming conditions will depend on the sheet thickness, the depth of draw of the mould, and the temperature stability performance required in the formed article.

If coloured NudecPET® sheet is to be thermoformed it is strongly recommended that transparent sheet is first used for any initial optimisation of the process conditions since this will provide instant visual indications of incorrect temperatures, etc.

Sheet goes cloudy white
- sheet overheated, reduce temperature/time.

Sheet goes pearl white
- sheet under-heated or over stretched.

Sheet remains transparent
- correct conditions.

No drying or other pre-treatment of the sheet is required prior to thermoforming.

7. THERMOFORMING (2)

Amorphous Products

Amorphous NudecPET® sheet may be thermoformed onto most conventional deep-draw thermoforming moulds such those used for PS, HIPS, PMMA or PC sheet.

A distinct advantage of NudecPET® sheet is that the moulding shrinkage is uniform and minimal when compared to other materials (typically 0.5% for an amorphous product and 2.0% for crystalline).

If a thermoformed article is required to possess amorphous characteristics the following thermoforming conditions are recommended:

The sheet should be heated quickly to a temperature above 80°C (the glass/rubber transition temperature). Due to its low forming temperature (typically 135°C) the heating time for NudecPET® sheet is typically one third of the time required for competitive sheet materials, resulting in a dramatic increase in productivity. Most sheet heating methods can be used with NudecPET® sheet but "Quartz" or ceramic type heating elements have been shown to be particularly efficient. For optimum results the sheet should be heated using both top and bottom heaters but for shallow moulding or sheet less than 3mm thickness, heating from one side only has proved effective. The heating elements should be proportionally controlled such that they remain on constantly but with a controlled power level.

If transparent NudecPET® sheet is overheated or remains at high temperature for too long it will gradually become cloudy due to crystallisation. Conversely, inadequate heating of the sheet will lead to cold stretching, especially in areas of high depth of draw. In extreme conditions this will produce a pearlecent stress whitening effect in the sheet and an inadequate degree of moulding.

Once the sheet has reached the optimum temperature it should be thermoformed onto a temperature controlled mould surface and cooled to below 60°C before demoulding in order for the sheet to spend as little time as possible within the crystallisation temperature range. Ideally, the mould should be constructed using a material of good thermal conductivity, ie, aluminium, and should be water-cooled to maintain a constant surface temperature within the range 10°C to 50°C.

For sheet thicknesses in excess of 3mm it may be advantageous to cool the upper surface of the sheet with air or a water mist spray to increase the sheet cooling rate whilst it remains in contact with the mould.

Crystalline Products

In order to produce a crystalline, heat stable product the sheet should be heated in the same manner and to the same temperature as that required for an amorphous product, ie, heated until just before it begins to show signs of crystallising. It should then be thermoformed onto a mould, the surface of which is maintained at a uniform temperature of between 150°C and 170°C until the necessary minimum level of 35% crystallinity has been allowed to develop in the material. Mould heating may be achieved by electric cartridges, plate heaters, or preferably by circulating hot oil within the mould.

A diagram of the optimum sheet thermal processing histories for producing either amorphous or crystalline thermoformed products is shown in Figure 2.

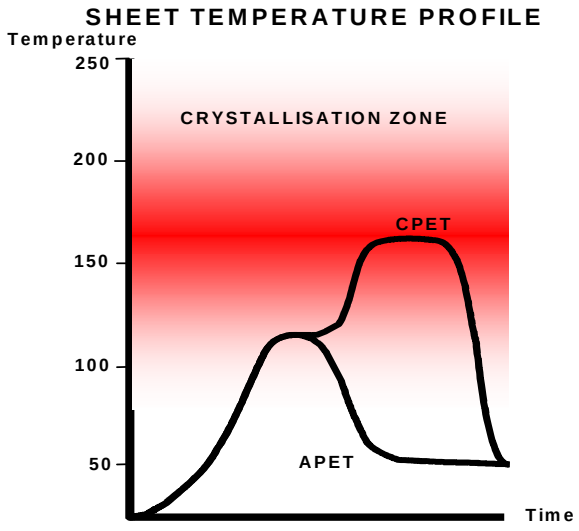


Figure 2

8. THERMOFORMING GUIDELINES

1. NudecPET® sheet does not need to be dried before use.
2. Use transparent sheet when starting any process optimisation since incorrect sheet heating will be instantly visible, ie:

   Sheet goes white
   - sheet overheated, reduce temperature/time.

   Poor moulding definition
   - sheet under-heated or over stretched.

   Sheet remains transparent and gives good moulding definition - correct conditions.
3. The sheet may be heated either in a hot air oven or by radiant heating panels. The sheet should be heated as rapidly as possible, preferably on both surfaces, until it reaches ***a temperature of between 130°C (266°F) and 145°C (293°F)*** depending on the process requirements. However, if the sheet is heated too quickly then sheet surface defects such as pin-hole marks or surface dimples may be caused due to rapid thermal expansion at the sheet surface.
4. When heating large sheet areas it is normal that the sheet will sag as it becomes hot. In this case it may be necessary to support the sheet using air pressure. This may be necessary when forming large areas of NudecPET® sheet.

The following is a guide to the heating times required for clear NudecPET® sheet. The times may vary significantly depending on the efficiency and type of heaters. Also, some sheet colours will absorb heat faster and others will reflect heat and take longer to reach the forming temperature. For instance, when using white sheet with ceramic heating elements it has been found that the sheet will normally take about 10 to 15 seconds less heating time compared to transparent sheet of the same thickness:

Gauge	**air oven:**	**radiant oven:**
2mm	- 3 min	- 25 to 30 sec
3mm	- 3½ min	- 35 to 40 sec
4mm	- 4½ min	- 55 to 60 sec
5mm	- 5 min	- 65 to 70 sec
6mm	- 5½ min	- 75 to 80 sec

5. After the sheet is heated it can be formed onto a mould using the normal techniques used for other sheet materials to obtain the optimum wall thickness distribution, ie, changing the sheet temperature profile at the sheet heating stage, speeding-up or slowing down the rate of vacuum, expanding the sheet prior to moulding by blowing the sheet into a dome or bubble using compressed air, etc.

To produce an amorphous part:
The mould surface temperature should be maintained at less than 60°C (140°F). The part can be released from the mould as soon as its temperature has fallen below 60°C (140°F).

To produce a crystallised part:
The mould surface temperature ***must*** be maintained at a temperature higher than 130°C (266°F) minimum and preferably at 160°C (320°F).

The sheet should be moulded in exactly the same way as for an amorphous part except that after the sheet has been drawn onto the mould the vacuum must remain on whilst the top sheet heater is returned over the mould to crystallise the sheet top surface. After the part has crystallised the top heater can be moved away. The top surface of the part should then be cooled by air fans/water mist before releasing the vacuum and demoulding.

The de-moulding temperature of crystallised NudecPET® will depend greatly upon the size and weight of the part. The sheet can remain relatively flexible directly after the moulding process and before it has had a chance to cool and develop maximum crystallinity. It is therefore recommend that a jig or fixture be used to support the part as it cools.

As crystallites are developed the material density will increase and the sheet will shrink in volume. Typically, a level of about 35% crystallinity will produce shrinkage of about 2% compared to shrinkage of about 0.4% to 0.6% for an amorphous part.

For totally amorphous sheet, ie; 0% crystallinity, (as supplied by Nudec S.A.) the density is 1.33g.cm^{-3}. The density of the sheet will vary in direct proportion with the crystallinity, ie; at 100% crystallinity the density will be 1.45g.cm^{-3}. For good heat stability the sheet should have at least 35% crystallinity (or a density of 1.38g.cm^{-3}). This density change in the material can be used to measure its crystallinity level.

