055 – NORWEGIAN OIL AND GAS RECOMMENDED GUIDELINES

FOR

NDT OF GRP PIPE SYSTEMS AND TANKS

NORWEGIAN OIL AND GAS ASSOCIATION
(Norwegian Oil and Gas)

GUIDELINE FOR NDT OF GRP PIPE SYSTEMS AND TANKS

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GUIDELINE FOR NON-DESTRUCTIVE TESTING AND EXAMINATION OF GRP PIPE SYSTEMS AND TANKS

PART 1 PHILOSOPHY & SCOPE

FORWORD

The objective of this Guideline is to provide the offshore oil and gas industry and the supporting engineering and manufacturing industry with recommended practices for non-destructive evaluation (NDE) and testing (NDT) of Glass-fibre Reinforced Plastic (GRP) materials.

This Guideline has been prepared to meet a need perceived by Norsk olje og gass (Norwegian Oil and Gas Association). Members of the Norwegian Oil and Gas GRP Workgroup working on this project comprised: Mr. B. Melve (Statoil), Mr. B. Moursund (Norsk Hydro), Mr. I. Mæland (AMOCO), Mr. J.D. Winkel and Mr. F. Thorstensen (Phillips Petroleum Co. Norway), Mr. H. Thon (Saga Petroleum). This Guideline is based on published literature, various joint industry R&D projects in Norway, the U.K., and the Netherlands, plus various operators' experience. References are cited only when taken from the open literature, but additional unpublished information is summarized in order to present a comprehensive picture of NDT of GRP piping and tank systems used in North Sea applications.

It is the intention of the Norwegian Oil and Gas GRP Workgroup that this Guideline will be adopted as a Norwegian NORSOK - and subsequently as an international (e.g. ISO) - standard.

Every reasonable effort has been made to ensure that this publication is based on the best knowledge available up to the time of finalising the text. However, no responsibility of any kind for any injury, delay, loss or damage can be accepted by Norwegian Oil and Gas or others involved in its publication.

1 INTRODUCTION

1.1 Need

GRP materials have been used with increasing frequency within the petroleum industry during the last 10 years, and are particularly suited for offshore applications. Compared to many metallic materials, GRP provides good corrosion resistance, low weight, high strength-to-weight ratio, long service life, low maintenance costs, and faster and easier installation. The lack of commonly accepted inspection practices and defect acceptance criteria causes most GRP users some uncertainity, which typically results in additional costs associated with overly conservative or non-conservative responses. This Guideline will help reduce uncertainity and associated costs by summarizing what is presently known about GRP inspection.

1.2 Guideline users

This Guideline is intended for use by all suitably qualified parties involved in the procurement, manufacture, prefabrication, installation, commissioning, and operation of GRP pipe systems and tanks. Typical parties will include:

- operators;
- manufacturers;
- fabricators and installation contractors;
- inspection, repair and maintenance personnel/contractors;
- Certifying Authorities and Government Agencies.

1.3 Guideline layout

There are six parts in this Guideline. The selected format follows both NORSOK M-CR-621 [1] and UKOOA's "Specification and Recommended Practice for the use of GRP Piping Offshore" [2] in order to facilitate possible consolidation with these standards in the future. Each of Parts 3-6 corresponds to a different stage in the life of the GRP product. In addition, Annexes A-H provide detailed information for each NDT method plus acceptance criteria.

Part 1 (Philosophy and Scope)[UKOOA Part 1] identifies the applications that the Guideline is intended to cover, together with anticipated end users. Design issues are not addressed in this Guideline except where redesign is the appropriate corrective action.

Part 2 (Inspection Objectives, Defect Types, and Currently Available NDT Methods) presents a brief summary of defect types and inspection methods which are in use with GRP piping and tank systems, along with inspection strategies.

Part 3 (Manufacture)[UKOOA Part 2] addresses quality assurance inspection during manufacture of basic piping components or tanks.

Part 4 (Prefabrication and Receiving Inspection)[UKOOA Part 4] addresses quality assurance inspection during prefabrication of piping spools at either manufacturers' or third party facilities, together with receiving inspection performed following transport of spools or tanks.

Part 5 (Installation and Commissioning)[UKOOA Part 4] addresses NDT performed to verify correct system installation and function.

Part 6 (Operation)[UKOOA Part 5] addresses inspection issues which may arise during operation.

2 SCOPE

2.1 Applications

This Guideline gives recommended practice for inspection of low to medium pressure GRP piping systems as defined in the Norsok standard M-CR-621. It also includes low pressure GRP tanks as defined in Refs. [3-7].

All components that form part of a GRP piping or tank system (e.g. pipe, branches, bends, tees, flanges, and joints) are covered.

This Guideline is directed towards GRP piping and tank systems used on offshore production platforms, but may also be used for similar onshore systems.

The guidance for NDT and NDE as outlined in this document is intended to supplement/replace requirements as given in ref [1] and [2].

2.2 Manufacturing methods

This Guideline covers GRP piping systems and tanks manufactured by:

- filament winding,
- hand lay-up,
- centrifugal casting,
- continuous winding.

3 REFERENCES

3.1 Standards

[1] NORSOK M-CR-621, "GRP Piping Materials", Dec. 1994

[2] "Specification and Recommended Practice for the use of GRP Piping Offshore", UKOOA, Mar. 1994

[3] ASME BPVC X, "Fiber Reinforced Plastic Pressure Vessels", The American Society of Mechanical Engineers, 1992

[4] BS4994:1987, "Design and construction of vessels and tanks in reinforced plastics", British Standards Institution, 1987

[5] "Swedish Plastic Vessel Code", The Swedish Pressure Vessel Commission,1983

[6] API Spec. 12P, "Specification for Fiberglass Reinforced Plastic Tanks", American Petroleum Institute, 1995

[7] ADN 1, "Druckbehalter aus textilglasverstarkten duroplastischen Kunststoffen (GFK)", Vereinigung der Technischen Uberwachungs-Vereine e.v.

[8] RTP-1, "Reinforced Thermoset Plastic Corrosion Resistant Equipment", American Society of Mechanical Engineers

4 DEFINITIONS

None

5 ABBREVIATIONS

NDE	non-destructive evaluation
NDT	non-destructive testing
GRP	Glass-fibre Reinforced Plastic materials
DSC	Differential Scanning Calorimetry

6 BIBLIOGRAPHY

1) Fredriksen A., Taberner D., Ramstad J.E., Steensland O., Funnemark E.: "Reliability of GRP Seawater Piping Systems", Veritec Report 90/3520, Veritas Offshore Technology and Services A/S, 1990, Norway.

2) de Bruijn J.C.M., van den Ende C.A.M.: "GRP pipes are safer that steel ones", Reinforced Plastics, February, 1996, pp. 40-42.

3) Winkel, J.D., "Maintenance and Cost Performance of GRP Piping at Ekofisk", Offshore Mechanics and Arctic Engineering Conference, Glasgow, June 20-24, 1993.

PART 2 INSPECTION OBJECTIVES AND STRATEGIES, DEFECT TYPES, AND AVAILABLE NDT METHODS

1 GENERAL

1.1 Inspection objectives

As with all other materials, flaws in GRP can be generated during different stages of the manufacturing process (from raw materials to finished components), during installation and commissioning, or during operation. The purpose of inspection prior to commissioning is to:

- Identify deviations from specifications or functional requirements as early as possible;
- Form a basis for corrective actions.

During service, the role of inspection is to:

- Assure high levels of safety and regularity during operation;
- Form a basis for maintenance evaluation/planning (including "fitness-for-purpose") - Contribute to the improvement of current and future design.

1.2 Inspection strategies

1.2.1 Current strategies - strengths and limitations

Most GRP piping and tank applications have historically been inspected using a combination of visual inspection and pressure testing. This approach has generally functioned quite well, and it is anticipated that these two methods will remain central to any inspection strategy for GRP. Some difficulties with the historical approach have been noted with GRP used on offshore production facilities. This Guideline will attempt to address the following weaknesses:

- Over-reliance on system pressure testing has occasionally been a contributing factor in inadequate quality control of the system during various stages of manufacture, receiving control, and installation.
- Visual inspection criteria have been overly subjective (i.e. photographic standards for piping applications have not been readily available).
- Pressure testing often occurs at a late stage in project construction when making any necessary repairs is most difficult (due to limited access) and costly.
- Occassionally the cost of pressure testing (including isolating the GRP systems) is more costly than the system itself.

1.2.2 Verification activities

It should be emphasized that following the routine quality control measures in [1-2] will greatly help to ensure that GRP piping and tank systems are installed without the problems which have sometimes been seen in the past. Verifying that these Q.C. procedures have been followed will not always be the inspector's responsibility, but may be (as in the case of new construction). The inspector shall pay particular attention to this verification activity whenever it is included in the inspection scope.

1.2.3 Responsibility for inspection strategy

Each user shall develop an inspection strategy particular to their own needs and applications. This strategy shall be documented and communicated to the appropriate equipment-responsible, inspection, and NDT personnel.

1.2.4 Suggested inspection strategies

A suggested inspection strategy, which considers system criticality and availability/ accessbility, is illustrated in Figure 1.2 for GRP systems on offshore production facilities. This may be used as a starting point for developing an appropriate, company-specific, inspection strategy. The limitations noted above are addressed by:

- highlighting key quality control activities.
- emphasizing visual inspection in accordance with Annex A.
- identifying the (limited) circumstances when full pressure testing (at 1.5 times design pressure) may be replaced with various combinations of additional NDT and functional testing at operational pressures.

It should be noted that Figure 1.2 refers frequently to Norsok M-CR-621 (GRP piping-based). While much of this standard - and this Guideline - can be applied directly to tanks, it may be more appropriate to use tank-based standards, e.g. [5-8], when developing inspection strategies for systems containing GRP tanks. This Guideline will concentrate more on piping systems than tanks, since the latter are covered at least to some extent by existing specifications, particularly as regards quality control and visual inspection. The information presented on various NDT methods in this Guideline can be applied when evaluating their possible use on tanks. However, It should be recognized that some tanks may be designed using sandwich-construction or very thick walls which may limit the applicability of the NDT methods presented here.

A sample inspection strategy which covers both piping and tanks exposed to a variety of fluids (including seawater and those typical of chemical processing plants) is presented in Annex H. This Annex can serve as an alternate starting point for developing a company-specific inspection strategy. However, by including chemical plant facilities, it is considerably more complicated than the majority of seawater piping and tank applications will need to be.

1.3 Defect types - what to inspect for?

Defects can occur in either the GRP material or in the mechanical and adhesive-bonded joints that make up a piping system. Possible defects, and an overview of NDT techniques suitable for detecting these defects, are briefly summarized in Table 2.1. Joint defects, including defects in prefabricated pipe spools, are typically more likely to occur than defects in the GRP material provided normal QA procedures are followed during manufacture and handling of pipe and fittings. Manufacturing processes used to produce fittings are typically more complicated and less automated than those used to produce pipes. The manufacturing problems which may occur tend, therefore, to be more prevalent in the fittings.

Defects that can occur in tanks are addressed in [5-8], and only a few of the more significant ones are summarized in Table 2.1. Some of the GRP materials defects listed in Table 2.1 will also apply to tanks .

Defects corresponding to specific stages in the manufacture and operation of GRP piping systems and tanks are given in Parts 3-6, where probability and possible causes are discussed in tabular form along with appropriate acceptance criteria. The Annexes referenced in each Table give more detailed descriptions of recommended NDT methods and parameters.

Fig. 1.2 (cont`d) - Suggest inspection strategy for GRP piping and tank systems (notes):

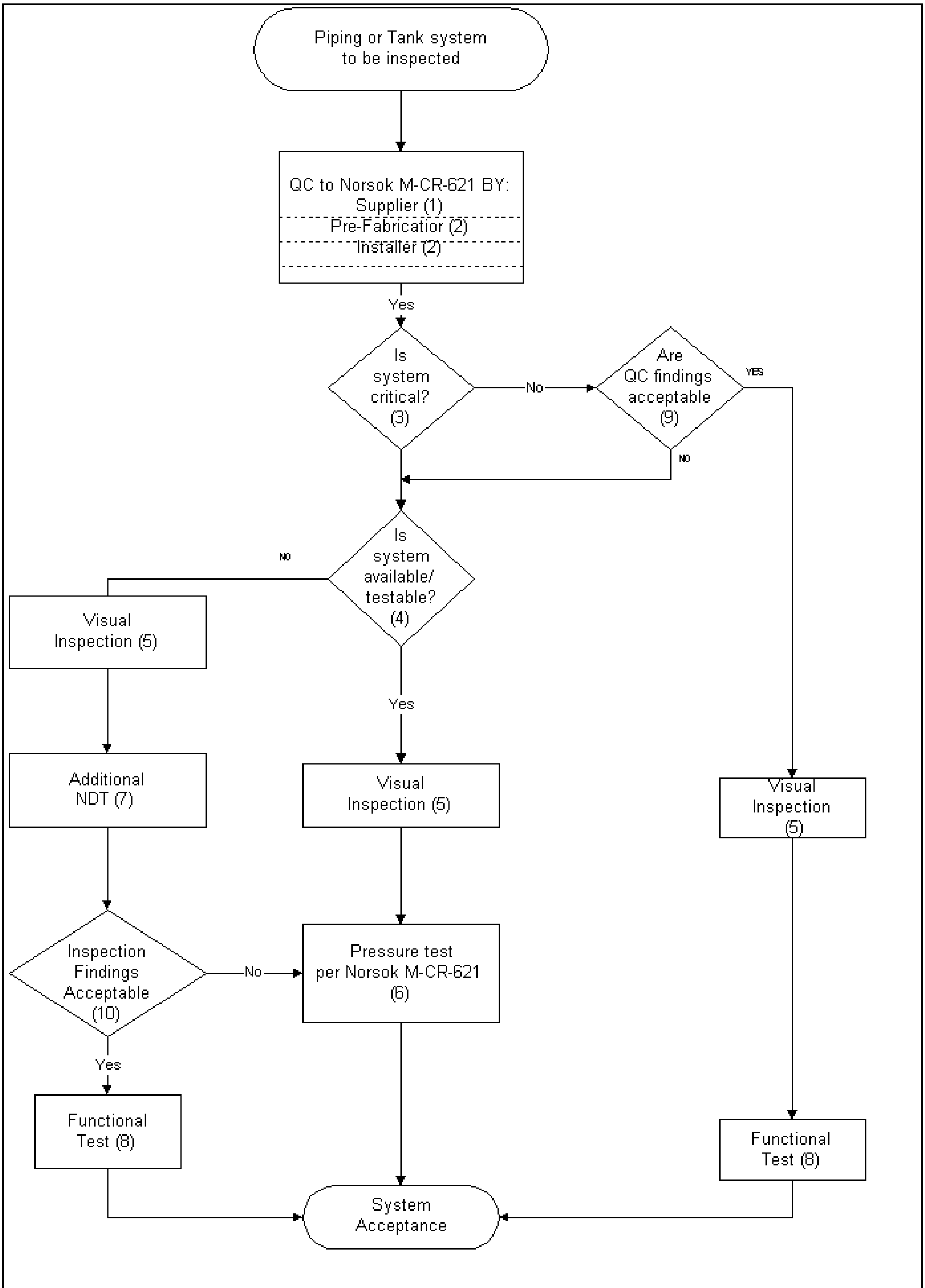


Figure 1.2 - Suggested inspection strategy for GRP piping and tank systems

(1) Includes 100% hydrostatic pressure testing. 100% visual inspection recommended.

