

PETRONAS TECHNICAL STANDARDS

DESIGN AND ENGINEERING PRACTICE

MANUAL

NON-METALLIC MATERIALS - SELECTION & APPLICATION

PTS 30.10.02.13

OCTOBER 2009



PTS Circular 2009 - 1



PTS No:	30.10.02.13
PTS Title:	NON-METALLIC MATERIALS – SELECTION & APPLICATION

This revision of PTS **30.10.02.13 – NON- METALLIC MATERIALS – SELECTION & APPLICATION (October 2009, Revision 2)** has been updated to incorporate PETRONAS Lessons Learnt, Best Practice and new information issued by relevant industry code and standards. All updates in the document are highlighted in italic font.

The previous version of this PTS **30.10.02.13 (April 2003)** will be removed from PTS binder / e-repository from herein onwards.

The custodian of this PTS is:

Name : Tan Yew Min

Tel. No : 603 – 2783 6218

Please direct any questions regarding this PTS to the above-named.

Document Approval

	Name	Designation	Date	Signature
Prepared/ Reviewed	Nurul Hana Bt Kamaruzaman	Engineer (Materials)	15/10/2009	
	Tan Su Anne	Engineer (Materials)	15/10/2009	
Approved	Tan Yew Min ZAMALUDDIN ALI	Staff Engineer (Materials)	19/10/2009	
Verified	Che Wan Ibrahim Che Wan Sudin	Technical Manager Materials, Corrosion & Inspection, GTS	2/11/2009	
Verified	Pau Kiew Huai	General Manager Engineering, GTS	3.11.09	
Endorsed	Pramod Kumar Karunakaran	Senior General Manager, GTS	3.11.09	

Revision History

Rev No.	Reviewed by	Approved by	Date
1	Nurul Hana Bt Kamaruzaman Tan Su Anne	Tan Yew Min	19/10/2009

PREFACE

PETRONAS Technical Standards (PTS) publications reflect the views, at the time of publication, of PETRONAS OPU/Divisions.

They are based on the experience acquired during the involvement with the design, construction, operation and maintenance of processing units and facilities. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good technical practice to be applied by PETRONAS' OPU/Divisions in oil and gas production facilities, refineries, gas processing plants, chemical plants, marketing facilities or any other such facility, and thereby to achieve maximum technical and economic benefit from standardisation.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where PTS may not cover every requirement or diversity of condition at each locality. The system of PTS is expected to be sufficiently flexible to allow individual operating units to adapt the information set forth in PTS to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use PTS they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the PTS. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use PTS rests with three categories of users:

- 1) PETRONAS and its affiliates.
- 2) Other parties who are authorised to use PTS subject to appropriate contractual arrangements.
- 3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) and 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, PETRONAS disclaims any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any PTS, combination of PTS or any part thereof. The benefit of this disclaimer shall inure in all respects to PETRONAS and/or any company affiliated to PETRONAS that may issue PTS or require the use of PTS.

Without prejudice to any specific terms in respect of confidentiality under relevant contractual arrangements, PTS shall not, without the prior written consent of PETRONAS, be disclosed by users to any company or person whomsoever and the PTS shall be used exclusively for the purpose they have been provided to the user. They shall be returned after use, including any copies which shall only be made by users with the express prior written consent of PETRONAS. The copyright of PTS vests in PETRONAS. Users shall arrange for PTS to be held in safe custody and PETRONAS may at any time require information satisfactory to PETRONAS in order to ascertain how users implement this requirement.

TABLE OF CONTENTS

1.	INTRODUCTION	6
1.1	SCOPE	6
1.2	DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS	6
1.3	DEFINITIONS	6
1.4	CROSS-REFERENCES	6
1.5	CHANGES FROM THE PREVIOUS EDITION	7
1.6	COMMENTS ON THIS PTS	8
2.	GENERAL	9
2.1	SELECTION GUIDELINES	9
2.2	ABBREVIATIONS	9
2.3	CATEGORIES OF NON-METALLICS	12
2.4	MATERIAL SELECTION	13
2.5	CHEMICAL RESISTANCE	133
2.6	FIRE PERFORMANCE	14
2.7	MATERIAL PROPERTIES	15
3.	THERMOPLASTIC MATERIALS	16
3.1	INTRODUCTION	177
3.2	PLASTICISED POLYVINYL CHLORIDE (PVC)	17
3.3	UNPLASTICISED PVC (UPVC)	18
3.4	POLYETHYLENE (PE)	19
3.5	POLYAMIDE (PA)	20
3.6	POLYPROPYLENE (PP)	21
3.7	FLUOROPOLYMERS (PTFE, PCTFE, PFA, FEP, PVDF)	22
3.8	POLYPHENYLENE SULPHIDE (PPS)	24
3.9	CROSS-LINKED POLYETHYLENE (PEX)	25
3.10	POLYETHERETHERKETONE (PEEK)	26
4.	FIBRE REINFORCEMENT MATERIALS	28
4.1	GENERAL	28
4.2	TYPES OF REINFORCEMENT FIBRES	28
4.3	TYPICAL PROPERTIES OF REINFORCEMENT FIBRES	29
5.	THERMOSET MATERIALS AND COMPOSITES	30
5.1	FIBRE REINFORCED PLASTIC COMPOSITES	30
5.2	EPOXY RESINS	31
5.3	POLYESTER RESINS	33
5.4	VINYL ESTER RESINS	35
5.5	PHENOLIC RESINS	36
5.6	FURAN RESINS	37
5.7	POLYURETHANE RESINS	38
6.	ELASTOMERIC MATERIALS	40
6.1	GENERAL	40
6.2	NATURAL RUBBER (NR)	41
6.3	STYRENE BUTADIENE RUBBER (SBR)	42
6.4	POLYCHLOROPRENE RUBBER (CR)	43
6.5	BUTYL RUBBER (IIR)	44
6.6	CHLOROSULPHONATED POLYETHYLENE (CSM)	45
6.7	NITRILE BUTADIENE RUBBER (NBR, HNBR)	46
6.8	ETHYLENE PROPYLENE RUBBER (EPDM)	47
6.9	FLUOROELASTOMERS (FKM)	48
6.10	PERFLUORO ELASTOMER (FFKM)	49
6.11	FLUORO-SILICONE RUBBERS (VMQ, PMQ, FMQ)	50
6.12	POLYURETHANE RUBBERS (AU, EU)	50
6.13	EXPLOSIVE DECOMPRESSION (RAPID GAS DECOMPRESSION) OF ELASTOMER SEALS	51
7.	CERAMIC MATERIALS	53
7.1	GENERAL	53

7.2	NON-OXIDE CERAMICS.....	53
7.3	OXIDE CERAMICS.....	53
7.4	TYPICAL PROPERTIES OF CERAMICS.....	54
8.	INSULATION MATERIALS	55
9.	REFERENCES	57

APPENDICES

APPENDIX 1	LIST OF COMMERCIALY AVAILABLE NON-METALLIC MATERIALS	61
APPENDIX 2	CHEMICAL RESISTANCE OF NON-METALLIC MATERIALS.....	83
APPENDIX 3	FIRE PERFORMANCE OF NON-METALLIC MATERIALS	111
APPENDIX 4	TYPICAL MECHANICAL AND PHYSICAL PROPERTIES OF OCCASIONALLY USED NON-METALLIC MATERIALS	113

1. INTRODUCTION

1.1 SCOPE

This PTS specifies requirements and gives recommendations for the initial selection of non-metallic materials.