The change in molecular structure from amorphous to crystalline is purely a ***physical*** change; the material does not change ***chemically*** in any way. The only way to change crystalline polyester back to the amorphous state is to melt the polymer.

As a guide for producing a crystallised part the following are examples of the times required for each part of a moulding cycle for 5mm sheet:

sheet heating time (5mm):	75 seconds
time in mould with upper heater:	180 seconds
cooling time with air fans on:	30 seconds
total cycle time:	300 seconds

9. FABRICATION (Machining)

Machining

NudecPET® sheet can be worked with most tools used for machining wood or metal. Keep tool speeds low so that the sheet does not soften or melt due to friction heating. In general, the highest speed at which overheating of the tool or sheet does not occur will give the best results. It is important to keep cutting tools sharp at all times. Hard, wear-resistant tools with greater cutting clearances than those used for cutting metal are suggested. High-speed or carbon-tipped tools are efficient and economical, especially for long runs. Since plastics are poor heat conductors, the heat generated by machining operations must be absorbed by the tool or carried away by a coolant. A jet of air directed at the cutting edge aids in cooling the tool and also in removing chips. Oil, soapy water, and plain water may also be used for cooling and to promote a smooth cut.

Drilling

Drills designed for plastics are available and their use is recommended. However, a twist drill designed for metal or wood often gives good results. Twist drills for plastics should have two flutes, a point with an included angle of 60 to 90°, and a lip clearance of 12° to 18°. Wide, highly polished flutes will expel the chips with low friction and thus tend to avoid overheating. Drills with substantial clearance on the cutting edge of the flutes make smoother holes. Drills should be backed out often to free chips, especially when drilling deep holes. Peripheral speeds of twist drills for plastics usually range from 30 to 60m/min. The rate of drill feed into the sheet can vary from 0.25 to 0.65 mm/rev. Drill bits designed for metal require much slower speeds and feed rates to drill a clean hole.

NOTE: When drilling, be sure to hold or clamp the part securely to prevent it from slipping and presenting a safety hazard to the operator.

Tapping

Conventional 4-flute taps can be used for cutting internal threads. However, such taps have a tendency to generate considerable heat during the tapping operation. A high-speed, 2-flute steel tap should offer longer life and greater tapping speed than conventional taps can provide. The 2-flute tap gives greater clearance for chip discharge. Flutes should be ground so that both cutting edges cut simultaneously. Cutting edges should be 85° from the centreline, giving a negative rake of 5° on the front face of lands so that the tap will not bind in the hole when it is backed out.

Routing

NudecPET® can be machined satisfactorily with standard high-speed router cutters designed for metal, provided the cutters have sharp edges and adequate clearance at the heel. An attractive surface can be achieved using a 15mm Ø bit at 500rpm with a travel of 125mm/min.

Routing is suitable for a variety of purposes including grinding holes and cut-outs or for engraving. It can also be employed for edge-smoothing and finishing. With adequate cooling and low rotation speeds (5000 rpm), excellent results can be achieved even at high throughputs. The surface texture is matt and smooth. Adequate cooling is important to prevent melting of the material.

Routers with sharp two-flute straight cutters produce excellent finished cuts. These are useful for trimming the edges of flat or formed parts particularly when the part is too large or too oddly shaped to use a band saw; or when a very smooth cut is required. The sheet should be fed slowly to the router to avoid excessive friction and jigs should be provided to guide the router or the plastic sheet, whichever is being moved.

Sawing

Any of the saw types, commonly used for wood or metal, should be satisfactory: circular saws, band saws, jigsaws, hacksaws, or handsaws. Of these, circular saws and band saws usually produce the best surfaces, and they can be used in most sawing operations.

Saw blade design plays an important part in the successful sawing of plastics. Band saw blades must have set teeth for any type of sawing, but for curved cuts, blades should be narrower and have more set than those required for straight cuts. The blade should be soft enough to permit filing, and it must be kept sharp to prevent melting or chipping of the plastic. The blade guide should be placed as close as possible to the material being cut.

For straight cuts, a circular saw is preferred because it produces a smoother cut. A perforated saw blade will run cooler than a solid blade. It is essential that the spindle bearing of a circular saw be tight so that the saw will run true. The saw should be hollow-ground with no set to the teeth. Carbide-tipped blades yield best results, as does polishing the faces of the blade.

For best results the following guidelines should be followed:

- The protective film should not be removed in order to avoid damage to the surface.
- The sheet must be adequately secured to prevent vibrations that could otherwise cause chipping and rough edges.
- For best results, use low and medium cutting speeds.
- Cutting swarf and dust are best removed with pressurised air.

Several different types of saw blade have been evaluated and a recommendation made based upon the smoothness and general cut appearance. The saw blades are listed in Table 1.

Table 1 - Sawing Recommendations

CUT TYPE	TOOL	BLADE TYPE	BLADE DIMENSIONS	BLADE SPEED
Straight Cut	Circular Saw	Carbide Tipped Plywood Blade	2-5mm tooth pitch	1,500 – 2,500 m/m
	Band Saw	12.5mm	2-3mm tooth pitch	1,000 – 1,500 m/m
	Jig Saw	Finish cutting blade	3-4mm tooth pitch	
	Hand Saw	Crosscut	8 or 10 pt.	
Trimming	Router	Carbide tipped, double-fluted spiral	10mm diameter	23,000 rpm

NOTE: *Be sure to hold or clamp the part securely while sawing to prevent it from vibrating, which can damage the sheet.*

10. FABRICATION (Saw Cutting - 1)

RECOMMENDATIONS FOR CUTTING NudecPET®WITH CIRCULAR CUTTING SAWS

1. DISC

a. Diameter: **350 - 450 mm.**

Larger diameter provides better performance.

b. N°. of teeth: **84 - 120.**

Depending on the diameter of the disc it has a larger number of teeth. A low number of teeth could cause a jagged cut.

c. Variable speed: **2,800 - 5,000 rpm**

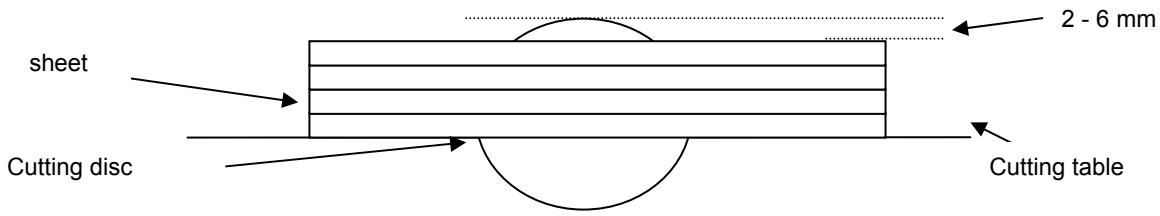
A slow speed could cause a jagged cut.

d. Variable advance speed: **5 - 25 m/min**

i) If burrs appear because of friction or heating, progressively increase the advance rate. If they continue to appear at the maximum advance rate reduce the speed.

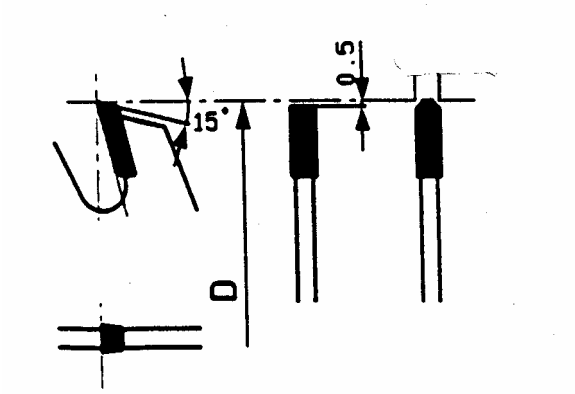
ii) If the advance rate is to fast, the cut is not correct and it leaves a jagged, grooved edge.

e. The cutting disc should project between 2 and 6 mm above the upper part of the sheet being cut.