(2) Certified personnel required for fabrication and installation. 100% visual inspection recommended.

(3) System is critical if failure can result in:
- Injury to personel
- Operational shutdown with unacceptable economic consequenses
  (Examples: Fire water delivery system,some cooling water systems)

System is non-critical if:
- Failure will not result in:
    - Injury to personel
    - Unacceptable economic consequenses
- Acceptable functionality is maintained even if most likely failure modes occured.
- Operating pressure << nominal design pressure.
  (Examples: Open drains,some cooling watersystems)

(4) System is ready available for testing if it is:
- Physically accessible
- Not prohibitively expensive to prepare for pressure testing (i.e. blinding off joints, blocking deluge nozzles, etc.)

(5) Visual inspection shall be done on 100% of system in accordance with Annex A.

(6) Full system hydrotest in accordance with Norsok M-CR-621

(7) Other NDT methods applied as appropriate (see Table 2.1).
NDT to be performed on at least:
- 10% of joints $\leq$ 250 mm Ø
- 25% of joints > 250 mm Ø
- All field joints

(8) Pressure testing per Norsok M-CR-621 to be replaced by a leak ap operating pressure.

(9) Supplier and prefabrication testing frequensies may be reduced for non-critical systems, however at least 10% of all components will be tested. QC findings are acceptable if there is no risk that system safety or function will be comprimised.

(10) Inspection

<u>QC findings are acceptable if there is no risk that system safety or function will be comprimised.</u>

Table 2.1. Defect Types, Description and NDT Techniques

DEFECT TYPE	DESCRIPTION	SUITABLE NDT TECHNIQUES	ANNEX
SPOOL / JOINT	DEFECTS:		
Incorrect spool dimensions	Incorrect dimensions, misaligned components	Visual inspection Measuring / surveying equipment	A
Mechanical damage	Overstressed /inadequately designed spools, e.g. branches too weak	Visual inspection Pressure test Acoustic emission	A B F
Flange cracks	Overstressed bolted joints	Visual inspection Acoustic emission	A F
Incorrect lamination	Laminated joint incorrectly layed up, lay up not structurally adequate	Visual inspection (incorrect dimensions, missing plies, etc.) Radiography Pressure test Ultrasonics Acoustic emission	A D B C F
Local lack of adhesive	Adhesive joint bondline not filled out	Ultrasonics Radiography Thermography Pressure test Acoustic emission	C D H B
Too much adhesive	Excessive adhesive causing restriction of pipe inner diameter	Visual inspection Radiography	A D
Debonds and 'kissing bonds'	Weak bonds between adhesive and GRP adherend	Pressure test Ultrasonics (in some cases) Acoustic emission	B C F
Incorrect cure	Adhesive not fully cured	DSC	G
TANK DEFECTS:			
Insufficient strength on nozzles	Improper lamination Poor design	Visual inspection Radiography Ultrasonics	A D C

(Table 2.1, cont.'d:)

DEFECT TYPE	DESCRIPTION	SUITABLE NDT TECHNIQUES	ANNEX
SPOOL / JOINT	DEFECTS:		
GRP MATERIALS DEFECTS:			
Delaminations	Area where plies within GRP laminate become separated	Visual inspection Ultrasonics Thermography Radiography Acoustic emission	A B C D F
Fractures and cracks	Cracking through the GRP wall thickness, fiber breakage	Visual inspection (e.g. dye penetrants) Acoustic emission (propagating cracks) Ultrasonics Radiography	A E C D
Matrix cracking	Cracking in resin-rich layers, without fiber breakage	Visual inspection(e.g. dye penetrants/felt-tip pen) Acoustic emission (propagating cracks)	A E
Microcracking (crazing)	Fine hairline cracks at or under the surface of the laminate.	Visual inspection	A
Incorrect volume fraction of fibers	Insufficient strength from too few fibers; dry spots where the reinforcement has not been wetted by resin.	Radiography Pressure testing Microscopic examination (of cross-section)	E B
Improper fiber alignment/poor distribution		Microradiography	E
Incorrect cure of matrix		Barcol hardness DSC Acoustic emission	G H F
Porosity, voids, and inclusions in matrix	Air, outgassing during cure, foreign matter cured into the laminate	Radiography Ultrasonics Acoustic emission	E C F
Erosion	Internal, localised material removal by abrasive erosion or cavitation	Visual inspection (internal) Ultrasonics Thermography Radiography	A C D E

(Table 2.1, cont.'d:)

DEFECT TYPE	DESCRIPTION	SUITABLE NDT TECHNIQUES	ANNEX
SPOOL / JOINT	DEFECTS:		
Material aging/ transformation	Brittleness Strength/modulus changes Softening/swelling	Visual inspection/Barcol hardness	A
Material aging/depletion: general local	Breakdown of resin or fiber strength and loss of material over long time period,e.g. from chemical exposure	Ultrasonics Radiography Pressure test Acoustic emission	C E B F
Deformation	Long-term change in dimensions, i.e. creep	Visual inspection	A
Dimensional changes	Changes in dimensions resulting from loads, deflections imposed on system	Visual inspection	A
Blistering	Blisters forming under outer plies of GRP laminate	Visual inspection	A
Fouling	Scale build-up Marine growth	Visual inspection Thermography Radiography	A D E
Pit (Pinhole)	Small crater in the surface of the laminate	Visual inspection Acoustic emission	A F
Chip	Small piece broken from edge or surface.	Visual inspection Acoustic emission	A F
Chalking	Minor breakdown of outer surface, e.g. from UV radiation	Visual inspection	A
Discoloring/Burn	Thermal decomposition, distortion or discoloration of the laminate surface	Visual inspection	A
Wear scratch	Shallow abrasion or marking of laminate, e.g. from improper handling, storage or transportation	Visual inspection	A
Weld Sparks	Minor breakdown of outer surface from close proximity welding	Visual inspection	A
Moisture ingress	Softening of matrix	Barcol hardness	G

1.4 When to inspect?

GRP piping and tanks are typically used in offshore systems that are not safety critical, e.g. seawater cooling systems. Many are classified as ANSI 31.3 Class D systems requiring no inspection. However, even seawater cooling systems can be crucial in maintaining uninterrupted production. Therefore the choice of when to inspect is largely an economic question: The probability and consequences of system failure must warrant the added cost of inspection. Some representative inspection times are included in the Annexes to help the Guideline user evaluate the economic trade-offs and determine when to inspect. (These times are elapsed times for inspections carried out in controlled conditions).

Economic and risk considerations will not only determine whether a GRP system is inspected at all, but also whether it should be periodically inspected while in service. A suggested , reasonable balance between costs and benefits of inspections is that non-critical and critical seawater piping and tank systems should at least be visually inspected within 1-2 years after start of service and and 3 to 5 times, respectively, during service (see Annex I).

1.5 Acceptance Criteria

Acceptance criteria shall be as given in Annex A (visual inspection) or Annex F (acceptance criteria).

PART 3 MANUFACTURE

1 SCOPE

This Part summarizes NDE/NDT methods to be used to locate defects which may occur during manufacture of pipes, bends, tees, tanks, and other components. Probable defects have been derived from experience with offshore GRP piping and tank projects, but should apply equally to onshore systems. The Guideline user shall also consider other defect types where warranted (e.g. where atypical installation conditions apply or where the consequences of failure occurrence are unacceptably large).

The use of qualified manufacturers shall be verified when verification activities are included in the inspector's scope of work (e.g. as a part of quality control on new construction), since this is a key means of not building defects into the piping or tank system. Manufacturers should comply with requirements of [1] and project quality assurance requirements, e.g. ISO 9001 or 9002.

2 PROBABLE DEFECTS, NDE/NDT METHODS, AND ACCEPTANCE CRITERIA

NDE/NDT methods recommended for use in detecting the defects most likely to occur during the manufacture of the GRP piping or tank system are given below along with recommended acceptance criteria. Possible causes and recommended corrective actions are also included for information.

Defects are listed in Table 3.1 according to how likely they are to occur. By far the most frequent defects involve incorrect dimensions (e.g. not achieving tolerances, bad input data from operator or engineering contractor, bad design, etc.). This contrasts with only a very few isolated incidences of leakage in Norwegian offshore projects due to poor quality pipe manufacture.

Table 3.1

MANUFACTUR-ING DEFECTS	CAUSE(S)	CONSEQUENCE(s)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
1) Incorrect dimensions	- incorrect design input from operator - spool design drawings not correctly verified - incorrect manufacture or prefabrication (e.g. - joint not shaved correctly)	- joint not sealed - GRP can be overstressed if joint pulled up	- visual inspection (measure, verify documented dimensions) -radiography -ultrasonics (wall thickness)	- in accordance with NORSOK M-CR-621 and Annex A	- replace - compensate for incorrect dimensions elsewhere in piping system (e.g. use field joints, hook up adjustments on metallic pipe, etc.)
2) Visible (major and minor) defects per Annex A	- bad workmanship - QA procedures not followed	- typically none for minor defects - weepage or failure if major defect	- visual inspection	- in accordance with NORSOK M-CR-621 and Annex A	-repair per NORSOK M-CR-621 (minor defects) - replace per NORSOK M-CR-621 (major defects)
3) Incorrect: - lamination (e.g. wrong lay-up) - filament winding (e.g. incorrect fiber orientation)	- bad workmanship - QA procedures not followed - incorrect raw materials used	- weepage - joint or pipe failure if strength not adequate	- pressure test - radiography Viisual inspection (incorrect dimens-ions, missing plies, winding angle, etc.)	. in accordance to supplier reqts	- replace (or repair - only if agreed by supplier and client).
4) Inadequate product design	- suppliers product design does not comply with project requirements	- failure of underdesigned components (e.g. flanges, etc.)	- pressure test	. in accordance to agreed project requirements	- replace
5) Inadequate curing of the resin	- incorrect formulation - out of date components -incorrect curing cycle - excessive ambient humidity	- poor laminate quality	- DSC (from samples cut from pipe ends or tank nozzle cut-outs) - Barcol hardness	. in accordance with manufacturers specification	- replace - post-cure

PART 4 PREFABRICATION AND RECEIVING INSPECTION

1 SCOPE

This Part summarizes NDE/NDT methods to be used to locate defects which may occur during the fabrication and transportation-to-site phase of a GRP project. Probable defects have been derived from experience with offshore GRP piping and tank systems, but should apply equally to onshore systems. This experience base includes both new projects (where GRP is installed onshore) and offshore maintenance. The Guideline user shall also consider other defect types where warranted (e.g. where atypical installation conditions apply or where the consequences of failure occurrence are unacceptably large).

The use of qualified personnel shall be verified when verification activities are included in the inspector's scope of work (e.g. as a part of quality control on new construction), since this is a key means of not building defects into the piping or tank system. Personnel should comply with the certification requirements of [1].

2 PROBABLE DEFECTS, NDE/NDT METHODS, AND ACCEPTANCE CRITERIA

NDE/NDT methods recommended for use in detecting the defects which are most likely to occur during the fabrication and installation of the GRP piping or tank system are given in Table 4.1 along with recommended acceptance criteria. Possible causes and recommended corrective actions are also included.

TABLE 4.1

POSSIBLE DEFECT	CAUSE(S)	CONSE-QUENCE(S)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
JOINT DEFECTS					
1) Incorrect dimension s	- incorrect manufacture or prefabrication - joint not shaved correctly - improper design	- joint not sealed - GRP can be overstressed if joint pulled up	- visual inspection (measure, verify documented dimensions) -radiography -ultrasonics (wall thickness) - Acoustic emission	- in accordance with NORSOK M-CR-621 and Annex A, Annex C, Annex E and Annex F	- replace - compensate for incorrect dimensions elsewhere in piping system (e.g. use field joints, hook up adjustments on metallic pipe, etc.)
2) Impact or wear damage	- incorrect transport - incorrect handling	- weepage or pipe failure	- visual inspection - pressure test - acoustic emission	- in accordance with NORSOK M-CR-621 and Annex A, Annex B and Annex F	- replace - temporary repair per NORSOK M-CR-621
3) Incorrect lay-up in lamination	- bad workmanship - QA procedures not followed	- weepage - joint failure if strength not adequate	- radiography - visual inspection (incorrect dimen-sions, missing plies, etc.) - acoustic emission	- in accordance to supplier reqts Annex A Annex F	- remake joint
4) Incorrect curing of: a) adhesive b) lamination	- outside temperature and humidity specs. - improper mixing - heating pad overlap or controller problems - cooling effect of air in pipe - out of date or incorrect materials	- weakened joint	- Acoustic emission a) DSC (or similar test) b) Barcol hardness	Annex F a) Tg-30C (Norsok M-CR-621) b) to suppliers reqts.	- remake joint - post-cure joint
5) Misaligned joints	- movement during curing - bending - incorrect dimensions	- air sucked in resulting in voids - residual stress resulting in less than rated performance	- visual inspection - ultrasonics - acoustic emission	- alignment to supplier's reqts - voids in accordance with Annex G - Annex A, Annex C and Annex F	- replace components or - remake joint

(Tab. 4.1, cont.'d:)

POSSIBLE DEFECT	CAUSE(S)	CONSE-QUENCE(S)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
JOINT DEFECTS					
6) Voids	- too little adhesive or not applied uniformly - bad workmanship - movement during curing	- weakened joint	- ultrasonics - radiography - acoustic emission	- voids in accordance with Annex G - Annex F	-remake joint
7) Improper treatment of joint adherends	- contaminated surface after grinding - bad workmanship: - ground surfaces too long or too short - ground too much (wall too thin)	- weakened joint	- pressure test - visual inspection - acoustic emission	- to suppliers reqts - Annex F	- remake joint
8) Excess adhesive	- too much adhesive applied	- restriction in pipe to flow - increased risk for erosion damage of pipe	- visual inspection - radiography		- remove excess adhesive - use as is if flow and erosion risk acceptable

3 DESIGN ISSUES

Although correct GRP design is not covered in this Guideline, the inspector should be aware of the types of design-related problems that have been experienced on offshore (and/or onshore) installations. This knowledge will enable the inspector to question suspected design flaws before pipe systems are installed (e.g. during receiving inspection).