This PTS is a revision of the PTS of the same title and number dated April 2003.

The purpose of this PTS is to guide and support the application of non-metallic materials through specification of the service limits in terms of minimum and maximum operating temperatures for both upstream and downstream applications.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by PETRONAS the distribution of this PTS is confined to companies forming part of PETRONAS or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them.

This PTS is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/marketing installations. When PTSs are applied, a Management of Change (MOC) process should be implemented. This is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this PTS, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this PTS which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this PTS as closely as possible.

1.3 DEFINITIONS

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment, materials and services to perform the duties specified by the contractor.

The **Principal** is the party that initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant, authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 CROSS-REFERENCES

Where cross-references to parts of this PTS are made, the referenced section number is shown in brackets. References used in this PTS are listed in (9).

1.5 CHANGES FROM THE PREVIOUS EDITION

The previous edition of this PTS was dated April 2003. Other than editorial changes, the following are the major changes to the previous edition.

Old section	New Section	Change
3.6	3.6	Reference standard for application of Polypropylene (PP) piping updated.
6.13.1	6.13.1	Added note: The term "rapid gas decompression" is now often used instead of "explosive decompression"
6.13.8.2	6.13.8.2	Replaced paragraph 1 with the following: For reliable, safe and long-term sealing applications at pressures in excess of 40 bar gas pressures, and decompression rates higher than 10 bar per minute, and elevated temperature, particularly above 80°C, ED resistant elastomer materials shall be selected. Deleted paragraph 2.
6.13.8.3	N/A	Deleted this section
N/A	6.13.9	Added this section: 6.13.9 Qualification
N/A	6.13.9.1	Added this section: 6.13.9.1 General The Manufacturer shall demonstrate that the elastomer seal material is resistant against the given service conditions, including its long-term resistance. For both sweet and sour gas services, with pressures in excess of 40 bar (class 300), and at elevated temperatures, resistance against ageing and ED shall be demonstrated by qualification testing.

N/A	6.13.9.2	Added this section: 6.13.9.2 Ageing To determine the long-term effect on the material properties when exposed to fluids at elevated temperatures, ageing tests shall be performed in accordance with Norsok Standard M-710. The acceptance criteria for material degradation shall be in accordance with Section 2.5 of this PTS.
N/A	6.13.9.3	Added this section: 6.13.9.3 Explosive decompression To determine the resistance of elastomer seal materials against rapid depressurisation, ED tests shall be performed in accordance with Norsok Standard M-710. The rating procedure for ED damage shall be in accordance with Norsok Standard M-710. The acceptance criteria shall be as follows. • The damage rating shall be less than 4. • For critical applications (the definition of which shall be agreed by the Principal), a damage rating of 0 shall be required, i.e., no visible damage after ED testing when performed at the maximum specified design pressure and temperature.
References	References	EUROPEAN STANDARDS Added the following: Plastics piping systems for non-pressure underground drainage and sewerage – Polypropylene with mineral modifiers (PP-MD) EN 14758

2. GENERAL

2.1 SELECTION GUIDELINES

Within this PTS, minimum and maximum temperature limits are given for classes of non-metallic materials under generalised service conditions, e.g., oil or gas service. These temperature limits are meant as a guide to initiate the material selection process. Having selected the appropriate non-metallic material is it recommended to assess the specific limits of application for the intended service, not solely for temperature and service conditions but also for loads, lifetime, installation and operational constraints.

It should be realised that material properties may be impaired or severely changed during fabrication or degrade during service lifetime. The potential for such events to occur should be taken into account when selecting a specific material for a given service application.

The materials engineer should therefore be consulted at the appropriate design phase of the project.

If an equipment PTS specifies a particular non-metallic material, that specification shall govern regardless of the general requirements stated in this PTS. For example, valves shall be as specified in the piping classes (PTS 31.38.01.12 And PTS 31.38.01.15) and details of the required sealing materials shall be as specified in the MESC specifications referenced therein (e.g., MESC SPE 77/130).

2.2 ABBREVIATIONS

Abbreviations are commonly used to describe non-metallic materials. A number of abbreviations standardised in various codes, e.g., ASTM D 1418 and D 1600, ISO 1043 and ISO 1629, are listed below.

ABR	Acrylate Butadiene Rubber
ABS	Acrylonitrile Butadiene Styrene
ANSI	American National Standards Institute
API	American Petroleum Institute
ASA	Acrylonitrile Styrene Acrylate
ASTM	American Society for Testing and Materials
BR	Butadiene Rubber
BS	Butadiene Styrene
CA	Cellulose Acetate
CAB	Cellulose Acetate Butyrate
CAP	Cellulose Acetate Propionate
CFM	Polychlorotrifluoroethylene
CM	Chloropolyethylene
CP	Cellulosepropionate
CPE	Chlorinated polyethylene
CPVC	Chlorinated Polyvinylchloride
CR	Chloroprene Rubber
CSM	Chlorosulphonated Polyethylene
DAP	Diallyl Phthalate
ECTFE	Ethylenechlorotrifluoroethylene

EPR	Ethylene Propylene Rubber
EPS	Expanded Polystyrene
EPDM	Ethylene Propylene Rubber
ESC	Environmental Stress Cracking
ETFE	Ethylene Tetrafluoroethylene
EVA	Ethylene Vinylacetate
EVAC	Ethylene Vinylacetate
EVAL	Ethylene Vinylalcohol
FEP	Fluorinated Ethylene Propylene
FKM	Fluorocarbon Co-polymer
FFKM	Perfluoro Elastomer
FMK	Fluor-silicone Rubber
FPA	Perfluoralkoxy
FRP	Fiber Reinforced Plastic
GR-A	Apolybutadiene Acrylonitrile Rubber
GR-I	Butyl Rubber, Polyisobutylene Isoprene Rubber
GR-N	Nitrile Rubber, Nitrile Butadiene Rubber, Polybutadiene Acrylonitrile Rubber
GR-S	Styrene Butadiene Rubber, Polybutadiene Styrene Rubber
GRE	Glass Reinforced Epoxy
GRP	Glass Reinforced Plastic
GRUP	Glass Reinforced Unsaturated Polyester
GRVE	Glass Reinforced Vinyl Ester
HDPE	High Density Polyethylene
HNBR	Hydrogenated Nitrile Butadiene Rubber
IIR	Butyl Rubber
IM	Polyisobutene Rubber
IR	Isoprene Rubber
ISSO	International Standards Organisation
MDI	Diphenylmethane Diisocyanate
MDPE	Medium Density Polyethylene
MF	Melamine Formaldehyde
NBR	Nitrile Butadiene Rubber
NR	Natural Rubber
PA	Polyamide
PAI	Polyaramide Imide
PAN	Polyacrylonitrile
PB	Polybutylene
PBTP	Polybutylene Terephthalate