2. TYPES OF TEETH

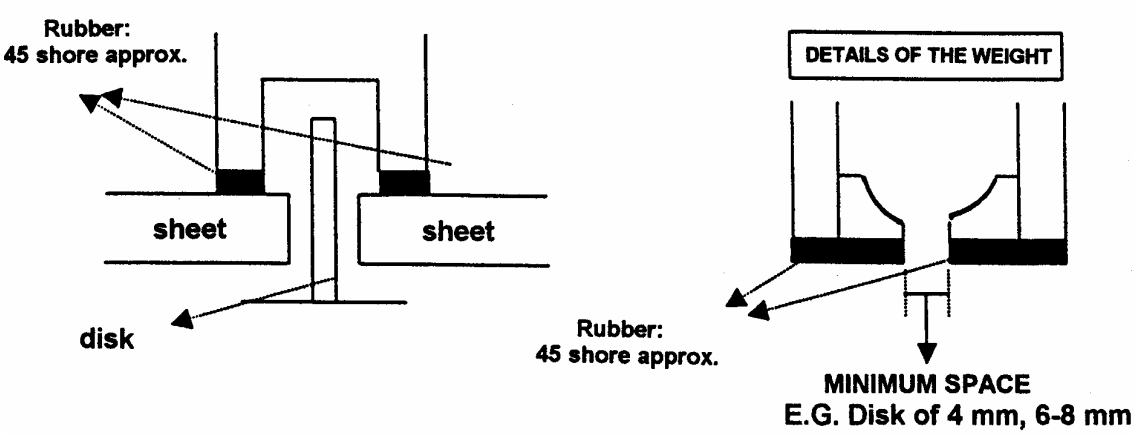
Flat trapezoid type:



11. FABRICATION (Saw Cutting - 2)

3. OBSERVATIONS

a. It is very important that the sheets to be cut are correctly clamped so that they do not lift as the disc passes. We recommend using a **double weight with a rubber or similar base** to absorb the vibrations produced by the disc. See drawing:



b. The cutting table should have the opening adjusted as close as possible to the width of the disc.
For example, for a disc of 4 mm, the ideal opening is 6 - 8 mm.

c. The cutting table should be as flat as possible.
If the saw has clamps, the grooves/guides should be of minimum depth to prevent excessive vibration.

d. When cutting stacks of several sheets at the same time, with a **total thickness of more than 10-15mm, it is advisable to cool the disc using compressed air.**

e. The best finish of the cut is obtained using an incisor disc.
This disc prevents the first sheet of the stack (the one touching the table) from splitting or cracking.
This disc should always be of hard metal and slightly wider than the cutting disc.
Number of teeth: approx. 54.

f. The breakage of corners can be prevented by using a pre-forming disc.
This disc prevents the corners from breaking because of the advance rate when extracting the cutting disc.

12. FABRICATION (Machining/Polishing/Bending)

Shearing, Blanking and Punching

Shearing, blanking and punching are also convenient methods for cutting NudecPET®. Shears produce straight-edged cuts; blanking dies produce shapes ranging from small circles to motorcycle windshields; and punches produce holes of almost any desired shape.

Metal shears can be used successfully to cut almost any sheet thickness. Cardboard cutters will generally produce some chipping and roughening of the edge. Punches may be used where a fairly rough edge is satisfactory. Power-operated punches are normally used to punch holes larger than about 6mm x 50mm rectangles and hand-operated punches can be used to punch small holes in thin sheet. If cracking or chipping occurs, the sheet should be warmed to 35 - 40°C prior to punching. Allowance for contraction upon cooling may be necessary. Holes punched in warmed sheet tend to have smoother sides than holes punched in sheet at room temperature. The sheet may also be cut satisfactorily with steel-rule dies, which are ribbons of steel about 0.8mm to 2.5mm thick, and 12mm wide, sharpened on one edge. They are generally mounted in slots of the appropriate shape that have been cut into plywood or solid wood blocks. They are relatively inexpensive, but the rule must be replaced or sharpened quite often.

Laser Cutting

NudecPET® can be cut by laser. Optimisation of both laser power and travel speed is required to minimise crystallising the material.

Edge Finishing

The edge of a sheet after cutting with a saw can be quite rough. For certain applications, a smooth and attractive edge is important. A smooth edge can also limit the risk of crack propagation during dynamic loading. A variety of methods for edge-finishing are described below. Common woodworking and plastic processing tools can be used.

Polishing with Steel Wool

Polishing with steel wool produces an edge comparable to a milled edge. Because this is a method carried out by hand, it is practical only for small areas.

Sanding

NudecPET® can be sanded using both wet and dry techniques. In either case, the part will require additional finishing using a hot air gun to restore its high gloss.

The edge finish obtained by sanding with 600 grade paper is similar to that obtained by milling. Finer paper will further improve the appearance. Transparent edges are possible employing 1200 grade paper or higher with outstanding clarity possible with 2400 grade paper. Cooling during the sanding process is advisable.

Planing

Rapid and simple smoothing results can be obtained with a standard woodworking planes. Electric planers can also be used with particular caution to ensure that the rotation speed of the blade is low to prevent melting of the surface, which can affect the edge appearance. Best results are obtained by selecting a shallow planing depth.

Polishing using a Hot-Air Gun

Following milling or planing, edges can be polished quickly and easily using a hot-air gun. The protective film should be peeled off to free about 1.5 - 2 cm from the edge. About 1 cm should then be carefully removed with a sharp knife. This prevents the film from melting onto the sheet during the polishing process. The gun should be moved slowly along the edge, maintaining a constant distance between the nozzle and the edge. The result depends on the temperature and the distance of the gun from the edge of the sheet. The edge becomes glossy and transparent. If the edge turns white, the material has been caused to crystallise. This can be avoided by increasing the distance of the gun, lowering the temperature, or a combination of both.

Gas Torch Polishing

Gas torch polishing is similar to polishing with a hot-air gun. The film should be removed as outlined above. Here too, the edge should be treated so as to avoid any signs of crystallisation. A standard butane torch with a small tip can be used. Since the temperature of the gas torch is higher than the temperature of the hot-air gun, the burner should be moved along the edge at a greater speed. High temperature H_2 or acetylene torches are not recommended.

Diamond Knife Planing

Standard cut edges can be smoothed and polished in one step by diamond knife planing. With this type of planing, high quality bevelled or plane edges can be obtained. In order to achieve these high quality surfaces, the material has to securely mounted and precisely guided to prevent vibration. This process yields a highly transparent and glossy surface with very good optical properties.

Cold Bending

Bending into simple shapes may be performed on sheet up to 3mm in thickness without heating the sheet; the degree of bending depending upon the thickness of the sheet. For example, 3mm sheet can be bent to a 90° angle using a conventional sheet metal folder.

Hot Bending

Bending the sheet into a small radius can be accomplished by simultaneously heating the sheet on both sides with simple electric strip heaters and quickly bending the sheet the desired amount along the heated line. Because NudecPET® cools quickly, the bends must be made quickly. Quick cooling also permits the formed piece to be used almost immediately and it need not be held in the bent position for more than a few seconds. If heat bending is performed at too low a temperature, internal stresses will be created in the sheet resulting in a brittle part. Heat-bending temperatures will need to be greater than 110°C to minimize internal stresses. Strip heaters are commercially available, or they can be made easily by using a resistance wire or a tubular metal heating element and a simple fixture.