The following design-related problems have all been experienced and are listed in order from worst consequences to least consequences:

DEFECT	CONSEQUENCE(S)	POSSIBLE INSPECTION METHOD(S)
Bad dimensioning, Improper placement of field joints	Joint failure, (Poor piping design/layout may result in pipe spools being manufactured to spec but difficult to install resulting in poor-quality mechanical or adhesive joints)	- Visual inspection
Improper design of branches or nozzles	Branches or nozzles < 100 mm are susceptible to mechanical damage resulting in leakage	- Visual inspection
Improper supporting of valves or pipe	Failure of pipe resulting from e.g.: - vibration from pumps on small diameter pipe - not installing pipe supports prior to pressure testing - excessive loads imposed on pipe due to unsupported valves	- Visual inspection
Improper placement/opening of valves, incorrect dimensioning of pipe	Resulting water hammer can cause pipe to burst open (particularly when air is entrapped)	- Review of piping design and operating procedure
Use of incorrect accessories (gaskets, bolts, supports, valves, other metallic fittings)	- Corrosion (using incorrect specs can result in greater than expected corrosion of metallic components) - Leakage (e.g. from incorrect gaskets, etc.)	- Visual inspection

PART 5 INSTALLATION AND COMMISSIONING

1 SCOPE

This Part summarizes NDE/NDT methods to be used to locate defects which may occur during the installation and commissioning phase of a GRP project. Probable defects have been derived from experience with offshore GRP piping and tank systems. This experience base includes both new projects (where GRP is installed onshore) and offshore maintenance. The Guideline user shall also consider other defect types where warranted (e.g. where atypical installation conditions apply or where the consequences of failure occurrence are unacceptably large).

The use of qualified personnel shall be verified when verification activities are included in the inspector's scope of work (e.g. as a part of quality control on new construction), since this is a key means of not building defects into the piping or tank system. Personnel should comply with the certification requirements of [1].

2 PROBABLE DEFECTS, NDE/NDT METHODS, AND ACCEPTANCE CRITERIA

NDE/NDT methods recommended for use in detecting the defects which are most likely to occur during the installation and commissioning of the GRP piping or tank system are given in Table 5.1 along with recommended acceptance criteria. Possible causes and recommended corrective actions are also included.

Table 5.1

POSSIBLE DEFECT	CAUSE(S)	CONSE-QUENCE(S)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
JOINT DEFECTS					
1) Flange cracks	- bolts overtorqued - GRP against raised-face flanges - wrong GRP flange design selected	- joint not sealed - reduced life - ultrasonics	- visual inspection (incl. depth gages, penetrants) - acoustic emission	- Annex A - Annex F	- grind and fill minor cracks with resin - replace flanges with major cracks
2) Incorrect dimension s	- incorrect manufacture or prefabrication - joint not shaved correctly - improper design	- joint not sealed - GRP can be overstressed if joint pulled up	- visual inspection (measure, verify documented dimensions) -radiography - acoustic emission	- in accordance with NORSOK M-CR-621 and Annex A - Annex E - Annex F	- replace - compensate for incorrect dimensions elsewhere in piping system (e.g. use field joints, hook up adjustments on metallic pipe, etc.)

Table 5.1

(Table 5.1, cont.'d:)

POSSIBLE DEFECT	CAUSE(S)	CONSE-QUENCE(S)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
3) Impact or wear damage	- incorrect transport - incorrect handling	- weepage or pipe failure	- visual inspection - pressure test - acoustic emission	- in accordance with NORSOK M-CR-621 and Annex A - Annex B - Annex F	- replace - temporary repair per NORSOK M-CR-621
4) Incorrect lay-up in lamination	- bad workmanship - QA procedures not followed	- weepage - joint failure if strength not adequate	- radiography -visual inspection (incorrect dimensions, missing plies, etc.) - acoustic emission	. in accordance to supplier reqts - Annex F	- remake joint
5) Incorrect curing of: a) adhesive b) lamination	- outside temperature and humidity specs. - improper mixing - heating pad overlap or controller problems - cooling effect of air in pipe - out of date or incorrect materials	- weakened joint	- Acoustic emission a) DSC b) Barcol hardness	- Annex F a) Tg-30C (Norsok M-CR-621) b) to suppliers reqts.	- remake joint - post-cure joint
6) Misaligned joints	- movement during curing - bending - incorrect dimensions	- air sucked in resulting in voids - residual stress resulting in less than rated performance	- visual inspection - ultrasonics - acoustic emission	- alignment to supplier's reqts - voids in accordance with Annex G - Annex F	- replace components or - remake joint
7) Voids	- too little adhesive or not applied uniformly - bad workmanship - movement during curing	- weakened joint	- ultrasonics - thermography - radiography	- voids in accordance with Annex F	-remake joint

Table 5.1, cont.'d:)

POSSIBLE DEFECT	CAUSE(S)	CONSE-QUENCE(S)	RECOMMENDED NDT METHOD(S)	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
8) Improper treatment of joint adherends	- contaminated surface after grinding - bad workmanship: - ground surfaces too long or too short - ground too much (wall too thin)	- weakened joint	- pressure test - visual inspection - acoustic emission	- to suppliers reqts - Annex F	- remake joint
9) Excess adhesive / cavitation (1)	- too much adhesive applied	- restriction in pipe to flow - increased risk for erosion damage of pipe	- radiography		- remove excess adhesive - use as is if flow and erosion risk acceptable

Notes: (1) Cavitation may be a contributing factor to erosion downstream of an excessive adhesive bead or other restriction (such as improperly sized valves). This collapsing of bubbles in the fluid being transported can be very audible. Although a very small number of GRP piping failures have been attributed to cavitation, it is very detrimental to GRP material. If noticed during commissioning the cause shall be corrected prior to continuing.

PART 6 OPERATION

1 SCOPE

This Part summarizes NDE/NDT methods to be used to locate defects which may occur during the operations phase. Probable defects have been derived from experience with offshore GRP piping and tank systems. This experience base includes both new projects (with GRP installed onshore) and offshore maintenance. The Guideline user shall also consider other defect types where warranted (e.g. where atypical installation conditions apply or where the consequences of failure occurrence are unacceptably large).

2 PROBABLE DEFECTS, NDE/NDT METHODS, AND ACCEPTANCE CRITERIA

NDE/NDT methods recommended for use in detecting the defects which are most likely to occur during operations are given in Table 6.1 along with recommended acceptance criteria. Possible causes and recommended corrective actions are also included for information. This table is not very comprehensive since most GRP piping and tanks systems installed offshore have been regarded as non-critical systems not subject to periodic inspection.

GRP pipe systems can be summarized as follows:

-*Some problems have been experienced during qualification testing, manufacturing and installation.*
This is confirmed by the results from a study performed by Fredriksen et al. [B1] showing that the failure rate for GRP seawater piping systems is lower than for steel under service conditions, while the failure rate is higher at commissioning. The report also points out the fact that most failures occur in the pipe joints and are caused by poor workmanship. A similar conclusion has been drawn in a study carried out in The Netherlands [B2] which estimates a failure rate of about 1-4% of the total amount of joints. 60% of the failures were due to leakages in the adhesively bonded or laminated joints, most of them field made.

- *Performance during operation has been very satisfactory.*
Studies by PPCoN [B3] and other operators point to very few problems once the GRP piping system has been successfully commissioned and put in operation.

The vast majority of operational problems can be traced back to poor piping design or improper maintenance activities (exceeding bolt torque, exceeding design loads, etc.)

TABLE 6.1

ANNEX A

DRAFT PRACTICE FOR CLASSIFYING VISUAL DEFECTS IN GLASS-REINFORCED PLASTIC PIPES AND TANKS

A.1 SCOPE

A.1.1 Pipe

This practice covers acceptance criteria for visual inspection of pipes, fittings, joints and pipe spools made from glass fiber-reinforced laminates, typically produced by filament winding.

Table A.1 is a combination of requirements taken from references (1), UKOOA document and (2), ASTM D 2563. Requirements have been been modified to reflect practical experience from operation of offshore piping systems.

This practice is intended to supplement and modify ASTM D 2563 in order to make it more applicable to glass fiber-reinforced filament wound laminates. ASTM D 2563 shall apply except as noted in section A.3.

ASTM D 2563 is based on manufacturing methods other than filament winding and is difficult to apply to products such as GRP piping and tanks. This deficiency has been addressed by pipe manufacturers by means of proprietary, internal QA procedures, but other inspection and engineering personnel need a standard approach for conducting visual inspection of GRP. This practice is a first step towards meeting this need.

A.1.2 Tanks

In addition to pipes and pipe fittings this Practice also covers acceptance criteria for visual inspection of tanks made from made from glass fiber-reinforced laminates.

Table A.2 contains requirements taken from reference (3) ASME RTP-1-1995 Edition and specifies acceptable tank repair methods.

A.2 MAIN DETECTABLE DEFECTS

- **Deformations and dimensional deviations**
- **Surface cracks and micro-cracks**
- **Near-surface delaminations, inclusions and air entrapments**
- **Impact damage**
- **Blisters**
- **Internal excess of adhesive (internal inspection)**
- **Corrosion and erosion (internal inspection)**

A.3 DEFECT TYPES AND ACCEPTANCE CRITERIA

A.3.1 DEFECT DESCRIPTIONS AND ASSESSMENT SCHEDULE

Table A.1

Numbers in "Defect Type" column make reference to example photographs collected at the end of Annex A.

Defect Type	Photograph references	Description	Acceptance Criteria	Corrective action		
				Manufacturing	Prefabrication	Operation
Burn		Thermal decomposition evidenced by distortion or discoloration of the laminate surface.	Distortion and/or burn deeper than surface resin layer	Reject	Reject / Major Repair	Reject/ Major repair
			Minor discoloration, and/or imited to surface resin layer, no extent limit	Minor Repair (???)	Use as is	Use as is
Chalking		Minor breakdown of outer surface due to effects of UV radiation and/or acid rain.	Depth limited to surface resin layer; no extent limit	N/A	N/A	Use as is
Chemical Spill		Minor breakdown of outer surface due to effects of UV radiation and/or acid rain.	If occurring	Clean. Use as is	Clean. Use as is	Clean. Use as is
Chip	A 18	Small piece broken from edge or surface. If reinforcement fibres are broken, the damage is considered to be crack.	If there are undamaged fibres exposed over any area: or no fibres are exposed but an area greater than 10 mm x 10 mm lacks resin	Minor Repair	Minor Repair	Minor repair
			If there are no fibres exposed, and the area lacking resin is less than 10 mm x 10 mm	Use as is	Use as is	Use as is

(Table A.1, cont.'d:)

Defect Type	Photograph references	Description	Acceptance Criteria	Corrective action		
				Manufacturing	Prefabrication	Operation
Crack	A 8	Actual separation of the laminate, visible on opposite surfaces, extending through the wall. A continuous crack may be evident by a white area.	None permitted	Reject	Reject / Major Repair	Reject/ Major repair
	A 17		Max. depth equal to or less than resin layer	Minor Repair	Minor Repair	Use as is
			Max. depth greater than resin layer	Reject	Reject / Major Repair	Major Repair
	A 14 A 15 A 16		Crack located in flange root; depth higher than resin layer, but less than 20% of flange step; crack located IN PARALLEL TO pipe axis. NB! Ultrasonic inspection may determine crack depth, along with direct measurement.	Reject	Reject / Major Repair	Detected during operation: Grind crack to max. depth less than 30% of flange step, and perform minor repair Crack deper than 30%, or detected during manufacture or pre-fab. or installation: No cracks permitted. Reject / Major repair
Crazing		Fine hairline cracks at or in the surface of the laminate. White areas are not visible as for cracks.	Crack lengths greater than 25.0 mm	Minor Repair	Minor Repair	Minor repair
			Crack lengths less than 25.0 mm			Use as is

(Table A.1, cont.'d:)

Defect Type	Photograph references	Description	Acceptance Criteria	Corrective action		
				Manufacturing	Prefabrication	Operation
Fracture	A 11 A 12	Rupture of the laminate with complete penetration. Majority of fibres broken. Visible as lighter coloured area of interlaminar separation.	None permitted	Reject	Major Repair	Major repair
Pit (Pinhole)		Small crater in the inner surface of the laminate, with its width max. diameter similar to, or smaller than, its depth.	Diameter greater than 0,8 mm, and/or depth higher than 20% of wall thickness, and/or damaged fibers	Reject	Major Repair	Major repair
			Diameter greater than 0,8 mm, and/or depth between 10% and 20% of wall thickness, and/or exposed fibers	Reject	Minor Repair	Minor repair
			Diameter less than 0,8 mm, and depth less than 10% of wall thickness, and no fibers exposed	Reject	Use as is	Use as is
Wear Scratch		Shallow mark caused by improper handling, storage and/or transportation. If reinforcement fibres are broken, the damage is considered to be a crack.	If there are undamaged fibres exposed over any area; or no fibres are exposed but an area equal to, or greater than, 10 mm x 10 mm lacks resin	Minor Repair	Minor Repair	Minor repair
			If there are no fibres exposed, and the area lacking resin is less than 10mmx10mm.	Minor Repair	Minor Repair	Use as is
Weld Sparks		Minor breakdown of outer surface due to effects of close proximity welding	Same as for "Wear/Scratch"	Minor Repair	Minor Repair	Use as is

(Table A.1, cont.'d:)