PC	Polycarbonate
PCTFE	Polychlorotrifluoroethylene
PEEK	Polyetheretherketone
PEI	Polyetherimide
PES	Polyethersulfone
PETP	Polyethylene Terephthalate
PEX	Cross-linked polyethylene
PF	Phenol Formaldehyde
PFA	Perfluoroalkoxy Copolymer
PFEP	Fluorinated Ethylene Propylene
PI	Polyimide
PIB	Polyisobutylene
PIR	Poly-isocyanurate rubber
PMMA	Polymethyl Methacrylate
POM	Polyoxymethylene, Polyformaldehyde
PP	Polypropylene
PPO	Polyphenylene oxide
PPS	Polyphenylene Sulphide
PS	Polystyrene
PSU	Polysulfone
PTFE	Polytetrafluoridethylene
PUF	Polyurethane (foam)
PUR	Polyurethane
PVAC	Polyvinyl Acetate
PVAL	Polyvinyl Alcohol
PVC	Polyvinylchloride
PVCC	Chlorinated Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
PVDF	Polyvinylidenefluoride
PVF	Polyvinyl Fluoride
SAN	Styrene Acrylonitrile
SB	Styrene Butadiene
SBR	Styrene Butadiene Rubber
SI	Silicone
SIC	Silicon carbide
TFE	Polytetrafluoroethylene
TPE	Thermoplastic Elastomers
TPU	Thermoplastic Polyurethane
(A)U, (E)U	Polyurethane AU (polyester), EU (polyether)

UF	Ureum Formaldehyde
UHMWHDPE	Ultra high molecular weight high density (Polyethylene)
UP	Unsaturated Polyester
UPVC	Unplasticised Polyvinylchloride
UV	Ultra violet light
VAC	Vinylacetate
VC	Vinylchloride
XLPE or PEX	Cross-linked Polyethylene consisting of long polymer chains in a 3-dimensional structure
XPS	Extruded polystyrene

2.3 CATEGORIES OF NON-METALLICS

The following categories of non-metallic materials are covered by this PTS:

- thermoplastic materials;
- thermoset materials;
- elastomeric materials;
- inorganic materials;
- insulation materials.

A broad list of commercially available non-metallic materials is included in (Appendix 1) including trade name, chemical classification and Manufacturer.

In this PTS the following definitions for classes of non-metallic materials are used:

- CERAMIC – Crystalline or partly crystalline structure produced from essentially inorganic, non-metallic substances and formed either from a molten mass solidified on cooling, or simultaneously or subsequently formed by the action of heat (ASTM C 242).
- COATING - a liquid or mastic compound which, after applying as a thin layer, converts into an adherent, solid and protective, decorative or functional film (ASTM D 16).
- ELASTOMER - a polymer material with similar properties to rubber (ASTM D 1566).
NOTE: This term should not be used as a synonym for rubber.
- INSULATION MATERIAL – a foamed or syntactic variation of a thermoplastic material, providing improved thermal resistance over the base thermoplastic polymer, fibrous inorganic material, cellular glass, amorphous silica and refractory.
- PAINT - a pigmented coating (ASTM D 16).
- REFRACTORY – an inorganic material with chemical and physical properties applicable for structures and system components exposed to environments above 538 °C (ASTM C 71).
- RUBBER - a material capable of quickly and forcibly recovering from all deformations (ASTM D 1566).
- THERMOPLASTIC - a plastic that repeatedly will soften by heating and harden by cooling within a temperature range characteristic for the plastic. In the softened state it can be shaped by flow into articles, e.g., by moulding/extrusion (ASTM D 883).
- THERMOSET - a plastic which is substantially infusible and insoluble after curing by heat or other means (ASTM D 883).

2.4 MATERIAL SELECTION

Material selection shall be determined by the:

- service conditions, i.e., operating temperature (maximum, minimum, range, etc.), and medium (internal, external);
- design requirements, i.e., design loadings (pressure, bending, static, dynamic, fatigue), design temperature, etc.

The material temperature limits given by the Manufacturer are normally approximate, based partly on measured data and partly on experience.

In this PTS, maximum and minimum operating temperatures for various service conditions are presented. These service conditions are generalised conditions. For example, water is quoted as a typical service condition. In this PTS, the term water covers, fresh, sea, produced, injection and potable.

Therefore, the values presented should be considered as an initial screening check and should be used for guidance purpose only.

2.5 CHEMICAL RESISTANCE

The material selection process shall ensure that the material is compatible with the service fluids to which it is exposed over the full operating temperature range so that the mechanical, physical and chemical properties of the component/system satisfy the design requirements throughout the intended lifetime.

The Manufacturer shall supply a chemical resistance list for all the service fluids for the specific material, quoting the highest known service temperature that the material has been subjected to, and if available, the service life that has been achieved under the service conditions. The chemical resistance list shall state whether the material has been laboratory tested (according to ASTM C 581 or other standard) and shall state the life expectancy for the intended service.

A survey of the chemical resistance of non-metallic materials in a variety of chemical environments (fluids) is given in (Appendix 2). The chemical resistance can be determined by various methods and depends primarily on factors such as temperature, test property and evaluation criteria. In (Appendix 2), the maximum operating temperature is given for inert conditions, along with the chemical resistance (in terms of maximum operating temperature) of the non-metallic materials to specific fluids. In (Appendix 2), the following definitions are used:

1. • – Resistant at ambient temperature, no maximum operating temperature available or limited resistant above ambient (advisable to consult supplier or materials expert);
2. **X** - Not resistant;
3. **Number** – Resistant up to quoted °C;
4. **Blank** – No data or experience.

Table 2.5 classifies the definition of chemical resistance in terms of a weighted value between 1 and 10. The link between Table 2.5 and (Appendix 2) is as follows:

(Appendix 2)	Resistant	Non-resistant	Limited resistant
Table 2.5	Weighted value 7-10	Weighted Value 1-3	Weighted value 4-6

Table 2.5 should only be used as a guide to defining chemical resistance. Actual data according to a recognised standard (e.g., ASTM C 581) should always be used when assessing chemical resistance of a given material to a specific environment.