13. PRINTING

Printing

NudecPET® can be easily printed with most conventional printing techniques such as silkscreen or tampo printing. Hot foil blocking and surface metallising have also been performed with good results. Because of the low thermoforming temperature of NudecPET® it is also possible to print the flat sheet prior to the forming process.

Due to the excellent chemical and solvent resistance of NudecPET® some ink systems may have difficulty in obtaining a good bond to the sheet surface. The following printing inks have been shown to be suitable for printing NudecPET®. However, Nudec S.A. are not manufacturers of printing inks and therefore the user should always consult the ink supplier for detailed recommendations for the use of their products.

In common with other plastic materials, special printing inks are usually required since the ink does not penetrate the plastic as it does paper and cloth. Also, since the ink is not absorbed into the plastic, it may be subject to abrasion. However, this can be minimised by the application of a light coat of clear lacquer over the printing.

Each application may require a different type of ink and therefore the ink manufacturers generally prefer to consider each application separately to determine the best ink for the purpose. A list of commonly used printing inks together with their suppliers is included below. In general, inks that are used on oriented PET film should perform satisfactorily on NudecPET®. Most common thinners have been found to be suitable with ®NudecPET, with the exception of methyl ethyl ketone (MEK), acetone, or benzene; however, we strongly recommend you seek the advice of the ink supplier

Useful hints for printing NudecPET®

- The protective film should be removed immediately before the printing process.
- To remove any dirt or particles without scratching the surface, only soft cloths or damp leather cloths should be used.
- Recommended ink systems and their thinners should be employed.
- A preliminary test with the inks to confirm the results should be performed.
- Ink systems should not be mixed.

Methyl ethyl ketone, acetone, benzene, or similar solvents should be avoided. Thorough ventilation of the work area during the drying process should be provided.

14. PRINTING INKS

Printing Ink Suppliers

The following printing inks have been shown to be suitable for printing NudecPET®. However, Nudec S.A. are not manufacturers of printing inks and therefore the user should always consult the ink supplier for detailed recommendations for the use of their products.

Quimovil: Quimopet
ES: Quimovil. Tel: +34 937291944, Fax: +34 937292923

Marabu: Marastar FX, Solvent: UKV (5-10%) or Maraflex+PUH (10%), Solvent: UKV (5-10%)
D: Marabuwerke GmbH & Co., 71732 Tamm. Tel: +49 71416910, Fax: +49 7141691147
F: Marabu. Tel: +33 148027373, Fax: +33 148024319
I: Serindustria di Lazzaretti Ugo e Celada Nazario & CSAS. Tel: +39 0290780501, Fax: +39 290780486
ES: Marabu-Espãna S.A., 08400 Granollers. Tel: +34 938467051, Fax: +34 938467126
Web: http://www.marabu.de

Coates Screen: Wiederhold Z + catalyst ZH (25%), Solvent: ZVH (3%) or Wiederhold YN + catalyst ZH (10%), Solvent: YV (3%) or Wiederhold Z-PVC + catalyst ZH/N-00 (10%), for external use
ES: Puntí i Llobet SL Tel: +34 933007464, Fax: +34 933003316
D: Wiederhold Coates Screen Inks GmbH, 90409 Nürnberg. Tel: +49 91164220, Fax: +49 9116422200
F: Andre Buisine SA. Tel: +33 140138686, Fax: +33 140261009
GB: Tampo Supplies Ltd. Tel: +44 01819430011, Fax: +4401819775166
I: A-Due. Tel: +39 0498074965, Fax: +39 0498074976
Web: http://www.coates.com/screen/default.htm

Sericol: Polyplast PY (+ rigid vinyl thinner ZV541 + 10% additive ZV 560)
ES: Sericol Tel: +34 934772244, Fax: +34 934770952
D: Sericol GmbH, 45141 Essen. Tel: +49 201832020, Fax: +49 2018320235
F: Sericol. Tel: +33 130693700, Fax: +33 130693769
GB: Sericol Limited, Broadstairs, Kent CT11 2PA. Tel: +44 1843866668, Fax: +44 1843872074
I: Imas Grafica SRL Tel: +39 0294969672, Fax: +39 0294969672
Web: http://www.sericol.co.uk/

Ramp & Co.: 988-UV, 450-JK
D: A. M. Ramp & Co. GmbH, 65817 Eppstein. Tel: +49 61983040, Fax: +49 61983228
GB: Kaydee Ltd., Sheffield S9 2TX. Tel: +44 1142 560222

Diegel GmbH: AR/Z, URA
D: Ernst-Diegel GmbH, 36304 Alsfeld. Tel: +49 66317850, Fax: +49 66314646
Web: http://www.diegel.de

Pröll GmbH: PUR-ZK, Norilit K
D: Farbenfabrik Pröll GmbH & Co, 91781 Weissenburg. Tel: +49 91419060, Fax: +49 914190649
GB: VT Graphic & Display Ltd, Witton, Birmingham B6 7EB. Tel: +44 1213287999, Fax: +44 1213288411

Eickmeyer: Visprox TCI 8700, Visprox TCI 8780
D: Siebdruckservice Eickrneyer GmbH., 32257 Bünde. Tel: +49 5223 6711, Fax: +49 5223 63936

Tampoflex: Farbe C
D: Tampoflex GmbH., 71254 Ditzingen. Tel: +49 7156 9370 10, Fax: +49 7156 9370 116
Web: http://www.tampoflex.de/

15. FINISHING AND ASSEMBLY (Joining/Adhesives)

Mechanical Fastening

Mechanical fastening of sheet will produce the sturdiest and, in may cases, the most attractive joint. Suitable mechanical fasteners include threaded screws, bolts, and permanent fasteners such as rivets. These techniques will produce a stronger part compared to cemented parts. They can be easily disassembled and cleaned, and they eliminate the use of adhesives altogether.

Welding

Although mechanical fastening and cementing are the preferred methods for joining plastics, they can also be welded to themselves by the common welding techniques used for thermoplastics. Ultrasonic, radio frequency, and spin welding have been found to be suitable. These welding techniques are similar to one another in that they utilize frictional heat to achieve welding, but they differ in the manner in which the frictional heat is generated. In ultrasonic welding, the frictional heat is generated by low-amplitude, high-frequency mechanical vibrations (about 20,000 Hz) at the interface of the plastic sections to be welded. Manufacturers of ultrasonic welding equipment should be contacted for suggestions on section and joint design.

Adhesive types

The optimum adhesive for use with any particular material will depend upon certain requirements such as cost, ease of application, bond strength required, resistance to humidity, UV light, transparency, etc. It is therefore essential that the recommendations of the adhesive supplier are closely followed regarding the suitability and use of their product. The adhesive products mentioned here are suggested in good faith and have been found suitable for use with NudecPET® sheet over a wide variety of applications and service conditions. However, Nudec S.A. is unable to accept any responsibility for the performance of any adhesive since the adhesive formulation and conditions of use are beyond our control.

Solvent adhesives are commonly used throughout the plastic sheet fabrication industry. These consist of two types; those which are solvents only (solvent type) and those consisting of another polymer dissolved in a solvent blend (dope type). In general, because of the outstanding chemical resistance of NudecPET® sheet most solvent type adhesives are unsuitable.

Alternative adhesive types which have been found to be suitable include hot-melt, pressure sensitive, two part reaction adhesives based on epoxy or polyurethane, silicone and rubber types, "instant" cyanoacrylate, and UV curing adhesives, etc.