Defect Type	Photograph references	Description	Acceptance Criteria	Corrective action		
				Manufacturing	Prefabrication	Operation
Dry spot		Area of incomplete surface film where the reinforcement has not been wetted by resin.	None permitted	Reject	Reject / Major Repair	Reject / Major Repair
Inclusion		Foreign matter wound into the laminate	None permitted	Reject	Reject / Major Repair	Use as is
Corrosion	A 5	Abscense of internal surface resin layer; fibers not damaged	None permitted	Reject	Minor Repair	Grinding and Minor Repair
Impact damage	A 3 A 8	Light area with or without broken fibers	None permitted.	Reject	Reject / Major Repair	Reject or Major Repair
			Discovered during operation: a) No leak at design pressure: a1) Service is sea or potable water a2) Service other than sea or potable water b) Leak at design pressure or at normal operating pressure	N/A	N/A	 a1) Acceptable, but monitoring required a2) Major repair b) Major Repair
Restriction/ Excessive adhesive	A 4	Excessive resin, adhesive, foreign matter on the internal wall of pipe/fitting causing restriction	No flow obstruction > 3% of inner diameter	Remove by careful grinding	If access: Remove by careful grinding If not access: Reject or Major Repair	If access: Remove by careful grinding If not access: Reject or Major Repair
Inadequate ("kissing") bond	A 7			N/A	Reject / Major Repair	Reject / Major Repair
Lack of adhesive	A 6			N/A	Reject	In accordance with Annex F
Uneven wall thickness after grinding of adhesive joint surface(s)	A 2		None permitted	N/A	Reject / Major Repair	Reject /Major Repair

(Table A.1, cont.'d:)

Defect Type	Photograph references	Description	Acceptance Criteria	Corrective action		
				Manufacturing	Prefabrication	Operation
Weeping	A 13	Liquid penetrating through pipe/tank wall	Manufacturing and prefab.: None permitted	Reject	Reject / Major Repair	Reject / Major Repair
			Operation:, water systems: Possibly acceptable. Monitoring (leak rate) and criticality assessment required. No fibre damage/fracture acceptable.	N/A	N/A	Major Repair if regular inspection/monitoring shows unacceptable leak rate or other unacceptable consequence/damage, otherwise Use as is.
Lack of fibers in laminate	A 9	Too high resin/fiber ratio	None permitted	Reject	Reject / Major Repair	Reject / Major Repair
Delamination, internal	A 1 A 8 A 10	"Bright" area in laminate due to lack of bond between resin and fibers. Separation of the layers of material in a laminate.	None permitted	Reject	Reject / Major Repair	Acceptable, but monitoring required

Acceptance criteria are based on experience from seawater service . More conservative criteria may be specifed for other services, e.g. acids.

Major repair and minor repair are defined in UKOOA, Part 5, Chapter 4.3.

Major repair is

- permanent replacement,
- temporary laminated joint priior to permanent replacement, or
- temporary clamps or saddles prior to permanent replacement.

Minor repair is on-site repair by grinding, cleaning, and application of resin/hardener as recommended by the manufacturer.

Photographs showing defect examples are contained at the end of this Annex A.

TABLE A.2 VISUAL INSPECTION ACCEPTANCE CRITERIA, GRP TANKS (Table 6-1, Ref. 3)

		MAXIMUM SIZE AND CUMULATIVE SUM OF IMPERFECTIONS ALLOWABLE after repair, see Notes a) and b) (Imperfections subject to cumulstive sum limitation are highlighted with an asterixs)				Corrective action (see Note c) for Repair Type descriptions)		
Type of defect	Description / Definition	Inner surface (veil(s), surfacing mat)	Interior layer (approx. 3.2 mm thick) (mat or chopped strand spray layers)	Structural layer and outer surface	Notes	Manufacturing	Prefabrication	Operation
Burned areas	Showing evidence of thermal decomposition through discoloration or heavy distortion	None	None	Never in more than one ply and not to exceed 100 cm^2 in any vessel	Discoloration only, never delamination or decomposition	Reject	Type 3	Monitor possible leakage. Use as is. Type 2 or Type 3 if/when required
Chips (surface)	Small pieces broken off an edge or surface	* 3.2 mm maximum by 50% of veil(s) thickness maximum	N/A	* 12.2 mm diameter or 25.4 mm length maximum by 1.6 mm deep maximum		Type 3 or Type 4	Type 3 or Type 4	Monitor possible leakage. Use as is. Type 2 or Type 3 if/when required
Cracks	Actual ruptures or debond of portions of the structure	None	None	None	Not to include areas to be covered by joints	Reject	Reject	Monitor possible leakage. Prepare for replacement of vessel section. Use as is. Type 2 or Type 3 if/when required

(Table A.2, cont.'d:)

		MAXIMUM SIZE AND CUMULATIVE SUM OF IMPERFECTIONS ALLOWABLE after repair, see Notes a) and b) (Imperfections subject to cumulstive sum limitation are highlighted with an asterixs)				Corrective action (see Note c) for Repair Type descriptions)		
Type of defect	Description / Definition	Inner surface (veil(s), surfacing mat)	Interior layer (approx. 3.2 mm thick) (mat or chopped strand spray layers)	Structural layer and outer surface	Notes	Manufacturing	Prefabrication	Operation
Crazing (surface)	Fine cracks at the surface of a laminate	None	N/A	Maximum 51 mm long by 0.4 mm deep, maximum density 1 in any cm^2		Type 1 or Type 2	Type 1 or Type 2	Use as is
Delamination (internal)	Separation of the layers in a laminate	None	None	* None in three plies adjacent to interior layer, none larger than 1 cm^2 total area		Reject	Reject	Monitor possible leakage. Prepare for replacement of vessel section. Use as is.
Dry spot	Area of surface where the reinforcement has not been wetted with resin	None	N/A	None		Type 1 or Type 2	Type 1 or Type 2	Monitor possible defect growth. Use as is. Type 2 or Type 3 if/when required
Edge exposure	Exposure of multiple layers of the reinforcing matrix to the vessel contents, usually as a result of shaping or cutting a section to be secondary bonded (interior of vessel only)	None	N/A	None	Edges exposed to contents must be covered with same number of veils as inner surface	Type 2 or Type 3	Type 2 or Type 3	Monitor possible defect growth. Use as is
Foreign inclusion	Particles included in a laminate which are foreign to its composition (not a minute speck of dust)	* 6.4 mm long maximum by diameter or thickness not more than 50% of veil(s) thickness	* 12.7 mm long maximum by diameter or thickness not more than 50% of interior layer thickness	* 25.4 mm diameter maximum, never to penetrate lamination to lamination	Must be fully resin wetted and encapsulated	Reject	Type 3	N/A

(Table A.2, cont.'d:)

		MAXIMUM SIZE AND CUMULATIVE SUM OF IMPERFECTIONS ALLOWABLE after repair, see Notes a) and b) (Imperfections subject to cumulstive sum limitation are highlighted with an asterixs)				Corrective action (see Note c) for Repair Type descriptions)		
Type of defect	Description / Definition	Inner surface (veil(s), surfacing mat)	Interior layer (approx. 3.2 mm thick) (mat or chopped strand spray layers)	Structural layer and outer surface	Notes	Manufacturing	Prefabrication	Operation
Gaseous bubbles or blisters	Air entrapment within, on, or between plies of reinforcement, 0.4 mm diameter and larger	Maximum diameter 1.6 mm by 50% of veil(s) thickness deep	Maximum diameter 3.2 mm	Maximum diameter 6.4 mm	Must not be breakable with a sharp point	Reject	Type 2 or Type 3	Type 1 or Type 2
Pimples (surface)	Small, sharp, conical elevations on the surface of a laminate	* Maximum height or diameter 0.8 mm	N/A	No limit	Must be fully resin filled and wetted; generally, captured sanding dust	Reject	Type 1 or Type 2	Type 1 or Type 2
Pit (surface)	Small crater in the surface of a laminate	* 3.2 mm diameter maximum by 50% of veil(s) thickness maximum	N/A	* 6.4 mm diameter maximum by 2.4 mm deep maximum	No fibers may be exposed	Reject	Type 1 or Type 2	Type 1 or Type 2
Porosity (surface)	Presence of numerous visible tiny pits (pinholes), approximate dimension 0.13 mm (for example, density 1 in any cm^2)	None more than 50% of veil(s) thickness	N/A	None to fully penetrate the exterior gel coat or gel coated exterior veil(s) No quantity limit	No fibers may be exposed	Reject	Type 1 or Type 2	Use as is
Scratches (surface)	Shallow marks, grooves, furrows, or channels caused by improper handling	* None	N/A	* None more than 300 mm long	No fibers may be exposed	Reject	Type 1 or Type 2	Use as is
Wet blisters (surface)	Rounded elevations of the surface, somewhat resembling a blister on the human skin; not	* None over 4.8 mm diameter by 1.6 mm in height	N/A	No limit	Must be fully resin filled; not drips loosely glued to surface, which are to be	Reject	Type 1 or Type 2	Use as is

	reinforced				removed			

(Table A.2, cont.'d:)

		MAXIMUM SIZE AND CUMULATIVE SUM OF IMPERFECTIONS ALLOWABLE after repair, see Notes a) and b) (Imperfections subject to cumulstive sum limitation are highlighted with an asterixs)				Corrective action (see Note c) for Repair Type descriptions)		
Type of defect	Description / Definition	Inner surface (veil(s), surfacing mat)	Interior layer (approx. 3.2 mm thick) (mat or chopped strand spray layers)	Structural layer and outer surface	Notes	Manufacturing	Prefabrication	Operation
Wet-out inadequate	Resin has failed to saturate reinforcing (particularly woven roving)	None	None	Dry mat or prominent and dry woven roving pattern not acceptable; discernible but fully saturated woven roving pattern acceptable	Split tests on cutouts may be used to discern degree of saturation on reinforcing layers	Reject	Type 3	N/A
Wrinkles and creases	Generally linear, abrupt changes in surface plane caused by laps of reinforcing layers, irregular mold shape, or mylar overlap	Maximum deviation 20% of wall or 3.2 mm , whichever is least	N/A	Maximum deviation 20% of wall or 3.2 mm , whichever is least	Not to cause a cumulative linear defect (outside defect adding to inside defect)	Reject	Type 3	N/A
Allowable cumulative sum of highlighted imperfections Maximum % repairs	Maximum allowable in any cm^2 Maximum allowable in any m^2 The maximum allowable area of repairs made in order to pass visual inspection	1 6 10%	1 6 10%	1 6 10% to structural, no limit to outer surface repairs	 Debond tests required prior to inner surface repairs	N/A	N/A	N/A

Table A.2 continued, General notes:

a) Above acceptance criteria apply to condition of laminate after repair and hydrotest.
b) Noncatalyzed resin is not permissible to any extent in any area of the laminate.
c) Repair Type descriptions (ASME RTP-1-1995 edition, Appendix M-9 "Repair Procedures"):

Type 1: Inner surface repairs - removing inner surface (surfacing veil) by grinding, and adding back the correct inner surface material.

Type 2: Interior layer repairs - removing both inner surface and interior layer laminate by grinding, and adding back the correct inner surface and interior layer laminate.

Type 3: Structural layer repairs - removing structural material by grinding, in accordance with special advice from the Customer's Specialist Engineer.

Type 4: Dimensional nonconformance repairs - adding additional laminate of the correct specified sequence.

Type 5: Miscellaneous general repairs due to acetone sensitivity or low Barcol readings - postcuring the affected laminate or re-top-coating the surface

Type 6: Repairs due to nonconformance with dimensional requirements - removing and new attachment of vessel parts provided the part is attached only to the outside structural layer of the vessel.

FIG.A1-A18

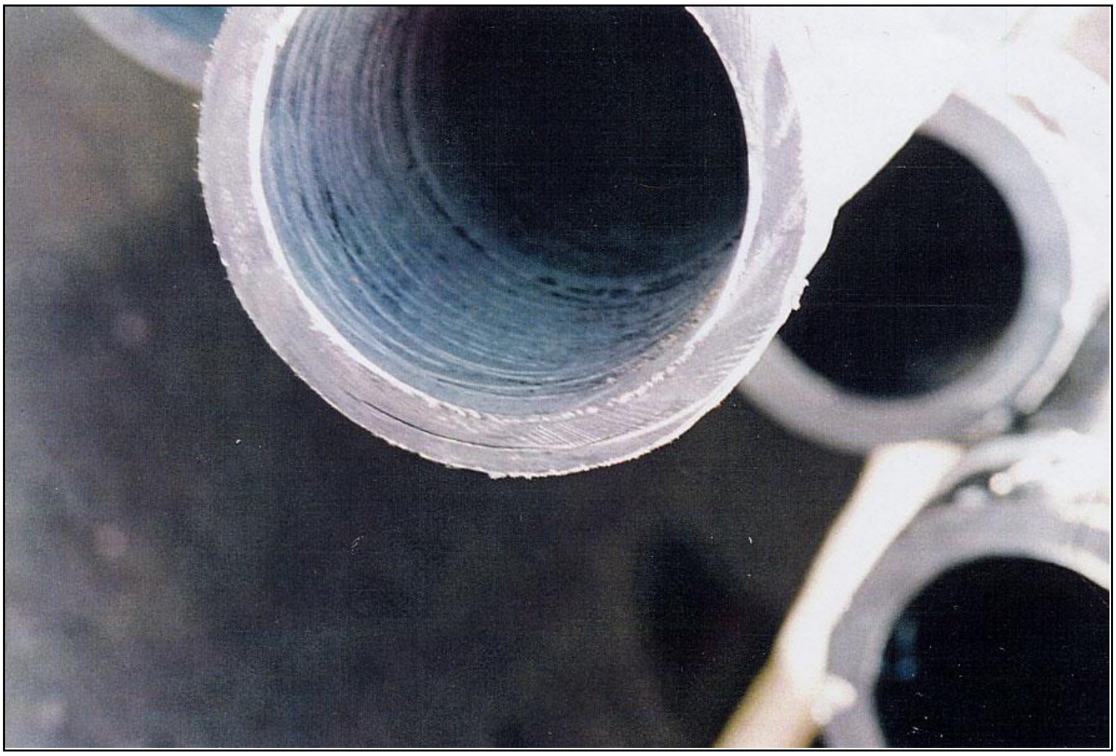


FIG. A1: Delamination, internal.
Caused by improper curing (residual cure stresses resulting in cracking and delamination)