Table 2.5 Definition of chemical resistance

Weighted value	Weight change [1]	Length change [1]	Thickness change [1]	Volume change [1]	Mechanical property retained [2]	Visual observed change
10	0 to 0.25	0 to 0.1	0 to 0.25	0 to 2.5	≥ 97	No change
9	> 0.25 but ≤ 0.5	> 0.1 but ≤ 0.2	> 0.25 but ≤ 0.5	> 2.5 but ≤ 5	94 to < 97	No change
8	> 0.5 but ≤ 0.75	> 0.2 but ≤ 0.3	> 0.5 but ≤ 0.75	> 5 but ≤ 10	90 to < 94	No change
7	> 0.75 but ≤ 1	> 0.3 but ≤ 0.4	> 0.75 but ≤ 1	> 10 but ≤ 20	85 to < 90	Slightly discoloured, slightly bleached
6	> 1 but ≤ 1.5	> 0.4 but ≤ 0.5	> 1 but ≤ 1.5	> 20 but ≤ 30	80 to < 85	Discoloured, yellows, slightly flexible
5	> 1.5 but ≤ 2	> 0.5 but ≤ 0.75	> 1.5 but ≤ 2	> 30 but ≤ 40	75 to < 80	Possible stress crack agent, flexible, possible oxidising agent, slightly crazed
4	> 2 but ≤ 3	> 0.75 but ≤ 1	> 2 but ≤ 3	> 40 but ≤ 50	70 to < 75	Distorted, warped, softened, slight swelling, blistered, known stress crack agent
3	> 3 but ≤ 4	> 1 but ≤ 1.5	> 3 but ≤ 4	> 50 but ≤ 70	60 to < 70	Cracking, crazing, brittle, plasticiser, oxidiser, softened, swelling, surface hardened
2	> 4 but ≤ 6	> 1.5 but ≤ 2	> 4 but ≤ 6	> 70 but ≤ 90	50 to < 60	Severe distortion, oxidiser and plasticiser, deteriorated
1	> 6	> 2	> 6	> 90	> 0 but < 50	Decomposed

[1] – All values are given as a percentage change from original

[2] – Percent mechanical properties retained include tensile strength, elongation, modulus, flexural strength and impact.

2.6 FIRE PERFORMANCE

(Appendix 3) summarises the fire performance of a broad class of non-metallic materials. This scheme is based on flame tests. The flammability characteristics of materials may change considerably by treating them with flame retardant additives.

2.7 MATERIAL PROPERTIES

The relevant mechanical and physical properties that may be required along with the relevant standard are listed in Table 2.7.

Table 2.7 Relevant mechanical and physical properties of non-metallic materials

Description	Unit	Standard
Mechanical		
Tensile strength at yield	MPa	ISO 527
Tensile strain at yield	%	ISO 527
Tensile strength at break	MPa	ISO 527
Tensile strain at break	%	ISO 527
Tensile modulus	MPa	ISO 527
Compressive strength at break	MPa	ISO 604
Compressive strain at break	%	ISO 604
Compressive modulus	MPa	ISO 604
Flexural strength at yield	MPa	ISO 178
Flexural strength at break	MPa	ISO 178
Flexural modulus	MPa	ISO 178
Poisson ratio	-	ASTM E 132
Creep modulus of elasticity (tensile or compressive)	MPa	ISO 899
Hardness, Ball indent.	MPa	ISO 2039-1
Hardness, Rockwell R	-	ISO 2039-1
Hardness, Shore A	-	ASTM D 2240
Hardness, Shore D	-	ASTM D 2240
Hardness (Barcol)	-	ASTM D 2583
Physical		
Density	kg/m ³	ISO 1183
Water, moisture absorption	%	DIN 53495
Thermal		
Heat distortion temperature	°C	ISO 75-1
Glass transition temperature	°C	ASTM E 1356
Thermal conductivity	W/m	ASTM C 177
Thermal expansion coefficient	m/m	ASTM D 696
Specific heat coefficient	J/kg/K	ASTM E 1269
Permeation coefficient	m ² /s/bar	ASTM F 1769

Impact		
Charpy (notched impact strength)	kJ/m^2	ISO 179
Izod	kJ/m^2	ISO 180
Rheological		
Melt volume flow rate	ml/min	ISO 1133
Optical		
Light transmission	%	ASTM D 1003
Refractive index	-	ISO 489
Flammability		
Oxygen index	%	ISO 4589

3. THERMOPLASTIC MATERIALS

3.1 INTRODUCTION

Thermoplastic materials intended for chemical resistant applications are supplied in the form of either extruded or pressed sheets or as tubing for pipe systems. The polymer may include additives such as pigments, UV stabilisers and fire retardants.

The application of thermoplastic materials for plastic pipes shall be in accordance with PTS 31.38.01.11-Gen.

The application of thermoplastic liners in carbon steel pipelines and flowlines shall be in accordance with PTS 31.40.30.34-Gen.

The application of polyethylene (PE) and polypropylene (PP) thermoplastic material for external coating of line pipe shall be in accordance with PTS 31.40.30.31-Gen.

The most commonly applied thermoplastics (or those having the greatest potential for use) in EP, OP and Chemicals applications are discussed in more detail in the following sections. They are:

- Plasticised Polyvinyl Chloride (PVC);
- Unplasticised PVC (UPVC);
- Polyethylene (PE);
- Polyamide (PA);
- Polypropylene (PP);
- Fluoropolymers (PTFE, PCTFE, PFA, FEP, PVDF);
- Polyphenylene Sulphide (PPS);
- Cross-linked Polyethylene (PEX);
- Polyetheretherketone (PEEK);

A summary of material properties of other thermoplastics that are occasionally used in EP OP and Chemicals applications is given in (Appendix 4).

3.2 PLASTICISED POLYVINYL CHLORIDE (PVC)

Plasticised PVC is widely used as a chemically resistant lining, particularly in oxidising conditions such as chromic and nitric acid. Because of its high strain to failure and good ductility, it can be bonded to metal without suffering adhesion failure due to differences in thermal expansion between steel substrate and the polymer.

PVC has a relatively low maximum operating temperature limit of 60 °C. PVC may suffer from embrittlement in extended service due to loss of plasticiser under certain chemical and environmental conditions.

Table 3.2a lists the maximum operating temperature as a function of fluid composition.

Table 3.2a Maximum operating temperature as a function of application for plasticised polyvinyl chloride (PVC)

Typical applications OP and Chemicals	T(max) (°C)	Typical applications EP	T(max) (°C)
80 % sulphuric acid	40	Water	60
chlorine gas, wet, dry	40		
70 % sodium hydroxide	40		
20 % sodium hypochlorite	40		

A summary of typical material properties of PVC under ambient conditions is presented in Table 3.2b.

Table 3.2b Typical material properties of PVC

Typical properties	PVC
Density (g/cm ³)	1.45
Mechanical properties at 23 °C	
Tensile strength (MPa)	50
Elongation at break (%)	15
Tensile modulus (MPa)	3300
Izod impact, notched (kJ/m ²)	2
Thermal conductivity (W/m.K)	0.17
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	70

3.3 UNPLASTICISED PVC (UPVC)

UPVC has excellent resistance to inorganic chemicals and certain organic chemicals, but resistance to aromatic and chlorinated hydrocarbons is poor. Generally, UPVC is reinforced with glass fibres to improve mechanical properties.