Bonding Techniques

Articles with plane surfaces to be joined can be cemented satisfactorily by placing the pieces to be joined together and applying the adhesive along the edges of the joint with a hypodermic needle, medicine dropper, or small oilcan. Care should be taken to make sure that the adhesive flows throughout the joint and that no air bubbles are present. The parts can be safely placed on a table to cure soon after the adhesive has been applied.
For larger articles, the preferred method of bonding is to coat the adhesive onto the surfaces to be joined and then to clamp or otherwise hold them in position until the bond is set. Clamping may cause the adhesive or cement to protrude at the joint. This protrusion can usually be removed by suitable machining operations followed by polishing. This should only be done, however, after the pieces have stood for the curing time recommended by the adhesive supplier. If a high finish is desired, it may be necessary to flame the surface at the joint after it has been machined and before it is polished.

NOTE: Health and safety recommendations provided by the suppliers of the solvents and other materials used in the polishing and cementing operations should be followed.

Cementing - Preparation

The precautions given below should be observed when bonding any plastic material.

1. The surfaces to be joined must be clean. A slight film of oil, water, polishing compound, or some other contaminant can cause poor bonding.
2. The surfaces should be accurately aligned and, if possible, the surfaces should be slightly roughened in order to provide a better bond surface.
3. The cement or adhesive must be of such composition that it will dry completely without blushing.
4. Pressure must be applied until the cement joint has set sufficiently to prevent any movement when the pressure is released.
5. Subsequent finishing operations must be delayed until the adhesive has cured.

16. FINISHING AND ASSEMBLY (Adhesives)

The choice of adhesive for bonding NudecPET® to itself or other materials is largely governed by the environmental conditions expected during service, along with the type of joint to be employed.

This requires the user to test the glue for a given application, particularly with regard to the desired transparency and long-term adhesion. In principle, any epoxide, polyurethane, cyanoacrylate, silicone or UV curing adhesives should be suitable.

The following table lists the contact details of adhesives manufacturers, together with their product names, who have experience in the bonding of NudecPET®. The corresponding supplier is also included.

Manufacturer	Bonding System	Address
Evode	TU1908, 2 part glass-clear polyurethane TE211, 2 part, rapid setting, toughened epoxy	Evode Speciality Systems Ltd., Wanlip Road, Syston, Leicester LE7 8PD. Tel: +44 (0)1533-606001, Fax: +44 (0)1533-692411
Engineering Chemicals	HE1908, 2 part glass-clear polyurethane HE 17017, 2 part clear polyurethane	Engineering Chemicals b.v. Van Andelstraat 7, 4651 TA Steenbergen, Nederlands Tel: +31 1675 66984, Fax: +31 1675 61118
Polytec	Epotec 715	Promatech Ltd., Unit 1, Elliot Centre, 20 Elliot Road, Cirencester, Gloucestershire GK7 1YS Tel: +44 (0)1285-644211
Panacol-Elosol	Penloc GTI Penloc GTI-S Vitralit 5634LV	Eurobond Adhesives Ltd., Unit 4A, Smeed Dean Centre, Eurolink Industrial Estate, Sittingbourne, Kent ME10 3RN Tel: +44 (0)1795-427888, Fax: +44 (0)1795-479685
Röhm	Acrifix 192 Acrifix 200	Röhm (Plastics Division) Ltd., Bradbourne Drive, Tilbrook, Milton Keynes, Bucks MK7 8AU Tel: +44 (0)1908-274414, Fax: +44 (0)1908-274588
Ciba	Araldite 2020	Ciba Additives., Hulley Road, Macclesfield, Cheshire SK10 2LY Tel: +44 (0)1625-665000
Ciba Geigy Plastics	XB 5102-1, clear, UV cured single-component	Ciba Geigy Plastics Ltd., Duxford, Cambridgeshire CB2 4QA Tel: +44 (0)1223-838141
Datac	ET1122, transparent pressure sensitive hot melt ET1227, non-transparent hot melt	Datac Adhesives Ltd., Globe Lane Industrial Estate, Dukinfield, Cheshire SK16 4XE. Tel: +44 (0)161-339-8400, Fax: +44 (0)161-343-2713
Henkel Chemicals	Q8731 hot melt	Henkel Chemicals Ltd., 292-308 Southbury Road, Enfield EN1 1TS. Tel: +44 (0)181-804-3343
Dymax Europe	Dymax 3-20256	Intertronics Ltd., Unit 9, Station Field Ind. Est. Banbury Road, Kidlington, Oxfordshire OX5 1JD Tel: +44 (0)1865-842842, Fax: +44 (0)1865-842172
Kleiberit	High Tack 851	Kleiberit Adhesives UK Ltd., 11 Coopers Close Borrowash, Derby DE7 3XW

Recommendations for adhesive bonding of NudecPET®

- The surface should be clean, dry and free from dust or loose particles.
- Degreasing: greatest adhesion is achieved by cleaning the surface with ethyl alcohol; good results can be obtained by cleaning with a detergent solution. Cleaning with acetone is not recommended.
- Follow manufacturer useful hints in bonding NudecPET® when using all adhesives.
- After the adhesive has been correctly applied, place the sheet substrates in contact and secure them firmly until the adhesive has cured.
- Depending upon the instructions given by the adhesive manufacturer, coat the sheet surface with the appropriate primer where necessary.
- Note that curing time can be as long as 24 hours in some cases.
- Use adhesives in a well ventilated room. Do not smoke in the area, and avoid skin contact.

Nudec is not an adhesive manufacturer and is therefore unable to accept any responsibility for the performances of adhesives used to bond NudecPET®.

17. BUILDING & CONSTRUCTION

In general, follow standard construction regulations when installing the sheet. The choice of mounting technique depends upon the particular requirements of each situation. The available play which allows for adequate thermal expansion is an important factor, as with all other plastic sheets. When NudecPET® is mounted outside, the allowance should be 3 mm per meter of sheet length, due to seasonal variations in temperature.

The following table shows a comparison of the thermal expansion coefficients of some materials:

Material	$*10^{-6}$ (m/m*°C)
NudecPET®	60
NudecPMMA®	70
aluminium	22
steel	13
glass	0.8

Sawing & Machining

NudecPET® can be cut quickly and easily with ordinary hand-held woodworking tools or with standard circular, band-, or jigsaws using normal saw blades. For best results the following guidelines should be followed:

- The protective film should not be removed to avoid damage to the surface.
- The sheet must be securely fastened to eliminate vibration that can result in chipping or rough edges.
- For best results, use low and medium cutting speeds.
- Cutting swarf and dust are best removed with pressurised air.

These additional guidelines should be considered, depending upon the type of saw used:

- Every second tooth of the circular saw blade should be bevelled at 45° on both sides.
- Thin kerf-design blades that are carbide-tipped yield the best results.
- Either vertical or horizontal band saws can be used.
- Hand crosscut saws should have taper-ground blades to resist binding and improve fast cutting action. The teeth should be bevel-filed for best performance.
- Sheets under 3 mm thick are best cut with band- or jigsaws.

The following table provides information for circular and band saws:

	Circular	Band
Bottom tip angle (°)	5 - 15	30 - 40
Front tip angle (°)	0 - 10	0 - 5
Saw blade speed (m/min)	1500 - 2500	1000 - 1500
Teeth distance (mm)	2 - 5	2 - 3

Drilling

Holes can easily be drilled into NudecPET® with normal high-speed HSS drills. Excellent results can be achieved with special drill bits designed for use with plastic materials. These do not overheat the material due to excessive friction.