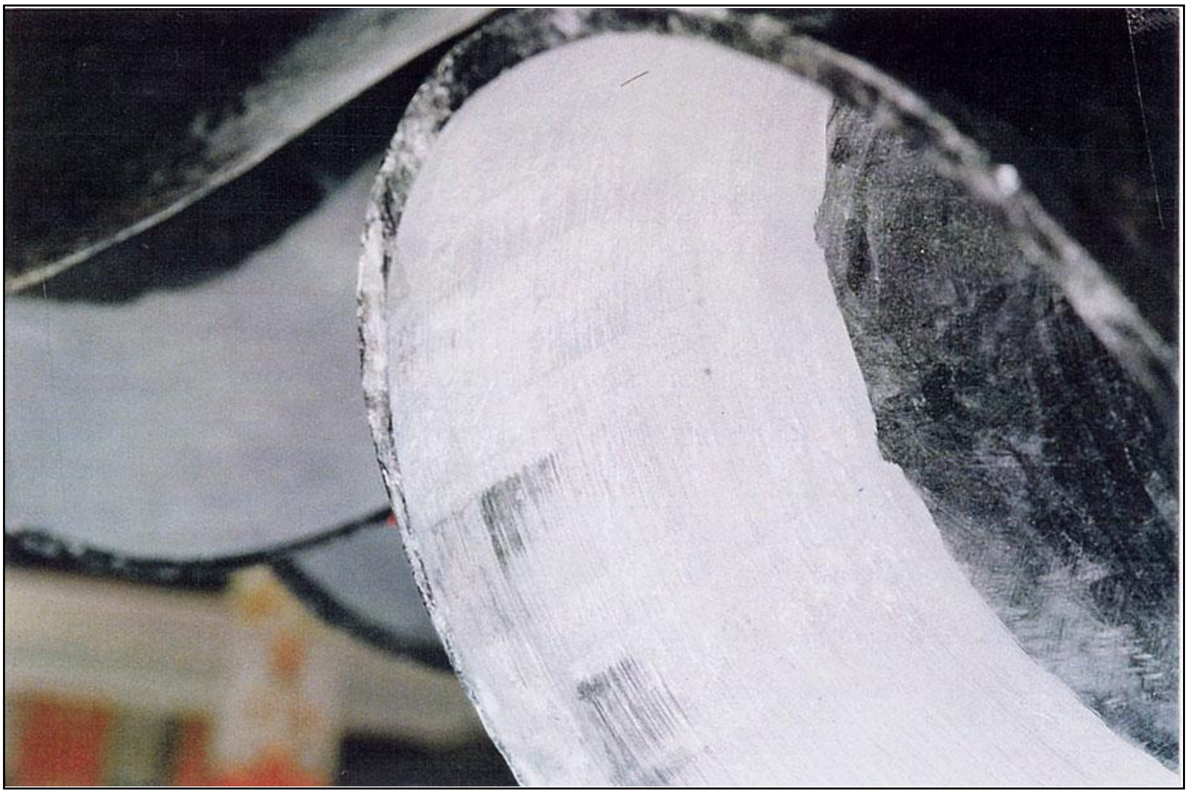


FIG. A2: Incorrect dimensions.

Uneven wall thickness after grinding of adhesive joint surfaces.

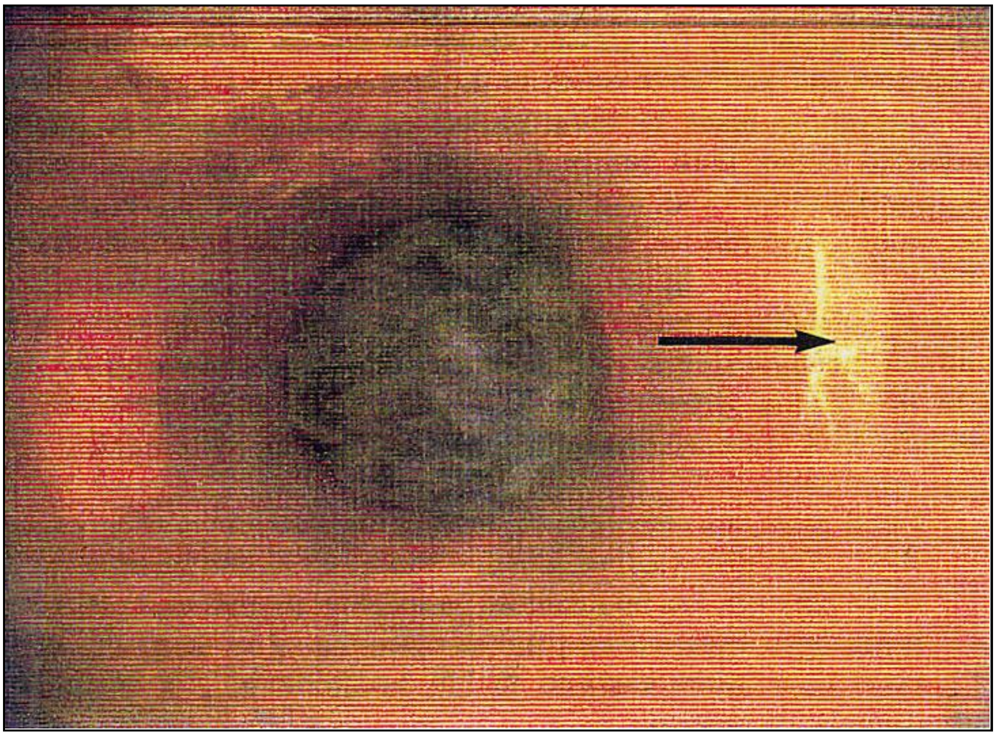


FIG. A3: Impact damage.
Illustrating internal video inspection of GRP pipe using a 45 degree mirror

FIG. A4: Excessive adhesive, internal. Illustrating internal video inspection of a couple-jointed GRP pipe with excess adhesive.

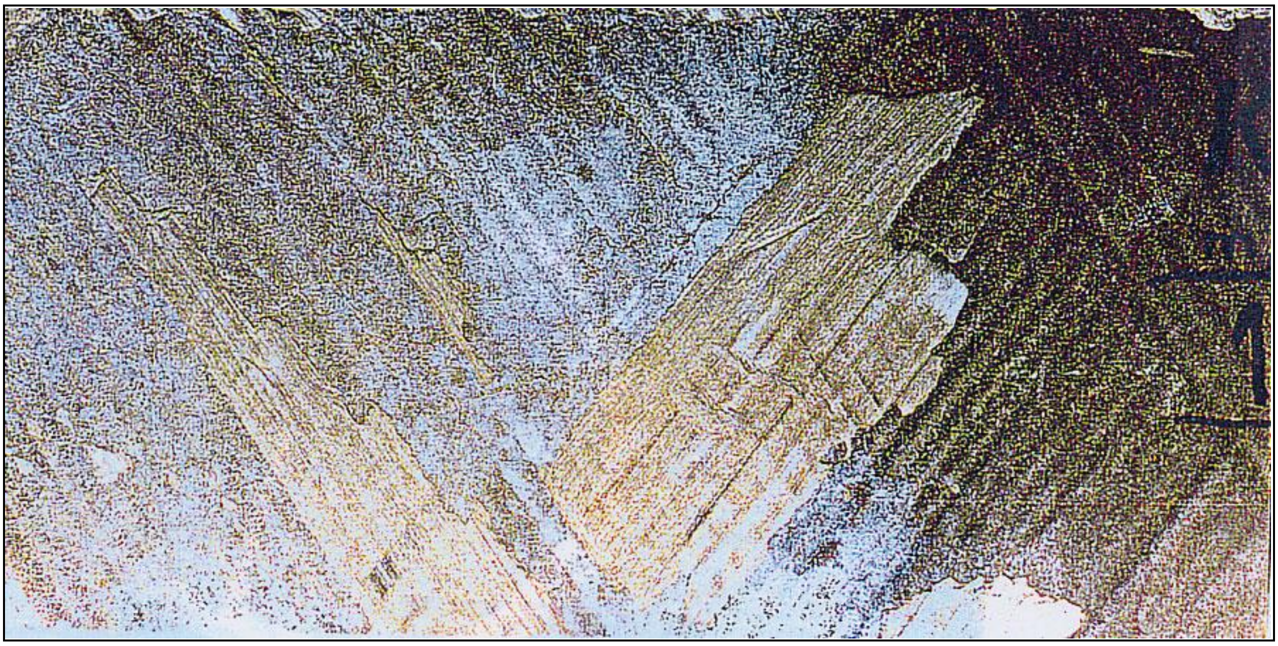
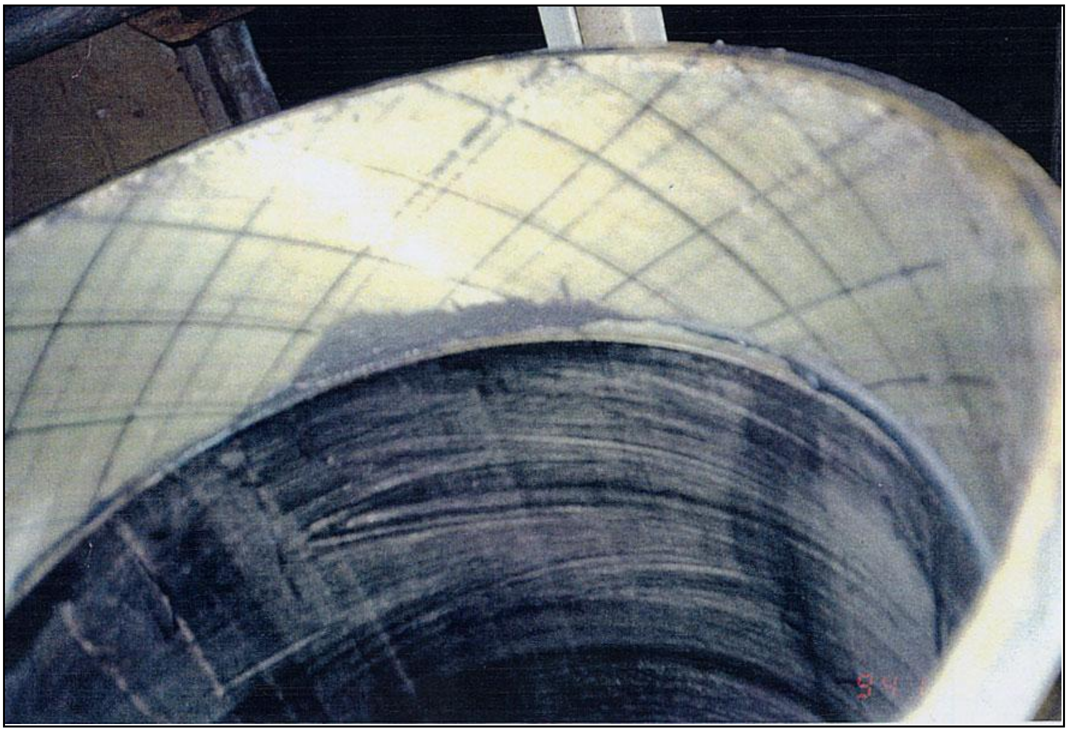


FIG. A5: Corrosion.
Breakdown of resin-rich liner layer due to chemical attack by media being transported.

FIG. A6: Lack of adhesive.
Failed joint showing voids on bonded surface.



Integral taper socket-end of 24" pipe

Taper spigot-end of 24” pipe

FIG. A7: Inadequate (“kissing”) bond.
Caused by improper preparation of female surface prior to bonding. May also be caused by contamination of surfaces, improper resin mixing or curing etc.

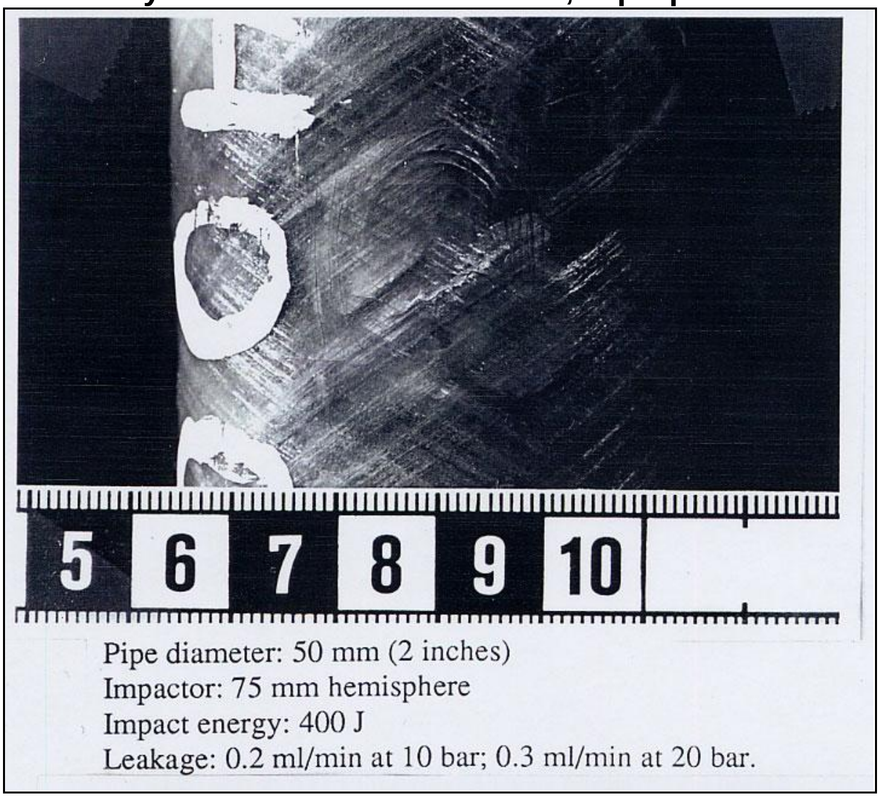
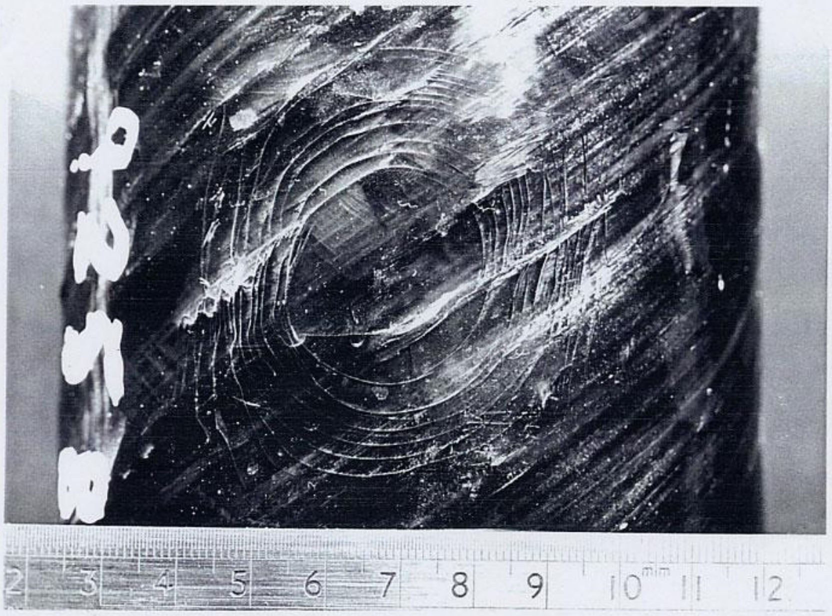


FIG. A8: Cracks. Delamination. Impact damage.
Combination of cracks and delaminations typical of impact damage. Shown here for increasingly severe damage (leakage rate) levels. Circular crack pattern in outer layers with little delamination can be seen for lower damage levels (A, C). Difference between hemispheral (A, C, D E) and sharp-edged impactors show that sharp-edged (B) often produce less extensive damage. Larger damage areas (lighter coloured delaminations and cracks following fibers) can be seen for increasing impact damage (D, E)



Pipe diameter: 100 mm (4 inches) 8C
Impactor: 75 mm hemisphere
Impact energy: 200 J
Leakage: 20 ml/min at 10 bar; 26 ml/min at 20 bar.