Typical applications for UPVC are components, e.g., valves, fittings and piping. For the application of UPVC pressure pipe for conveying water up to 15 bar and operating at ambient temperature, CEN EN 1452-2 should be used. For UPVC pipe joints and fitting, CEN EN 1452-3 should be used.

Table 3.3a lists the maximum operating temperature as a function of fluid composition.

Table 3.3a Maximum operating temperature as a function of application for UPVC

Typical applications OP and Chemicals	T(max) (°C)	Typical applications EP	T(max) (°C)
80 % sulphuric acid	60	Water	75
chlorine gas, wet, dry	60		
70 % nitric acid	20		
70 % sodium hydroxide	60		
50 % formic acid	50		
20 % sodium hypochlorite	60		

A summary of typical material properties of UPVC under ambient conditions is presented in Table 3.3b.

Table 3.3b Typical material properties of UPVC

Typical properties	UPVC
Density (g/cm ³)	1.55
Mechanical properties at 23 °C	
Tensile strength (MPa)	70
Elongation at break (%)	15
Tensile modulus (MPa)	3500
Izod impact, notched (kJ/m ²)	2
Thermal conductivity (W/m.K)	0.16
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	60

3.4 POLYETHYLENE (PE)

Polyethylene has excellent chemical resistance (except to strong oxidising agents and aromatic hydrocarbons) and good resistance to solvents. The material is resilient even at sub zero temperatures. The upper and lower operating temperature limits are 60 °C and -100 °C, respectively, based on non-corrosive test conditions.

Polyethylene is widely used as gas piping and for lining Carbon Steel flowlines and equipment. For the application of PE pipe for underground conveying of oil, gas and industrial water, API 15 LE should be used. For the application of PE pipe for general purposes, including use in chemical plants, BS 6437 should be used. For application of PE pipe for conveying gaseous fuels, BS 7281 should be used.

Numerous PE grades are available. Their difference is primarily a result of either polymerisation processes for the production of the base polymer or chemical modifications or enhancements with additives. Base polymer density is used to indicate PE type. Low, medium and high density grades are distinguished as LDPE, MDPE and HDPE. For lining applications, three types of PE are used and in increasing order of strength and chemical resistance are:

- MDPE, used in low pressure water and gas distribution applications;
- HDPE, used in all types of service;
- Ultra High Molecular Weight (UHMW-HDPE), used in demanding applications.

MDPE (or PE 80) is a relatively soft grade and is used in (low) pressure applications under ambient conditions. It has good 50-year creep-rupture performance and is easy to manufacture (extrude) and install.

HDPE (or PE 100) is the basic engineering grade of PE. Compared to MDPE, it has a higher yield and ultimate strength, a higher modulus and better chemical resistance. These improved properties come with the penalty of slightly more difficult extrusion and installation. However, HDPE is more sensitive to notches and has a lower environmental stress cracking (ESC) resistance than MDPE.

UHMW-HDPE has been developed for aggressive chemical environments and high toughness. Compared to HDPE it has a higher yield and ultimate strength, a higher modulus and better chemical resistance. This results in reduced swelling in crude oil and an increased capability of bridging pinhole leaks in the carbon steel outer pipe. However, these improved properties come with the penalty of considerably more difficult extrusion.

Table 3.4a lists the maximum operating temperature as a function of fluid composition.

Table 3.4a Maximum operating temperature as a function of application for polyethylene (PE)

Typical applications OP and Chemicals	T(max) (°C)	Typical applications EP	T(max) (°C)
80 % sulphuric acid	60	Oil/gas/water mixture	50
25 % nitric acid	60	Oil/water mixture	50
40 % hydrochloric acid	60	Gas and condensate	50
70 % sodium hydroxide	60	Dry gas	60
50 % phosphoric acid	60	Water	60

A summary of typical material properties of PE under ambient conditions is presented in Table 3.4b.

Table 3.4b Typical material properties of PE

Typical properties	PE (MD)			PE (HD)			PE (UHMW)		
Density (g/cm ³)	0.926-0.94			0.941-0.965			0.989		
Mechanical properties at 23 °C									
Yield (tensile) strength (MPa)	18			25			30		
Tensile stress at break (MPa)	20			20			25		
Elongation at break (%)	> 400			> 400			> 400		
Tensile modulus (MPa)	400			700			1100		
Izod impact, notched (kJ/m ²)	4			6			7		
Thermal conductivity (W/m.K)	0.35			0.4			0.4		
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	200			200			200		
Mechanical properties (function of temperature)	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C	23 °C	40 °C	60 °C
Modulus (MPa)	400	250	130	700	450	250	1100	600	400
Poisson ratio	0.35	0.38	0.4	0.35	0.38	0.4	0.35	0.38	0.4

3.5 POLYAMIDE (PA)

PA is a commodity engineering plastic with a price higher than PE. PA has excellent resistance to hydrocarbons but limited resistance to water at elevated temperatures.

Because of the molecular structure of PA, e.g., PA-6 and PA-11, different grades can essentially be considered as different materials. PA-11 is used as a liner in conventional flexible flow-lines and risers transporting gas and crude with low water cuts. It has good material properties for liner applications, high modulus and strength, with relatively high

strain to failure in its non-aged condition. It has been used as a liner in carbon steel pipelines at temperatures up to 75 °C. Installation of PA-11 based liners below –30 °C is not recommended.

Table 3.5a lists the maximum operating temperature as a function of fluid composition, typically used within EP. Within OP and Chemicals applications, PA is generally not used.

Table 3.5a Maximum operating temperature as a function of application for polyamide PA-11

Typical applications E & P	T(max) (°C)
Oil/gas/water mixture	65
Oil/water mixture	75
Gas and condensate	80
Dry gas	80
Water	75

A summary of typical material properties of PA-11 (e.g., Rilsan) under ambient conditions is presented in Table 3.5b.

Table 3.5b Typical material properties of PA-11

Typical properties	PA-11			
Density (g/cm ³)	1.05			
Mechanical properties at 23 °C				
Yield (tensile) strength (MPa)	26			
Tensile stress at break (MPa)	48			
Elongation at break (%)	>230			
Tensile modulus (MPa)	300			
Izod impact, notched (kJ/m ²) at −30 °C	8			
Thermal conductivity (W/m.K)	0.21			
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	110			
Mechanical properties (function of temperature)	23 °C	40 °C	60 °C	80 °C
Flexural modulus (MPa)	300	210	190	170
Poisson ratio	0.47	0.47	0.46	0.45

3.6 POLYPROPYLENE (PP)

Polypropylene has similar chemical resistance properties to those of Polyethylene. The maximum operating temperature is 100 °C, while the lower temperature limit is –20 °C, based on non-corrosive test conditions. The limitations of resistance to oxidising chemicals are the same as for PE. Polypropylene has excellent resistance to water and liquid hydrocarbons, but limited resistance to aromatics. At ambient temperatures, PP has comparable stiffness characteristics to PE, but at elevated temperatures, the stiffness of PP is higher.