In general, the following recommendations apply:

- The sheet should be clamped tightly to minimize vibration.
- The distance of the holes from the edge of the material should be 1.5 - 2.0 times the diameter of the hole.
- The holes should be at least 50 % larger than the diameter of the screw, nail, or rivet. This allows for thermal expansion of the sheet.
- While drilling, retract the drill several times to allow the material to cool, and to minimise the swarf.

Recommended drill angles and feed speeds:

Swarf angle (°)	3 - 5
Drill tip angle (°)	60 - 90
Pitch (°)	5 - 15
Cutting speed (m/min)	20 - 50
Feed (mm/rpm)	0.15 - 0.5

Mounting methods

Screw mounting

For internal installations, the drill hole should be a minimum of 1 mm larger than the circumference of the fixing screw to allow for thermal expansion. If the sheets are mounted flush together, a slight gap should remain between them. Large washers should be used to distribute the force on the sheet over a larger surface area.

In order to prevent tension it is important that the holes of the sheet are aligned with the holes in the structure onto which it will be mounted. It is best is to drill both holes at once. The distance of the holes to the edge of the sheet should as great as possible to reduce notch stress. The use of counter-sunk screws is not recommended, since they leave no play for expansion. Self-tapping screws should only be used with washers, spring-washers or clips.

Example:

- 0.8 x 1.5 m NudecPET® sheet with a 5 mm thickness
- Use 4 mm diameter screw at an interval of 40 cm
- The distance to the edges should be a minimum of 9 mm

Frame mounting

When NudecPET® is mounted in a wooden, metal or plastic frame, two other factors along with thermal expansion must be taken into account: the groove depth, and the correct sheet thickness. Once again, the thickness depends on the size and shape of the sheet and the maximum loads it will encounter (e.g., wind pressure).

Other mounting methods

NudecPET® can easily be mounted in standard industrial clamping systems. These clamping systems are very practical, especially when thermal expansion is a major factor. Clear adhesive tapes like Scotch™ 200 MP or 468 MP can be also used in some transparent applications or for coloured sheets.

NudecPET® sheets may also be fastened with rivets. It is recommended that washers be used to reduce pressure during riveting. The hole in the sheet should be 1.5 to 2 times the diameter of the rivet to allow for expansion.

18. CHEMICAL RESISTANCE

Solvents:

All Ketones will attack NudecPET® to some degree. The simpler ketones such as acetone will attack more quickly.

Fully chlorinated solvents such as carbon tetrachloride do not appear to attack PET whereas compounds such as chloroform or tetrachloroethylene attack PET very quickly.

There appears to be no general trend for the compatibility of aromatics to PET. Both phenol and orthochlorophenol dissolve PET, chlorobenzene and benzene will attack it but xylene has no effect, as do organic oxidising agents such as hydrogen peroxide.

General Chemicals:

The following information is provided only as an indication of the reaction of various chemicals with NudecPET® sheet. It is stressed that the data is only indicative since any reaction can be greatly influenced by other parameters such as temperature, concentration, full immersion or one-side contact, etc. In cases of doubt Nudec Ltd always recommends that the customer performs their own testing. The data has been obtained from various polymer suppliers and is usually the effect of the chemical on polyester after 3 years at 23°C.

+ = good resistance, 0 = limited resistance, - = not resistant

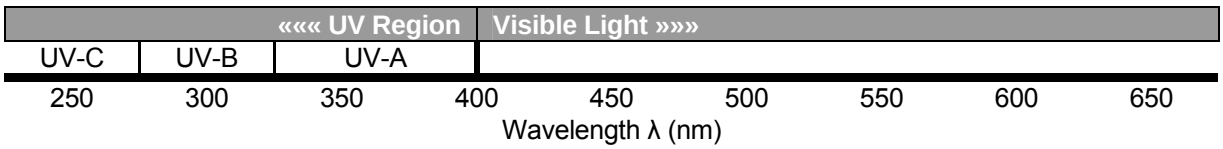
Acetic Acid	40% aq.	+
	Glacial	0
Acetic Anhydride		-
Acetone		-
Aluminium Sulphate	solid	+
Ammonia 10%	aq.	-
Ammonium Chloride	solid	+
Ammonium Persulphate	solid	+
Ammonium Sulphate	solid	+
Amyl Acetate		0
Amyl Alcohol		+
Amyl Methyl Ketone		0
Aniline		-
Anthraquinone	solid	+
Barium Chloride	solid	+
Benzene		-
Benzoic Acid	solid	+
Benzyl Acetate		-
Benzyl Alcohol		-
Benzyl Benzoate		0
Butyl Acetate		-
Butyl Alcohol		+
Butyl Lactate		+
Butyl Stearate		+
Calcium Hypochlorite	solid	+
Camphor	solid	+
Camphorated Oil		+
Carbon Tetrachloride		+
Castor Oil		+
Cetyl Alcohol	solid	+
Chloral Hydrate	solid	-
Chlorobenzene		-
Chloroform		-
Chromic Acid	plating solution	-
Citronellol		+
Cupric Sulphate	solid	+
Cyclohexanone		-
Cyclohexanol		+
Diacetone Alcohol		+
Di-alkyl Phthalate		+
Di-butyl Phthalate		+
Di-nonyl Phthalate		+
Di-octyl Phthalate		+
Dimethyl Formamide		-
Dioxane		-
Dipentene		+
Di-l-phenyl Ethanol		0
Ethyl Acetate		-
Ethyl Alcohol		+
Ethyl Benzine		0
Ethyle Digol		+
Ethylene Chlorohydrin		-
Ethylene Dibromode		-
Ethylene Dichloride		-
Eugenol		-
2-Ethoxy Ethanol		+
Ferric Nitrate	solid	+
Formaldehyde	40% aq.	+
Formic Acid	30% aq.	+
Furfuryl Alcohol		-
Geraniol		+
Glycerine		+
Glycol		+
Hydrobromic Acid	50% aq.	+
Hydrochloric Acid	10% aq.	+
Hydrofluoric Acid	60% aq.	0
	conc.	-
Hydrogen Peroxide		+
Hydroquinone	solid	+
Isopropyl Alcohol		+
Linalol		+
Linseed Oil		+
Lubricating Grease		+
Lubricating Oil		+
Magnesium Chloride	aq.	+
Maleic Acid	50% aq.	+
Mercuric Chloride	solid	+
Mercury		+
2-Methoxy Ethanol		0
Methyl Alcohol		+
Methyl Cyclohexanol		+
Methyl Ethyl Ketone		-
Methyl Methacrylate		0
Methyl Salicylate		-
Methylene Chloride		-
Mineral Oil		+
Naphtha	crude	+
	solvent	+
Nitric Acid 10%	aq.	+
Olive Oil		+
Oxalic Acid	solid	+
	solution	+
Paraffin	medicinal	+
Paraffin Oil		+
Petrol		+
Petroleum Ether		+
Phenol		-
Pinene		+
Potassium Bromide	solid	+
Potassium Chromate	solid	+
Potassium Cyanide	solid	+
Potassium Dichromate	solid	+
Potassium Hydroxide	aq.	-
Potassium Permanganate		0
Propionic Acid		-
Propyl Alcohol		+
Propylene Glycol		+
Salicylic Acid	solid	+
Sodium Bicarbonate	solid	+
Sodium Borate	solid	+
Sodium Bromide	solid	+
Sodium Carbonate		+
Sodium Chloride	aq.	+
Sodium Cyanide	solid	+
Sodium Hydroxide	aq.	-
Sodium Nitrite	solid	+
Sodium Phosphate	solid	+
Sodium Sulphite	solid	+
Sodium Thiosulphate	solid	+
Stearic Acid	solid	+
Sulphur	solid	+
Sulphuric Acid	aq.	+
Tartaric Acid	solid	+
Tetrahydrofuran		-
Tetralin		+
Toluene		+
Transformer Oil		+
Trichloroethyl Phosphate		+
Trichloroacetic Acid		-
Trichloroethylene		-
Triethanolamine		-
Vinegar		+
Xylene		+
Zinc Chloride	solid	+

19. WEATHERING PERFORMANCE

Background

Almost without exception, the optical and physical properties of materials such as plastics, metals, glass, etc, will deteriorate to varying degrees when exposed to external atmospheric conditions over prolonged periods of time. For the majority of plastic materials the most critical aspect of weathering has been found to be the effect of ultraviolet (UV) light, i.e., light of wavelength less than 400nm., together with surface chemical attack and erosion due to atmospheric pollution.