Pipe diameter: 100 mm (4 inches) 8D
Impactor: 75 mm hemisphere
Impact energy: 200 J
Leakage: 45 ml/min at 10 bar; 60 ml/min at 20 bar.

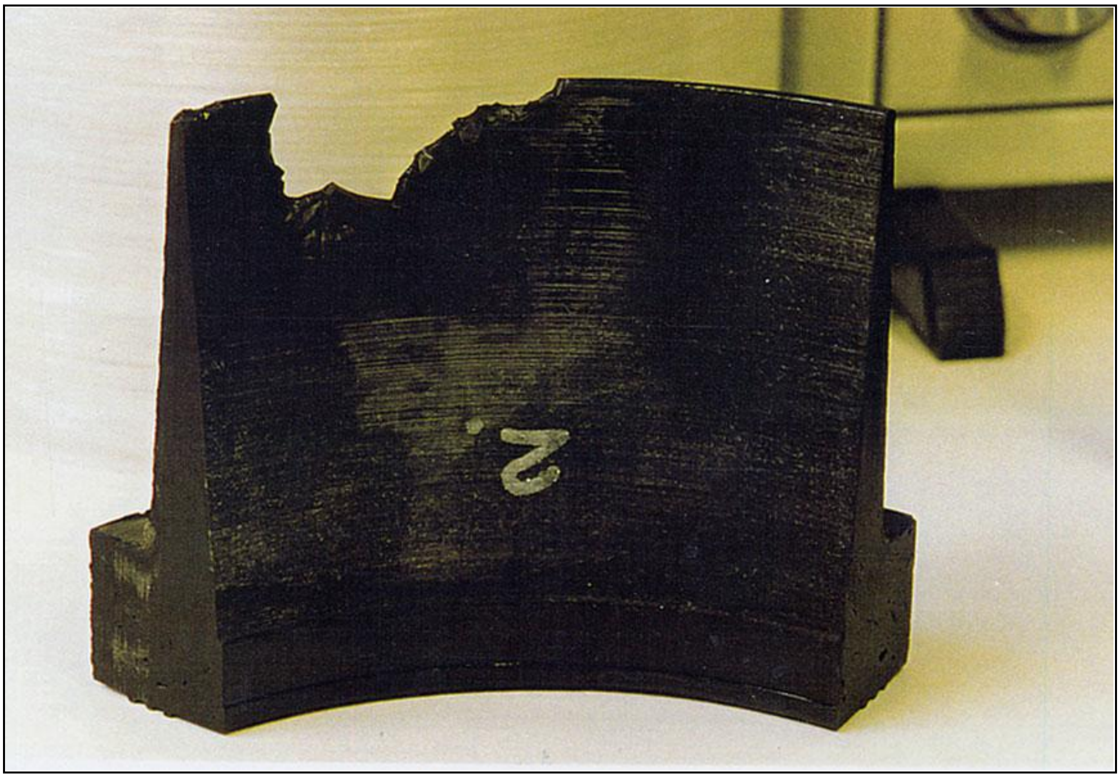


FIG. A9: Incorrect resin/Fiber ratio.

Norwegian Oil and Gas Association, Recommended Guidelines for NDT of GRP pipe systems and tanks

Lack of fiber in laminate (shown in both x-ray and visual appearance)

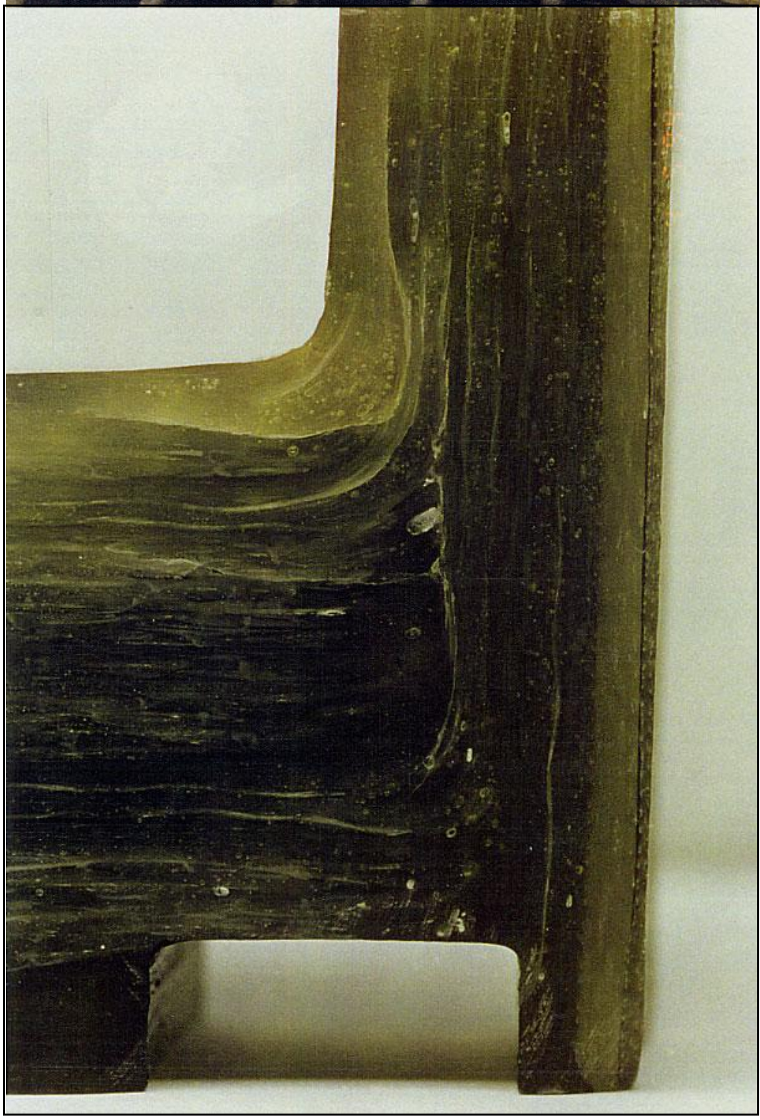
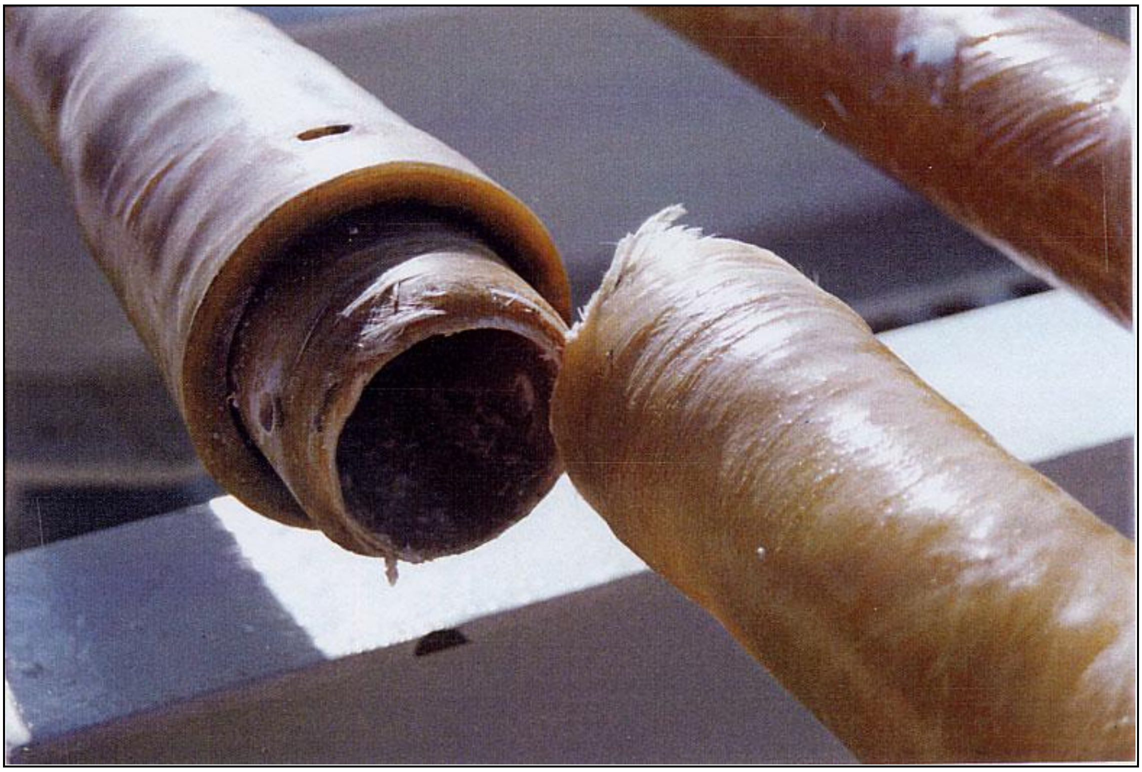


FIG. A10: Delamination. Internal. Delamination in flange root (caused by stressing flage with plies layed-up using incorrect sequence)



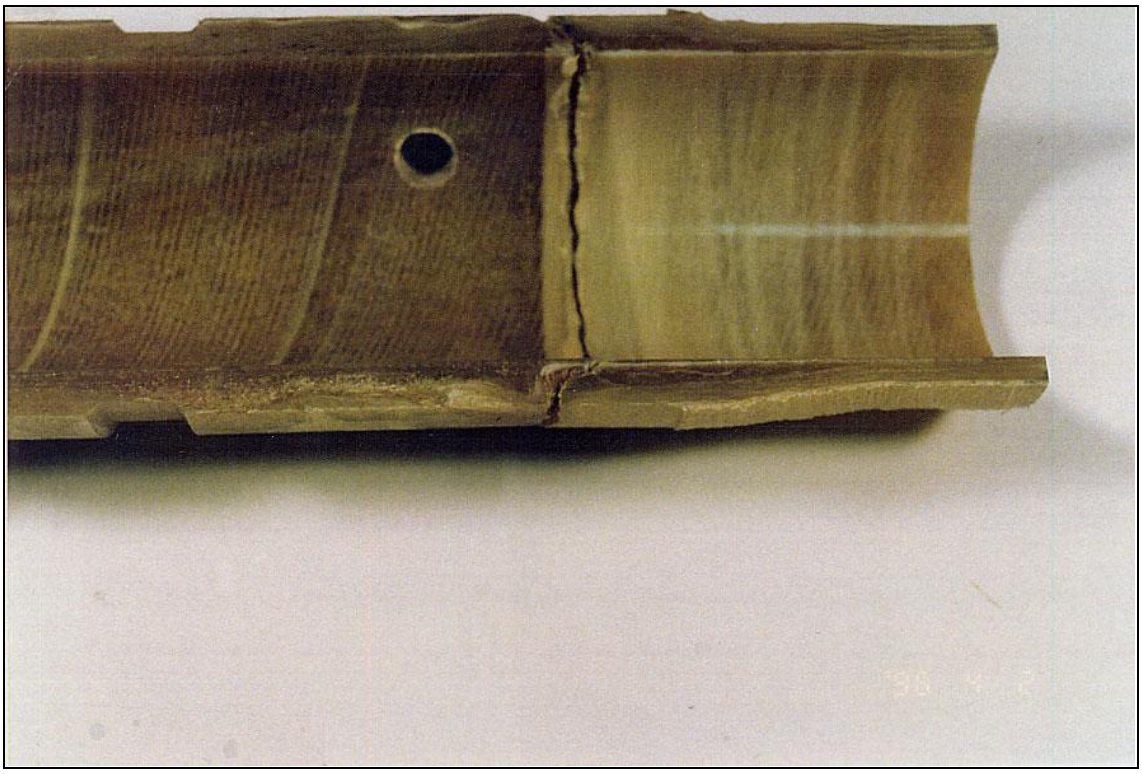


FIG. A11: Fracture.
GRP pipe ruptured at fitting (caused by improper fabrication, sufficient axial fibers missing)

Pipe diameter: 50 mm (2 inches)
Impactor: 75 mm hemisphere
Impact energy: 400 J
Leakage: complete at 10 bar; complete at 20 bar.

FIG. A12: Fracture. GRP pipe ruptured (by severe impact)

FIG. A13: Weeping.
Weeping through laminate will appear this way, but will typically be more localized (since most GRP defects are localized). Picture shows condensation which can be confused with weeping. Surface being visually inspected should be dried and re-

inspected if weeping is suspected.

FIG. A14: Crack, in flange root.
Crack in flange root (propapbly caused by overtorquing bolts). Flange root cracking is located at a greater radial distance than is adhesive bondline;

adhesive bondline is a more critical location with respect to cracking.