PP is commonly used as chemically resistant piping, valves and fittings. For application of PP piping, [EN 14758](#) should be used. **

PP reinforced with glass fibre mat, termed “Celmar”, is often used as structural material for chemical resistant equipment. Typical applications include scrubbing towers for phosphoric

acid plants, which are also considerably lighter and more corrosion resistant than the alternative lined carbon steel systems.

Table 3.6a lists the maximum operating temperature as a function of fluid composition.

Table 3.6a Maximum operating temperature as a function of application for polypropylene (PP)

Typical applications OP and Chemicals	T(max) (°C)	Typical applications EP	T(max) (°C)
50 % sodium hydroxide	85	Oil/gas/water mixture	70
35 % hydrochloric acid	85	Oil/water mixture	70
80 % sulphuric acid	80	Gas and condensate	70
80 % phosphoric acid	85	Dry gas	85
-	-	Water	85

A summary of typical material properties of PP under ambient conditions is presented in Table 3.6b.

Table 3.6b Typical material properties of PP

Typical properties	PP
Density (g/cm ³)	0.9
Mechanical properties at 23 °C	
Tensile strength (MPa)	40
Elongation at break (%)	> 100
Tensile modulus (MPa)	1200
Izod impact, notched (kJ/m ²)	6
Thermal conductivity (W/m.K)	0.22
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	180

3.7 FLUOROPOLYMERS (PTFE, PCTFE, PFA, FEP, PVDF)

In general fluoropolymers show excellent chemical resistance, e.g., to fuming nitric and sulphuric acids, hot caustic soda, chlorine gas and most other chemicals, even at relatively high temperatures.

The following lists the commercially available fluoropolymers, including their minimum and maximum operating temperatures. The temperature limits are based on non-corrosive test conditions.

- Polytetrafluoroethylene (PTFE): -240 °C to 230 °C
- Polychlorotrifluoroethylene (PCTFE): -240 °C to 200 °C
- Perfluoralkoxy (PFA): -200 °C to 230 °C
- Fluorinated ethylene propylene (FEP): -30 °C to 150 °C
- Polyvinylidene fluoride (PVDF): -30 °C to 120 °C

Fluoropolymers should not be used in the following environments: fluorine gas, strong reducing agents such as alkaline metals, sodium and potassium and reactions of sodium metal in anhydrous solvents, such as naphthalene and anhydrous ammonia.

PTFE linings and coatings are generally extruded and moulded, which limits the size of the equipment to be lined. PTFE is typically used as a lining of pipes and equipment in chloroacetic acid plants, operating at temperatures in the range of -30°C to 165°C .

PCTFE is a fluorocarbon-based polymer that offers a unique combination of physical and mechanical properties, high chemical resistance, non-flammability, high optical transparency and near zero moisture absorption. The material is typically used for seals, gaskets and components for valves, pumps, bearings, etc, including cryogenic applications. The trade name for PCTFE is "Kel-F".

FEP and PFA are melt processable (extrudable) fluoropolymers and these materials can be welded.

PVDF is also a melt processable fluoropolymer with a price higher than that of both PE and PA. PVDF has excellent chemical resistance and its superior thermal stability means that its application envelope in terms of operating temperature extends up to 120°C for all applications. PVDF is also used in bromine transfer lines and lined steel pipes for transport of hydrochloric acid at temperatures up to 100°C .

PVDF has good mechanical properties. The modulus and yield strength are high, but the yield strain is low. The pure polymer is difficult to extrude and, to overcome this, plasticised grades are used, for example as pressure sheaths in flexible flow-lines and risers.

Table 3.7a and 3.7b lists the maximum operating temperature as a function of fluid composition for the different fluoropolymers.

Table 3.7a Maximum operating temperature as a function of application for PTFE/PCTFE/FEP/PFA

Typical applications OP and Chemicals	T(max) ($^{\circ}\text{C}$)
50 % sulphuric acid	150
25 % hydrochloric acid	150
85 % phosphoric acid	150
30 % nitric acid	150
50 % formic acid	130

Table 3.7b Maximum operating temperature as a function of application for PVDF

Typical applications OP and Chemicals	T(max) ($^{\circ}\text{C}$)	Typical applications EP	T(max) ($^{\circ}\text{C}$)
50 % sulphuric acid	120	Oil/gas/water mixture	120
98 % sulphuric acid	50	Oil/water mixture	120
25 % hydrochloric acid	100	Gas and condensate	120
85 % phosphoric acid	120	Dry gas	120
30 % nitric acid	100	Water	120
50 % formic acid	100		
Sodium hypochlorite	100		

A summary of typical material properties of PVDF under ambient conditions is presented in Table 3.7c. In Table 3.6c data for both homopolymer and copolymer grades are presented. Homopolymer grades contain little plasticiser, whereas copolymer grades are heavily plasticised.

Table 3.7c Typical material properties of PVDF

Typical properties	PVDF (homopolymer)					PVDF (copolymer)				
Density (g/cm ³)	1.78					1.78				
Mechanical properties at 23 °C										
Yield (tensile) strength (MPa)	55					25				
Tensile stress at break (MPa)	40					35				
Elongation at break (%)	> 20					> 50				
Tensile modulus (MPa)	2200					1000				
Izod impact, notched (kJ/m ²)	20					20				
Thermal conductivity (W/m.K)	0.19					0.18				
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	130					140-180				
Mechanical properties (function of temperature)	23 °C	40 °C	75 °C	90 °C	120 °C	23 °C	40 °C	75 °C	90 °C	120 °C
Modulus (MPa)	2200	1750	1000	750	400	1000	650	250	150	110
Poisson ratio	0.35	0.35	0.40	0.45	0.5	0.35	0.35	0.40	0.45	0.5

3.8 POLYPHENYLENE SULPHIDE (PPS)

PPS is an engineering plastic with a price similar to that of PVDF. It is not currently used but has the potential to be a high temperature thermoplastic liner. It has excellent high temperature properties, good chemical resistance to water, dry gas and most hydrocarbons, but limited resistance to high concentrations of aromatics.

There are many different grades of PPS available but because of its molecular structure, PPS must be plasticised to enable extrusion and to provide the flexibility required to enable insertion as a liner. PPS has good mechanical properties, high modulus and strength but a limited strain to failure.

Table 3.8a lists the maximum operating temperature as a function of fluid composition.

Table 3.8a Maximum operating temperature as a function of application for Polyphenylene Sulphide (PPS)

Typical applications EP	T(max) (°C)
Oil/gas/water mixture	150
Oil/water mixture	150
Gas and condensate	150
Dry gas	150
Water	150

A summary of typical material properties of PPS under ambient conditions is presented in Table 3.8b.