Light Wavelength Spectrum



The reduction in properties caused by natural weathering can vary considerably depending on:-

- local geographical position and environment, e.g., climate, temperature, altitude, latitude, etc.
- orientation of the sample (e.g., South or North facing),
- other external effects such as chemical attack from ozone, petrol fumes, salt spray, etc.

For these reasons comparative test data must be generated under identical conditions to obtain meaningful results.

NudecPET® Performance

The weathering performance of NudecPET® is being continually monitored under natural weathering conditions, supported by the most technically sophisticated accelerated weathering tests but **because of the variability of natural weather it is virtually impossible to correlate artificial weathering performance to that of natural weathering.**

Nudec S.A. has commissioned accelerated weathering tests under closely controlled artificial conditions using modern equipment, and has also performed natural weathering tests in which the performance of NudecPET® has been accurately compared to that of other sheet materials. All accelerated tests should be performed according to the following International Standards:-

ASTM G53-88 "Standard Practice for Operating Light and Water Exposure Apparatus for Exposure of Non-metallic Materials",

BS 2782, Part 5 Method 540B "Methods for Exposure to Laboratory Light Sources",

ISO4892-1989 "Plastics - Methods of Exposure to Laboratory Light Sources"

When using accelerated weathering test equipment it is essential to realise that, due to thermal aging, the temperature at which the test is conducted can have a large effect on the physical properties of the sample as well as the optical properties. Therefore, when investigating the effect of weathering on the physical properties of a material it is important that the temperature of the test sample does not exceed the likely maximum service temperature.

The inherent weatherability of PET is clearly proven by the fact that commercial products such as vehicle registration plates, road hazard warning beacons, extruded mudguards for bicycles, etc, have been successfully used in external situations throughout Europe over the past 20 years.

In critical applications where exposure to UV light is expected to be high, such as in southern latitudes and high altitudes, it may be necessary to employ NudecPETuv® UV stabilised sheet.

Please contact Nudec S.A. for a copy of the 10-year Warranty for NudecPETuv®.

20. FLAMMABILITY

Information on the flammability of plastics is often required if they are used in building construction. Normally, materials must comply with country-specific tests, for instance, in Germany, France, the United Kingdom and the United States. Sometimes one country will accept the results of a test mandated by another.

In Great Britain plastic sheet is tested according to **BS 476 Part 7**. This method is used to rate the speed of the fire propagation on the surface of the sample. The sample is held vertically. The classification of the test material is made according to the flame size and the propagation.

In Germany, the flammability of construction materials is tested according to the Standard **DIN 4102-1**. Materials are then categorised into non-flammable materials (building material classes A1 and A2), and flammable materials (building material classes B1, B2 and B3). Since most thermoplastics are ignitable, they all fall into the categories B1 to B3, which are described below:

Building material class B1, fire-resistant:
The average of the remaining sample length must be greater than 15cm, and none of the samples are permitted to have a length of 0cm. The exhaust temperature must be not greater than 200°C, and the B2 requirements of the small-burner-test have to be met.

Building material classes B2, moderately flammable:
Five samples have to meet the requirements of the small-burner-test. The tip of the flame must not reach the mark within 20 seconds for any of the samples.

Building material classes B3, flammable:
All materials fall in category class B3 when they do not comply with the requirements of class B1 or B2.

The fire rating in France is performed according to **NF P92-507**. Aside from the fire rating there is the Standard **NF X10-702** which tests smoke and fume behaviour. The M classification for fire, and the F classification for smoke can then be determined.

The different national fire rating classifications of NudecPET® are provided in the following table:

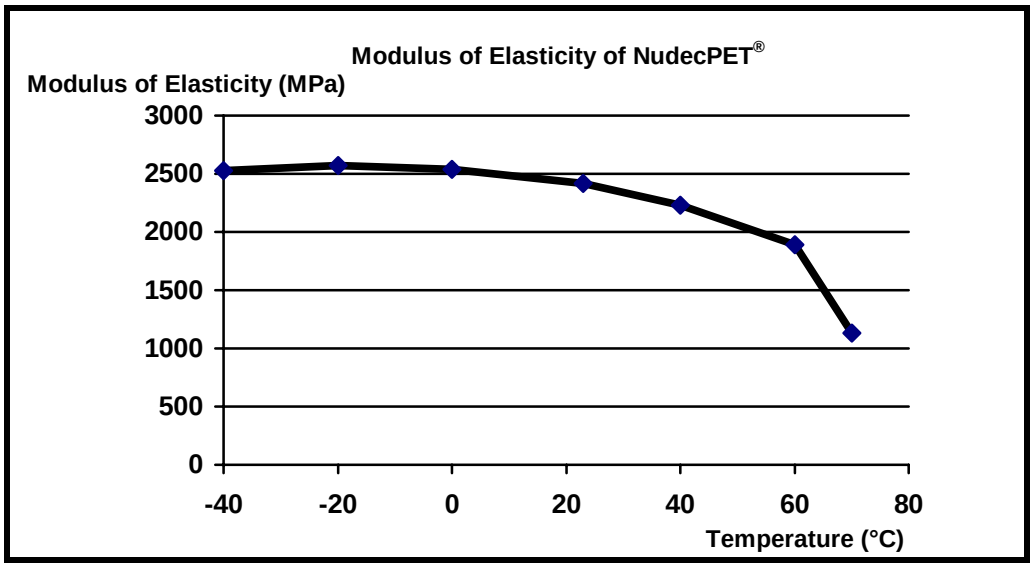
Flammability Classification	Sheet Thickness (mm)	Class
Fire rating: DIN 4102-1 (Germany)	1 - 6	B 1
Fire rating: BS 476 part 7 (United Kingdom)	3 - 6	1 (y)*
Fire rating: NF P92-507 (France)	1.25 - 4.0	M 2
Fire Rating: UNI 9177 (Italy)	3.0	Classe 1

(*) The supplementary Y means that the sample softened and/or an influence on the flame propagation within allowable tolerances was observed.

21. THERMAL BEHAVIOUR

NudecPET® is a transparent amorphous thermoplastic. The molecules of amorphous thermoplastics are not arranged in a structure but are randomly distributed. The molecules can therefore move easily when the material is heated. The flat NudecPET® sheet can be reformed with heat and pressure into another shape, e.g., by pressure or vacuum forming, or hot-bending, to produce a three-dimensional part.

The material stiffness is a function of the modulus of elasticity. The following graph shows the modulus of elasticity in relation to the temperature. The material is rigid below 60°C, showing a fairly constant modulus of elasticity, and begins to soften above 65°C. The material starts to become plastic at the glass-transition temperature (Tg), which is 80°C for NudecPET®. The Vicat softening temperature, the heat deflection temperature, and the coefficient of linear thermal expansion give additional information about the temperature behaviour.