FIG. A15: Crack, in flange root.
Detail showing typical cracking (not same flange as FIG. A14)

FIG. A16: Cracks, in flange root and bolt ring. Cracking caused by overtorquing bolts or overstressing flange (white on surface is salt)

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FIG. A17: Crack, in resin-rich surface layer.
(A) View of flange (white particles are snow)

FIG. A17: Crack, in resin-rich surface layer.
(B) Close-up view showing crack depth to surface resin layer thickness (white particles are snow)

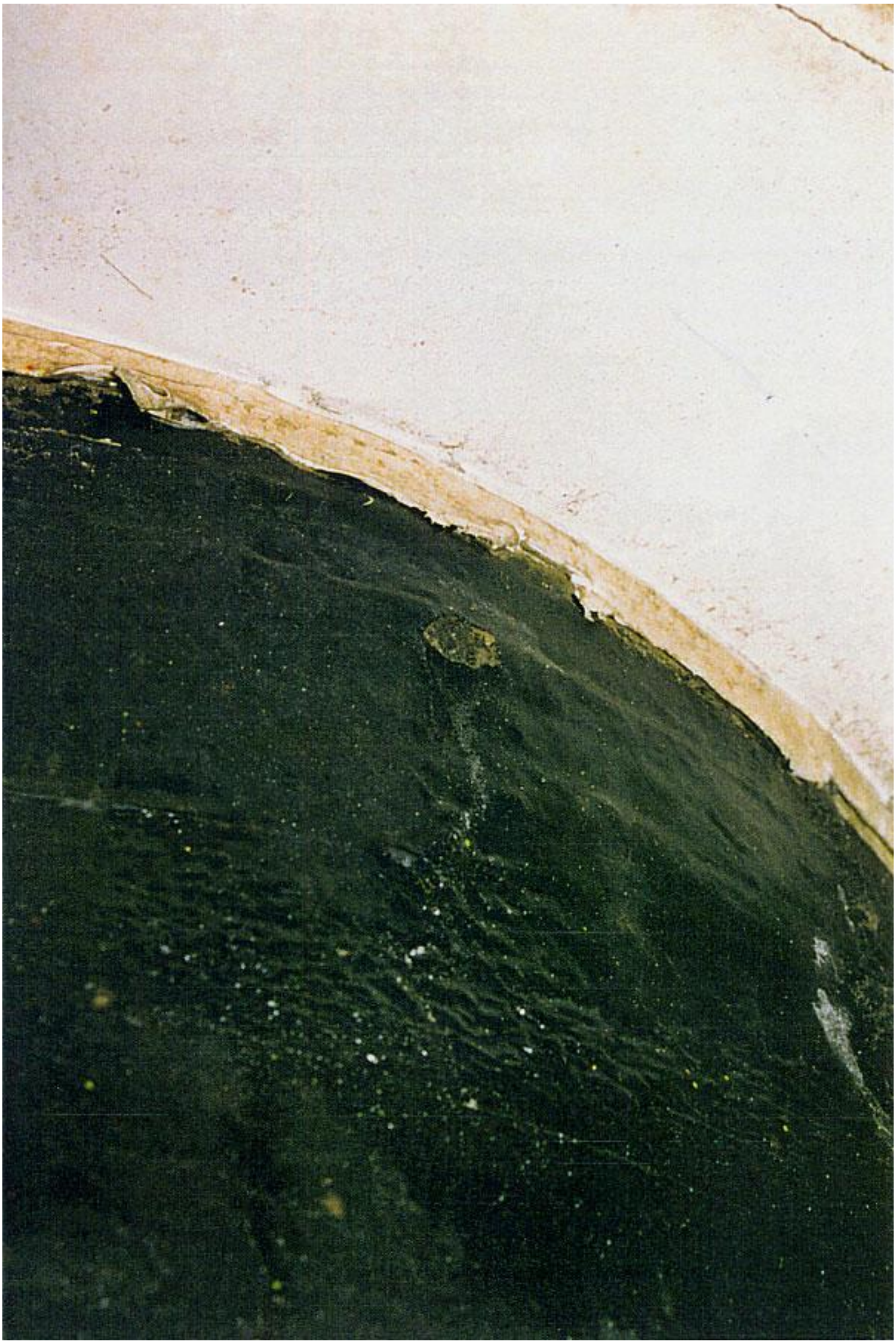


FIG. A18: Chip.
Outer ply of laminate chipped off (may first have blistered in this case)

A.3.2. ACCEPTANCE CRITERIA / ASTM D 2563 MODIFICATIONS

Sub-section numbering under A.3.2 corresponds to ASTM D 2563. Modifications and additions are shown in *italics*.

1.1 This practice covers acceptance criteria for visual inspection of parts made from glass fiber-reinforced plastic laminates, *including piping and tanks*.

2.2 Dimensions and Tolerances - Parts shall be inspected for conformance with dimensions and tolerances specified on the drawings. Any dimensions falling outside the specified limits shall be cause for rejection. *Dimensions and tolerances shall be consistent with joining requirements. Particular attention shall be paid to alignment of joined components. Misalignment may indicate movement during curing which can result in poor adhesive joints or components overstressed by "pulling up" joints as in metallic piping practice. Surveying equipment (MERCAD or equivalent) may be used to improve accuracy of dimensional measurements, particularly for systems having few field joints and little adjustment available during installation*.

Pipes and fittings shall be as uniform as commerciably practiable in color and opacity. All pipe ends shall be cut at right angles to the axis of the pipe and any sharp edges removed. (NB! Reviewers, this text is from ASTM D 2996:)

The inside surface of each pipe shall be free of bulges, dents, ridges, and other defects that result in a variation of the inside diameter of more than 3.2 mm or 3% of the diameter, whichever is greater, from that obtained on adjacent unaffected portions of the pipe wall. No glassfiber reinforcement shall penetrate the interior surface of the pipe wall. (NB! Reviewers, this text is from ASTM D 3517:)

2.7 Allowable Defects - The defects in noncritical areas which by nature, content, or frequency do not affect serviceability of the part are designated as allowable defects. Allowable defects shall be fully described as to type, size, number, extent and spacing. The appropriate acceptance level (Table 1) for defects in these areas must be specified. *Level II values (Table 1) shall apply for GRP piping and tank components if not otherwise agreed. Some defects will typically not apply to filament-wound GRP pipes and tanks (Table 1, Note 2).* Where Level IV is used the defects must be fully described on the product drawing. Defects greater than those listed in the product specifications, drawings, or contracts for the part shall be cause for rejection. *For GRP piping and tank components Table 1 shall be modified as shown in Table A.1 and Table A.2 of this practice.*

For GRP pipes, fittings and tanks, variations in wall thickness should not exceed 10% of the nominal wall thickness, unless otherwise agreed with the equipment supplier.

Table 1 -Note 2: The following defects are not prevalent for filament-wound GRP pipes and tanks:

- Lack of fillout
- Fish-eye
- Orange-peel
- Pre-gel
- Shrink-mark (sink)
- Wash
- Wormhole
- Short.

2.8 Repairable Defects - Repairable defects, if any, shall consist of those which can be repaired without affecting the serviceability of the part unless prohibited in the product drawing or in the contract. Acceptable methods of repair shall be agreed upon between the purchaser and the seller and shall be only as specified in the product drawing or contracts for the part. *If not otherwise agreed by the purchaser and seller, the repair methods given in Table A.1 of this practice shall apply for GRP piping (Table A.1) and tank (Table A.2) components.*

2.9 Surface Finish - The over-all surface finish of laminates may vary with the process used and the type of reinforcement. Unless surface finish is specified on part drawings, contracts, or orders from the purchaser, parts shall not be rejected for any reading less than 150 rms. *For GRP pipes, fittings and tanks, variations in wall thickness should not exceed 10% of the nominal wall thickness, unless otherwise agreed with the equipment supplier.* (REVIEWERS, ESPECIALLY MANUFACTURERS, TO SUGGEST SUITABLE VALUE). Defects shall be considered as not included in over-all surface finish.

3.1 Visual Inspection - *Various instruments and accessories may be utilized in order to facilitate the inspection, including*

-Lenses
Strong light sources
-Penetrants
-Fibre-optic devices, boroscopes and endoscopes; for limited access
-Video systems for remote inspection
-Measuring tapes, pi tapes,
-Felt-tip pens, and other miscellaneous tools.

However, for classification purposes each part shall be checked visually without the aid of magnification.......

2.11 *Barcol Impressor and Coin Tapping may be used in combination with visual inspection. The measurement of indentation hardness by a Barcol Impressor can be used for the detection of undercure or swelling of the resin. Barcol hardness measurements shall comply with supplier's specified values. (Ref. Annex G.)*

Planar defects located near the surface such as delaminated and disbonded areas in GRP may be detected by the "coin tapping" method. The "coin tapping" method is a local vibration technique which involves tapping the surface with a coin and listening to the response. Planar defects located near the surface such as delaminated and disbonded areas in GRP sound "dead" compared to flawless areas. Such areas shall be marked and noted in the reported visual inspection results. The "coint tapping" method is not recommended as it is subjective and limited to outer portion of laminate.

A.4. AREAS FOR FURTHER DEVELOPMENT

Revision of ASTM D 2563 to include the above modifications, along with appropriate information and pictures from manufacturers' internal inspection procedures showing acceptable defect levels, will go far towards eliminating the present, subjective variations in interpreting visual inspection results between different inspectors.

A.5. DRAFT INSPECTION PROCEDURE

1.0 Surface preparation

Clean the surface to be subject to inspection with a clean cloth or liquid cleaning agent (acetone, detergent and water).

2.0 Inspection

- Perform visual inspection using criteria in Table A.1 or Table A.2.

- Draw the contours of all detected defects on the GRP surface with a permanent ink.

3.0 Reporting

The following information shall be included on the Inspection Report form:

- Size and position of any observed defects
- Identification and location of the pipe/tank/area/item inspected.
- Name and certification level of operator.
- Date and time of the inspection

Draft Inspection Report form:

Page 1 of X	
INSPECTION REPORT **VISUAL INSPECTION OF GRP PIPING AND TANKS**	
INFORMATION	DATA
Project -number.	
Pipe no. / tank no. / spool no./ other identification of inspected component or area	
Inspection Operator info.	Name: Certification level: Certificate no.: Certificate validity (from date - to date):
Defect type, dimentions and locations	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
- Defect no. 1:	Type : Dimensions : Location :
- Defect no. 2:	Type : Dimensions : Location :
- etc.	

A.6. REFERENCES

1) UKOOA, "Specification and Recommended Practice for the Use of GRP Piping Offshore", March 1994.

2) ASTM D 2563-70, "Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts", Reapproved 1987.

3) ASME RTP-1-1995 Edition: "Reinforced Thermoset Plastic Corrosion Resistant Equipment".

ANNEX B

PRESSURE TESTING

B.1 MAIN DETECTABLE DEFECTS

- Adhesive bonded joints lacking adhesive, or improperly prepared, made-up or cured.
- Manufacturing defects in GRP materials
- Leaking joints

B.2 LIMITS OF DETECTABILITY

A pressure test at 1.5 times design pressure will reveal leaks and such major defects as severe impact damage (from e.g. improper transport), improperly designed or fabricated systems (lacking adequate strength), or very poor adhesive bonding. However, various analytical and experimental studies (ref. Annex F) have shown that adhesive bonded joints are designed with a large margin of safety. Bonded joints having as large as 85 % unbonded area can pass a pressure test. Thus the pressure test is a major element in ensuring that the GRP pipe or tank system is structurally and functionally adequate, but cannot be viewed as an absolute guarantee of performance.

B.3 GENERAL

Pressure testing is the most frequently used method to ensure that a GRP pipe or tank system has been properly fabricated and installed. Pressure testing gives more certain assurance than other NDE/NDT methods that the system is installed and functioning properly. Pressure testing of an improperly installed system can result in destructive failure, e.g. of joints, but most often results in leakage requiring local repair of the system. Since bonded joints having as much as 85% void area can pass a short term pressure test, it is important to follow all installation and Q.A. procedures when installing the piping system. Doing so will avoid the detrimental effects on service life of excessive void areas. Other NDT methods (e.g. random verification of joint quality using ultrasonics) can be used along with pressure testing for critical systems where extra certainity is desired. There are two significant drawbacks associated with pressure testing; (a) cost of blinding off systems can be significant, and (b) pressure testing is usually done late in the project cycle where any failures can lead to commissioning delays.

B.4 TEST PROCEDURE

Pressure testing shall be carried out in accordance with Part 4, Section 7 of Ref. [2]. This serves as the basis for (and is identical with) the pressure testing requirement in Norsok [1]. Test procedure details regarding loading rates, test pressures, hold times, etc. are provided in [2].

Pressure testing shall, to the extent practical, be carried out on system sub-segments at an early opportunity in order to minimize blinding-off costs and commissioning delays.

Pressure testing at operational pressures may be performed as outlined in Fig. 1.2, but only if this does not adversely effect system safety or function.