Table 3.8b Typical material properties of PPS

Typical properties	PPS
Density (g/cm ³)	1.64
Mechanical properties at 23 °C	
Yield (tensile) strength (MPa)	90
Tensile stress at break (MPa)	140
Elongation at break (%)	5
Tensile modulus (MPa)	3800
Izod impact, notched (kJ/m ²)	2
Thermal conductivity (W/m.K)	0.2
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	90

3.9 CROSS-LINKED POLYETHYLENE (PEX)

PEX is an engineering plastic manufactured by cross-linking PE, however, it is more expensive than PE.

Polyethylene is a thermoplastic material but once it is cross-linked it acts more as a thermoset material. Cross-linked polymeric materials have all the characteristics required for a high performance liner; high operating temperature, toughness and excellent chemical resistance. The degree of cross-linking is important for product performance. For liner applications, the degree of cross-linking should be in excess of 70 % to achieve optimum performance of the material. PEX has excellent resistance to hydrocarbons and water at elevated temperatures up to 85 °C.

Table 3.9a lists the maximum operating temperature as a function of fluid composition.

Table 3.9a Maximum operating temperature as a function of application for cross-linked polyethylene (PEX)

Typical applications EP	T(max) (°C)
Oil/gas/water mixture	85
Oil/water mixture	85
Gas and condensate	85
Dry gas	85
Water	85

A summary of typical material properties of PEX under ambient conditions is presented in Table 3.9b.

Table 3.9b Typical material properties of PEX

Typical properties	PEX
Density (g/cm ³)	0.95
Mechanical properties at 23 °C	
Yield (tensile) strength (MPa)	25
Tensile stress at break (MPa)	30
Elongation at break (%)	> 50
Tensile modulus (MPa)	800
Izod impact, notched (kJ/m ²)	30
Thermal conductivity (W/m.K)	0.35
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	120

3.10 POLYETHERETHERKETONE (PEEK)

PEEK is a crystalline material, moulded at temperatures in the range of 360 °C to 395 °C. Melting temperature of PEEK is 334 °C and its heat deflection temperature (HDT) is 160 °C. Its very high melt viscosity made it originally a coating and wire-covering material, but at present several moulding grades are available, e.g., used for compression moulding of fibre-reinforced components (RTP).

PEEK has excellent properties at high temperatures, e.g., high flame resistance, low smoke generation, high chemical and solvent resistance. Mechanical properties include a high stiffness at ambient temperature with non-brittle failure on impact. Flexural strength is high and the material has excellent fatigue resistance. Various grades are available, e.g., glass-fibre or carbon-fibre reinforced tape, sheet or components.

Main applications for PEEK are high temperature applications requiring flame-resistance and chemical resistance. Typical applications are valve seats, pump components/impellers for hot oil, etc. PEEK is not resistant against concentrated nitric acid, sulphuric acid and liquid bromide.

Table 3.10a lists the maximum operating temperature as a function of fluid composition.

Table 3.10a Maximum operating temperature as a function of application for PEEK

Typical applications EP, OP and Chemicals	T(max) (°C)
50 % sulphuric acid	100
85 % phosphoric acid	100
Benzene, Toluene	150
Hexane, Heptane	70
Water	150

A summary of typical material properties of PEEK under ambient conditions is presented in Table 3.10b.

Table 3.10b Typical material properties of PEEK

Typical properties	PEEK
Density (g/cm ³)	1.32
Mechanical properties at 23 °C	
Tensile strength (MPa)	105
Elongation at break (%)	35
Tensile modulus (MPa)	4400
Izod impact, notched (kJ/m ²)	8
Thermal conductivity (W/m.K)	0.25
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	50

4. FIBRE REINFORCEMENT MATERIALS

4.1 GENERAL

High strength, low density, organic fibres are used to reinforce both thermoset and thermoplastic polymers, as well as elastomers. Typical components that can be made from composite materials include pipes, vessels, structural components, gaskets, and seals. Composite materials can be used also as linings for internal protection of tanks, storage vessels and downhole tubulars.

Fibres used for reinforcement come in various forms:

- surface veils, typically used for chemically resistant layers, e.g., internal linings for piping;
- chopped strand mat or chopped fibres, e.g., panels;
- rovings, typically used in filament wound components, e.g., piping, vessels;
- woven rovings;
- fabrics;
- flakes, typically used in high performance coatings.

The most common fibre types are:

- glass;
- aramid;
- carbon;

4.2 TYPES OF REINFORCEMENT FIBRES

Glass fibres are the most widely used for reinforcement of polymer materials. Glass fibres are produced in four forms:

- **E-Glass**, the most commonly used type of glass. It is least expensive and has good mechanical properties. This type of glass is used throughout all structural composites, e.g., pipes, vessels, structural components.
- **S-Glass** is stronger than E-glass, but substantially more expensive. It is little used in applications that require high corrosion resistance.
- **C-Glass** has a high degree of chemical resistance. It is used where the fluid may come into contact with the reinforcement. C-glass is used for surface veils.
- **ECR-Glass** offers improved chemical resistance over E-glass and is only slightly more expensive. ECR-glass is often used for internal surface veils when severe corrosive conditions occur.

Aramid fibres are used for low weight, high strength structures, e.g., components for space and aircraft industry. However, Aramid fibres are increasingly used in the petrochemical industry, e.g., in gaskets and reinforced thermoplastic high pressure pipe, e.g., Aramid reinforced Polyethylene flow-lines for the transport of crude oil. Resistance to high temperatures is good, but Aramid fibres degrade due to UV. In compression, the fibres fail at low stress level due to fibre buckling (kinking).

Carbon fibres are used for low weight, high strength and stiffness structures, e.g., components for the aerospace industry. Carbon fibres are commercially available as Carbon-HS (high-strength) and Carbon-HM (high-modulus). Within the oil industry, carbon fibres are also used in lightweight, high strength and stiffness composite risers.

4.3 TYPICAL PROPERTIES OF REINFORCEMENT FIBRES

Table 4.3 presents mechanical properties of commercially available reinforcement fibres.

Table 4.3 Mechanical properties of reinforcing fibres

Material	E-glass	S-glass	Aramid	Carbon-HS	Carbon-HM
Density (g/cm ³)	2.54	2.59	1.45	1.81	1.85
Tensile Strength (MPa)	2400	3500	3000	5000	2700
Tensile Modulus (GPa)	73	86	130	240	390
Elongation at break (%)	4	4	2.1	1.8	0.7
Thermal expansion (10 ⁻⁶ /mK)	5	5	-2	-0.1	-0.5

The fibre content (by volume) in polymer composites is typically in the range of 50 % to 60 %.

The fibre content (by weight) for glass fibre reinforced components, e.g., pipes, is typically:

- hand lay-up: 50 % to 65 %;
- filament wound fittings: 65 % to 75 %;
- filament wound pipes: 70 % to 82 %.