Heat Deflection Temperature (HDT)

The test set-up is similar to the set-up of the vicat-softening temperature. In this case, the sample rests on two supports while a load is applied in the centre of either 1.8MPa for HDT A, or 0.45MPa for HDT B.

Property	Value (°C)
HDT A (1.8MPa)	69
HDT B (0.45MPa)	73

Temperature Range

Because of its chemical structure, NudecPET® has good mechanical behaviour over a wide temperature range. The temperature range is from below -70°C up to more than 160°C when crystallised. The modulus of elasticity (Young's modulus) decreases significantly above this temperature range and the material softens quite rapidly. The functional lifetime of NudecPET® is reduced, however, when this temperature is exceeded for a longer period of time. NudecPET® can be used in very low temperatures, but the material becomes brittle in these environments.

Stable mechanical properties over a large temperature range are important for the user. The impact resistance and stiffness of NudecPET® show only minimal changes between -70 °C to +60 °C, even over a longer period.

Other thermal properties of NudecPET® are:

Property	Value (°C)
Recommended Maximum use Temperature	65
Glass Transition Temperature (T_g)	80
Crystalline Melting Point (T_m)	approx. 245

22. ENVIRONMENTAL ASPECTS

Recycling

In recent years, the plastics industry has faced increasing criticism over the effects on the environment of waste plastic materials, particularly with regard to packaging products. Articles manufactured from plastic materials are therefore expected by the public to be increasingly more environmentally benign. The prime requirement, alongside recyclability, is the safe disposal of the products after their service life has ended. This is the very area where NudecPET® offers major advantages since PET is a material which is already being actively recycled. Even if incinerated for the recovery of energy the products of the combustion of NudecPET® in air are only water vapour, carbon dioxide, and small amounts of carbon monoxide, i.e., similar combustion products to those produced when incinerating any natural product such as wood or paper.

PRODUCTS WHICH CAN BE MADE FROM RECYCLED NudecPET® SHEET

*** Polymer compounds:**
- Strapping tape
- Scouring pads
- Fence posts
- Industrial paints
- Paint brushes

*** Fibre:**
- Twine
- Filter material
- Apparel
- Rope
- Carpet backing

*** Textiles:**
- Belts
- Webbing
- Sails
- Woven Bags
- Tyre Cord

*** Engineering plastics:**
- Appliance handles
- Automotive applications

*** Thermoformable sheet for packaging:**
- Six-pack carriers for soft drink bottles
- Non-food containers
- Audio cassette cases

*** HDPE (high density polyethylene)**

*** Lumber boards for:**
- Boat piers
- Pig & calf pens
- Garden furniture

*** Fibrefill for:**
- Pillows
- Ski jackets
- Cushions
- Sleeping bags

*** Other products:**
- Base cups for bottles
- Flower pots
- Pipe
- Toys
- Pails & Drums
- Traffic-barrier Cones
- Golf Bag Liners
- Kitchen Drain Boards
- Milk Bottle Carriers
- Soft Drink Bottle Carriers
- Waste Bins

*** Polyol - one chemical component used by urethane foam manufacturers to produce:**
- Laminated board for both wall and roof housing insulation
- Refrigeration truck panelling
- Domestic and commercial freezer and fridge insulation
- Storage tank insulation
- Automobile bumpers
- Furniture
- Sporting goods, e.g., skis and surfboards

*** Unsaturated polymer - a chemical component used to produce:**
- Boat hulls
- Swimming pools
- Marbled material
- Shower stalls
- Corrugated awnings
- Automobile exterior panels

*** Chemical conversion back to original polymer building blocks:**
- DMT (diamethylterephthalate)
- TPA (pure terephthalic acid)
- Ethylene glycol

23. ENVIRONMENTAL QUESTIONS ANSWERED

Q - What is NudecPET®?

A - NudecPET® is the brand name for a family of plastic sheet products manufactured from polyethylene terephthalate (PET). PET is composed only of carbon, hydrogen and oxygen and is produced from two petroleum derived feedstocks, monoethylene glycol and pure terephthalic acid.

Q - What is NudecPET® used for?

A - The combination of purity, strength and light weight make NudecPET® an ideal material for a wide range of high quality durable domestic and engineering applications as such as vehicle registration plates, point of sale displays, telephone kiosks, signage, roof lights and machine guards.

Q - Is NudecPET® toxic?

A - No. NudecPET® is chemically and toxicologically inert, and as such poses no harm to the consumer or to the environment. NudecPET® complies with all major food contact regulations, including those of the Food and Drug Administration (USA) and the Bundesgesundheitsamt (FRG).

Q - Is NudecPET® occupationally hazardous?

A - NudecPET® is safe to handle at all times during any subsequent processing operations such as thermoforming, etc.

Q - Is NudecPET® biodegradable?

A - NudecPET® is not biodegradable. The durability, strength and resistance to attack of NudecPET® sheet by both bio-organisms and chemicals are amongst its major assets

Q - Can NudecPET® be recycled?

A - Yes. NudecPET® is one of the easiest plastics to recycle once it has been collected and separated from other materials. NudecPET® can then be reclaimed and used by a variety of other industries. For example, used sheet can be granulated, dried and re-extruded into high value fibres for carpets, duvets and anoraks. NudecPET® can even be re-extruded into yet more sheet for applications such as internal building wall cladding, etc.

Q - Can NudecPET® be re-used over and over again?

A - With care, NudecPET® can be recycled many times without significantly reducing its properties. If recycled with other plastics NudecPET® can still be made into durable products such as crates, road cones and fence posts.

Q - Is NudecPET® hazardous if burnt?

A - Burning NudecPET® is no different from burning any other organic material, and is as environmentally safe as burning paper or wood. In fact, burning NudecPET® in municipal incinerators aids the combustion of wet newspapers and vegetable matter. It is also one of the most economical ways to reduce the presence of NudecPET® in the waste stream as it will release the same heat as soft coal ..... heat which can then be recovered for hospitals, swimming pools, factories, homes and offices.

Q - Does NudecPET® contribute to the depletion of the ozone layer?

A - No. Burning NudecPET® simply returns carbon dioxide and water back into the atmosphere.

Q - What is the contribution of NudecPET® to the greenhouse effect?

A - As with other carbon based products, burning NudecPET® releases carbon dioxide. However, on the positive side, a truck can save 40% of fuel with a corresponding reduction in emissions if carrying NudecPET® instead of sheet metal or glass.

Q - Does NudecPET® contribute to dioxin formation?

A - No. NudecPET® will not release dioxins when incinerated.

Q - What happens if NudecPET® is buried?

A - When buried, NudecPET® will remain stable and safe for extremely long periods, unaffected either by alkaline or mild acidic conditions. NudecPET® is therefore ideal for disposal by landfill. NudecPET® will not give off vapours, leach additives and pigments, or break down and contaminate water supplies. NudecPET® can even help to stabilise and contain a landfill site.

24. STORAGE AND TRANSPORTATION

- To avoid damaging the surface, do not remove the protective film.
- NudecPET® should be stored and transported on stable, flat pallets. The size should be equivalent to -, or slightly larger than -, the sheets.
- Sheets should be lifted and handled one at a time.
- To prevent scratching, sheets should not be allowed to slide over each other during handling.
- Sheets should be stored indoors and protected from direct sunlight ('magnifying-glass effect') and also from moisture.
- In external applications, both protection film must be removed immediately because if they are exposed to sunlight, they can be permanently bonded to the sheet.
- When storing in a vertical position, sheets should be supported to their full height.