5. THERMOSET MATERIALS AND COMPOSITES

5.1 FIBRE REINFORCED PLASTIC COMPOSITES

The most common fibre used in FRP structures is glass. In GRP structures, the fibre carries the load and the resin or matrix provides the chemical resistance. The wall of GRP structures, e.g., pipes, normally consists of a resin rich layer (with or without a fibrous cloth) on the inside to provide a chemical barrier, a fibre reinforced laminate to carry the load, and an external resin layer for protection.

GRP structures can be manufactured via hand lay-up, filament winding, centrifugal casting or combinations of techniques. Pultrusion is a manufacturing method, similar to extrusion, which can be used to manufacture GRP sections of limited size, e.g., ladders, gratings, cable trays, beams, etc.

If the GRP structure is not sufficiently resistant to the service fluids at operating conditions, lining the GRP structure with a thermoplastic should be considered.

The application of GRP pipelines and piping systems should be according to PTS 31.40.10.19-Gen. Design and installation of GRP tanks and vessels should be according to PTS 31.22.30.14-Gen.

Resin types used for GRP structures, process equipment and coatings are:

- Epoxy;
- Vinyl Ester;
- Polyester;
- Phenolic;
- Furane;
- Polyurethane.

A summary of material properties of other thermoset resins that are occasionally used in EP, OP and Chemicals applications is given in (Appendix 4).

5.2 EPOXY RESINS

Epoxy resins have excellent resistance to a wide range of moderately strong acids and alkalis, plus most hydrocarbons. There are several types of base epoxy resins and associated curing agents.

The curing agents for epoxy resin are:

- Aliphatic Amine - Minimum glass transition temperature, T_g , 115 °C. This system has good resistance against caustics and solvents, however resistance against acids is fair.
- Cyclo Aliphatic Amine - Minimum glass transition temperature, T_g , 140 °C. This system has excellent resistance against caustics and solvents, however resistance against acids is fair.
- Aromatic Amine - Minimum glass transition temperature, T_g , 140 °C. This system has excellent resistance against caustics and solvents, however resistance against acids is fair.
- Anhydride - Minimum glass transition temperature, T_g , 115 °C. This system has excellent resistance against acids, however resistance against caustics and solvents is poor.

Epoxy resins are also used as corrosion resistant paints as they have good adhesive properties, particularly to steel substrates. In addition, flexible epoxy systems are also available, although with reduced chemical resistance. Flexibility is achieved by modifying both the resins and hardeners, or by blending with Polyurethanes or rubbers.

Table 5.2a lists the maximum operating temperature as a function of various service fluid compositions for GRE. For Epoxy systems, it is a further requirement that the T_g of the Epoxy resin must be greater than the maximum operating temperature by 30 °C. The minimum temperature for Epoxy resin is -50 °C.

Table 5.2a Maximum operating temperature as a function of application for GRE

Typical applications	T(max) (°C) hot-cured system	Typical applications	T(max) (°C) hot-cured system
Water (fresh, salt, sea, brackish)	100	Water, chlorinated < 100 mg/kg	100
Acetic acid, < 50 %	80	Acetone, 5 % to 10 %	25
Acetic acid, 50 % to 75 %	25	Air	110
Acetone, 10 % to 25 %	25	Benzene	50
Alcohol, methyl	40	CO ₂ gas	110
Allyl chloride	25	Condensate	95
Butane gas	60	Gasoline	65
Citric acid	90	Heptane	60
Gas, natural	90	Crude oil	100
Glycol, ethylene	90	Sodium hydroxide, < 50 %	90
Hexane	60		
Jet Fuel (kerosene)	100		
Petrol; sour, refined	60		
Toluene	50		
Xylene	60		

A summary of typical material properties of Epoxy resin under ambient conditions is presented in Table 5.2b.

Table 5.2b Typical material properties of Epoxy resin (non-reinforced)

Typical properties	Epoxy
Density (g/cm ³)	1.8
Mechanical properties at 23 °C	
Tensile strength (MPa)	75
Elongation at break (%)	4
Tensile modulus (MPa)	3300
Izod impact, notched (kJ/m ²)	20
Barcol hardness	35
Thermal conductivity (W/m.K)	0.24
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	60

5.3 POLYESTER RESINS

The uses of Polyester systems in the general chemical industry are numerous and diverse. Chlorine plants, in particular, use large quantities of glass-fibre reinforced polyester (GRP) for chemically resistant applications. Polyester resins are also used as the matrix for flake glass coatings. Conventional GRP utilises glass fibres in chopped strand, rovings and woven rovings form.

Types of Polyester resins include:

- Isophthalic Polyester. This is a relatively low cost resin, which is rarely used for chemical services. One major application is for underground gasoline tanks. However if alcohol is used as a fuel additive, Isophthalic resins cannot be used as they are not sufficiently resistant. The maximum operating temperature for Isophthalic Polyester is 60 °C.
- Bisphenol A Polyester. This is a high temperature, chemically resistant resin that is extensively used in chemical service. It is a general purpose resin and is easy to manufacture. Although Bisphenol Polyester is inherently brittle, current resin developments include grades which are more flexible. Bisphenol Polyester has superior acid resistance compared to Epoxy. The maximum operating temperature for Bisphenol Polyester is 95 °C.
- Chlorinated Polyester. This resin has many of the properties of Bisphenol A Polyester, with the addition of inherent fire retardant characteristics. This property can be enhanced by the addition of antimony oxide particles. Therefore, these resins are used extensively for ducting and other structural applications where fire retardancy is required. Chemical resistance in chlorine services is excellent. The maximum operating temperature for Chlorinated Polyester is 120 °C.

Compared to Epoxy resins, Polyester resins have a higher shrinkage due to the catalytic reaction and evaporation of the styrene monomer. This will limit the maximum allowable wall thickness in GRP structures. The minimum operating temperature for Polyester systems is -50 °C.

Table 5.3a lists the maximum operating temperature as a function of various service fluid compositions for GRUP.

Table 5.3a Maximum operating temperature as a function of application for Isophthalic GRUP

Typical applications	T(max) (°C) post-cured system	Typical applications	T(max) (°C) post-cured system
Water (fresh, salt, sea, brackish)	50	Water, chlorinated < 100 mg/kg	50
Air	60		

A summary of typical material properties of Polyester resin under ambient conditions is presented in Table 5.3b.

Table 5.3b Typical material properties of Polyester resin (non-reinforced)

Typical properties	Polyester
Density (g/cm ³)	1.1
Mechanical properties at 23 °C	
Tensile strength (MPa)	60
Elongation at break (%)	3
Tensile modulus (MPa)	3500
Izod impact, notched (kJ/m ²)	15
Barcol hardness	35
Thermal conductivity (W/m.K)	0.2
Coefficient of thermal expansion (m/mK * 10 ⁻⁶)	60