ANNEX C

ULTRASONICS TEST METHODS AND DETECTABLE DEFECTS

C.1 MAIN DETECTABLE DEFECTS

- Areas in the joint lacking adhesive
- Delaminations, voids
- Deviations in wall thickness

C.2 LIMITS OF DETECTABILITY

Various researchers have demonstrated ultrasonics test methods, particularly on adhesively bonded joints in small diameter piping systems. A summary of detectable defects (based on several different test pieces) follows:

DEFECT TYPE	DETECTABLE SIZE (1)	METHOD [SOURCE] (EQUIPMENT / FREQUENCY)	PIPE TYPE / DIA./ DEFECT DEPTH	COMMENTS
Lacking adhesive	10mm	IPM [1], (BondaScope 2100/ 50-500 kHz)	Wavin, Ameron straight pipe with coupling / 100,200mm/ BONDLINE	TIME TO TEST (excluding setup) = or < 0,25 hr/joint Smooth pipe surface req'd. 25, 50mm dia. pipe too small for probe.
Lacking adhesive	ca. 15 mm (5% of circum-ference)	IPM , (Snavely Bondmaster/ 110,165 kHz)	Ameron Bondstrand 2000M/ 100-200 mm/ BONDLINE	Bends, tees, flanges tested
Lacking adhesive	ca. 15 mm (5% of circum-ference)	Pulse-echo (Panametrics Epoch II / 0,5; 1,0; 2,25 MHz)	Ameron Bondstrand 2000M/ 100-200 mm/ BONDLINE	Bends, tees, flanges tested
Lacking adhesive Wall thickness (erosion)	10 mm <30%	Pulse-echo (Krautkramer USD15 / 2.25 MHz)	Ameron straight pipe with coupling / 100mm/ ca. 7 mm	
Lacking adhesive	10 mm	Pulse-echo (1-2.25 MHz)	Flat plates, woven roving/ 10 mm/ 10 mm	
Lacking adhesive	7.5mm	Pulse-echo (ANDSCAN/ 2 MHz)	Ameron 2020/6000 pipe with coupling / 100mm/ BONDLINE	

DEFECT TYPE	DETECTABLE SIZE (1)	METHOD [SOURCE] (EQUIPMENT / FREQUENCY)	PIPE TYPE / DIA./ DEFECT DEPTH	COMMENTS
Lacking adhesive	10mm	IPM [1], (BondaScope 2100/ 50-500 kHz)	Wavin, Ameron straight pipe with coupling / 100,200mm/ BONDLINE	TIME TO TEST (excluding setup) = or < 0,25 hr/joint Smooth pipe surface req'd. 25, 50mm dia. pipe too small for probe.
Lacking adhesive	12mm	P-scan [3]	Ameron 2020/ 400mm / BONDLINE	Planned defects moved. Problem with taper.
Lacking adhesive Kissing bond	ca. 15mm Not detected	P-scan [2] (0.5 MHz)	200mm/ BONDLINE	Kissing bond defect (oiled surface) was not observed when pipe sectioned.
Wall thickness, Delamination	Detected, but not quantified	Pulse-echo (0.5, 1.0, 2.25 MHz)	Ameron pipe/ 635 mm/ 25 mm wall thickness	
Wall thickness Delamination	Not detected	Pulse-echo (0.25, 0.5 MHz)	Ameron curved section with bonded joints/ 700 mm/ 30-100 mm wall thickness	Bend most likely made by tape winding. High porosity and high attenuation.
Wall thickness	5%	Pulse-echo [4] (1 MHz)		
Flange crack depth	> 5 mm from surface	P-scan [7]	Ameron flange 80-110 mm thick	
Impact delamination	>12 mm x 12 mm	Pulse-echo (ANDSCAN/ 2 MHz)	Ameron pipe/ 100 mm	Back wall echo used to located delaminations

Notes: (1) Minimum detectable defect diameter is given (unless otherwise noted).

It can be seen from the above that voids and areas lacking adhesive can be detected using available ultrasonics methods to resolutions of ca. 10 mm and to depths of 10+ mm. Areas of poor adhesion, i.e. "kissing bonds" will not be reliably detected by this method. Delaminations can be detected with similar resolution as for voids. Variations in wall thickness of 5-10% can also be detected.

C.3 GENERAL

The pulse-echo (PE) method (where one transducer functions as both transmitter and receiver) is the most commonly used ultrasonics test method for GRP. In addition, through-transmission (using two transducers) and impedance plane methods (one transducer with phase monitoring) have been successfully used. Instrument settings, transducer frequency, and calibration should be optimized or performed for the test object itself, or for a very similar, representative object.

Probe selection should recognize the trade-offs between resolution (typically improved at higher frequencies, i.e.> 2.25 MHz), depth penetration (typically best a lower frequencies, i.e. < 2.25 MHz), signal damping characteristics, and diameter (larger diameters allow higher energy input, but at the expense of spatial definition of defects and successful coupling to curved surfaces).

Use of back-wall echoes is recommended for inspecting adhesively bonded joints since missing adhesive will cause the back-wall signal to disappear.

The quality of the surface finish will effect coupling and ultrasonics results. Results may be improved by use of coupling agents (e.g. water, gels, etc.) or by smoothing the surface as outlined in [1]. Single point inspections are not recommended due to the uncertainities associated with coupling, surface finish, and materials fabrication. Scanning devices (or multiple point inspections) are recommended for two reasons: (a) the resulting maps are easier to interpret, and (b) one inaccurate reading will not lead to wrong conclusions about the quality of the GRP joint/ product.

Because of much greater attenuation in GRP compared to steel ultrasonic frequencies must be reduced. A relatively low frequency, typically between 0.25 MHz and 2.25 MHz, is considered to be best suited for PE ultrasonic testing of GRP where the wall thickness is typically in the range 8 to 25 mm. Low frequency waves are able to penetrate the wall thickness twice (back and forth), and are thus used for PE which permits one-side access only. However, the use of low frequency transducers decreases resolution. It is extremely difficult to detect flaws that are less than a half wave length in diameter. Although resolution improves with increasing frequency, measurements have clearly demonstrated that attenuation also increases. The optimimum frequency range will most likely correspond to that given above.

Different GRP pipe manufacturing methods also affect attentuation. Fabrication methods resulting in a low degree of laminate porosity (e.g. filament wound pipe) will result in less attenuation than methods which tend to entrap air during the manufacturing process (e.g. hand layed-up fittings, or tape-wound fittings). This effect can make it impossible for ultrasonics to be used due to high attentuation. Uneven (e.g. some hand layed-up) or corroded (e.g. chemical process plant equipment) reflecting surfaces may also severely disperse the ultrasonic signal.

Reflected pulses in GRP have more complex waveforms and less time separation between the reflected pulses than is the case for steel. Therefore multiple echoes cannot reliably be used in signal interpretation.

A method which would increase time between reflected signals (i.e. similar to ultrasonic stand-off techniques) has been proposed and demonstrated [4,6]. This method makes use of transmission through flooded GRP pipes with the signal returning from the opposite pipe wall. It has been used successfully in small diameter pipes (200 mm). Another method of increasing time (and compensating for the dead-zone immediately underneath the probe) is to use a suitable stand-off. A suitable stand-off for GRP is PMMA and a length of ca. 6 mm allows defects which are near the surface to be detected.

The speed of sound in GRP (2000-4000 m/s, with most quoted values for GRP pipes ranging from 2700-3000 m/s) also differs from that of steel (6000 m/s). This is important to remember when calibrating equipment or when comparing ultrasonically and physically measured thicknesses.

Time-of-flight measurements are of less interest than for metals since it is usually sufficient to merely identify the presence of a defect. However, if this method is used to estimate how deep a particular defect is, the user should be aware that the sound velocity may vary locally within the laminate based on glass content (ca. 1% change for a 1% volume fraction change in 60% glass content) and glass orientation (ca. 3% if fibers approach 30% deviation from being parallel to the surface)[5].

C.4 AREAS FOR FURTHER DEVELOPMENT

Existing ultrasonics methods should be used as outlined above for pipe diameters up to 400 mm and can be used as a starting point for inspection of larger diameters. Increased wall thicknesses make use of ultrasonics more difficult as diameters increase. Additional improvements could be achieved with this method provided further development is performed in the following areas:

- Construction of standard calibration blocks. (It is difficult to fabricate calibration blocks where defects are repeatibly placed where intended, because of adhesive movement during joining and curing.) The method given in B5 appears to be optimum given present knowledge.

- Optimising parameters for use with larger diameter pipes where defect depth increases.

- Further optimization of coupling techniques.

C.5 DRAFT INSPECTION PROCEDURE FOR ULTRASONIC INSPECTION OF ADHESIVELY BONDED FIBRE GLASS PIPE JOINTS

1.0 SCOPE

This procedure describes the requirements for ultrasonic testing of glass-fibre reinforced plastic (GRP) piping systems and tanks. It applies to both automatic and manual scanning, and to both pulse-echo and impedance plane methods.

2.0 GENERAL REQUIREMENTS

Personnel performing this inspection shall be certified NDT level II (minimum) in ultrasonic, as described in SNT-TC-1A by the American Society for Non-destructive Testing. Additionally, they shall also have had specific training in the ultrasonic test method to be used.

Fibre glass pipe joints inspected with this procedure must have a clean, smooth and uniform exterior surface. The condition of the surface roughness must be in a state that gives repeatable, stable signals when the probe is placed on the surface of the tested material. If the surface roughness is too large, a power driven sander with grade 80 sand paper can be applied to the exterior joint surface. The sanded surface shall be cleaned and dried before inspection. The sanded surface shall be sealed with a thin layer of epoxy or polyester for protection of the exposed fibres after inspection has been completed.

Ultrasonic techniques may be used to measure laminate thickness. The number of thickness measurements shall be as needed to provide for adequate calibration of equipment (e.g. ultrasonic impedance unit) or as desired to quantify potential erosion, wear, define conical surfaces, etc.

All defects found shall be drawn on the laminate surface with a permanent ink.

3.0 EQUIPMENT

The ultrasonic unit to be used for the inspection must be portable and rugged enough for the intended service. Equipment intended for laboratory use will normally not be suitable for field use. In particular moisture is detrimental. If outdoor testing is performed, the necessary precautions shall be taken to protect the equipment from rain, wind etc.

Most offshore platforms have EX 1 zones, in which no electric equipment that can produce sparks are allowed. The operator of the equipment must ensure that the equipment to be used fulfils the EX requirements, or obtain special permission from the safety department on board to execute the inspection in special zones, in shut-down periods etc.

4.0 CALIBRATION

4.1 Calibration standard

A calibration standard shall be fabricated for each size and type of piping system or tank laminate to be inspected. The calibration standard shall be matched to the various types of defects to be found.

Variations in wall thickness should be calibrated using a portion of a pipe, joint or tank laminate with a machined (milled) area on the interior surface equivalent to the desired defect resolution, but not smaller than 10 mm in diameter as shown in Figure 1.

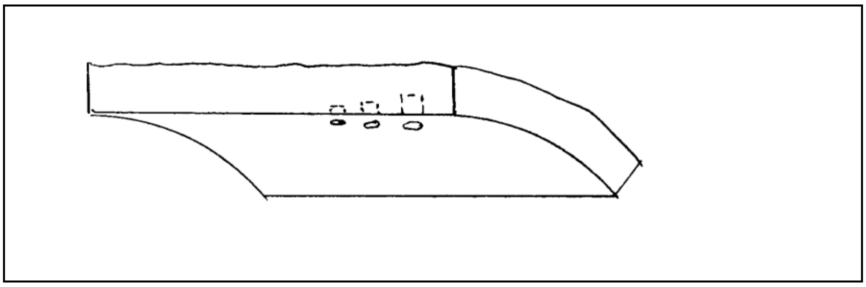


Fig. 1 - Calibration Standard for Voids and Delaminations
(Pipe segment showing simulation of voids and delaminations in the GRP material or in the adhesive bondline. Defects achieved by machining holes with diameter and depth selected to match defects to be detected).

The calibration standard for adhesive bonded joints should be produced using adherends (pipe segments or tank laminates) with matching stair-step patterns machined into the surfaces. Controlled voids (areas lacking adhesive) may be achieved by not completely coating steps with adhesive (or by including removable strips of e.g. Teflon). This type of calibration standard is shown in Figure 2. Both exterior surfaces and inner, machined surfaces should be representative of the surface roughness achieved during fabrication and shaving of adherends prior to adhesive bonding.

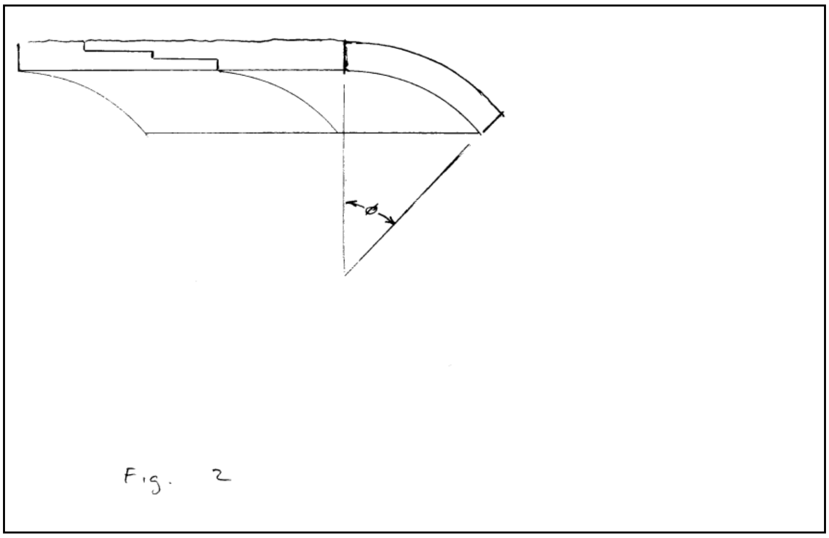


Fig. 2 - Calibration Standard for Bonded Pipe Joints
(Pipe segments machined so that vertical faces are in contact and horizontal faces are separated by specified bondline thickness. Pipe is then bonded and sectioned, with Ø > 45 degrees. Teflon (or similar) inserts may be placed on horizontal faces during bonding and withdrawn when sectioned, thus guaranteeing that known defects are precisely and repeatibly located. Multiple steps may be selected in order to simulate different pipe diameters with a single calibration standard).

Each calibration standard shall be labelled with:

- Pipe manufacturer

- Fitting assembler
- Date of assembly
- Serial number

4.2 Calibration

The ultrasonic equipment shall be frequently calibrated as specified by the manufacturer in the operator's manual for the instrument.

5.0 COUPLANT

Water or standard, commercially available ultrasonic couplants may be used for this type of inspection.

6.0 PREPARATIONS

If an automatic scan covering the entire area being inspected is not used, a multi-point inspection template should be used. The template should systematically define the points to be measured. The position of the template should be marked on the test object with permanent ink, to ensure repeatability of the measurements. Indications of orientation, for instance the 12 o'clock position and flow direction, should coincide on the test object and on the template.

8.0 SCANNING

The number of points tested or scanned shall be sufficient to identify defects larger than the agreed acceptance criteria. Size and position of any observed defects shall be marked on the exterior surface and included in the inspection report.

9.0 REPORTING

For each inspection, the following information shall be recorded:

- Size and position of any observed defects
- Identification and location of the joint inspected.
- Name, type and serial number of the instrument used.
- Probe type and operational frequency.
- Identification of the calibration standard used.
- Identification of inspection template used.
- Name and certification level of operator.
- Date and time of the inspection

C.6 REFERENCES

1) A.B. Hansen: "Development of a Non-Destructive Evaluation Method (NDE) for Adhesively Bonded GRP Pipe Connections Offshore".
2) B. Melve,T. Kulbrandstad: Demonstration of ultrasound and thermography on GRP-pipe pipe bonds at Aker GRP Center 19 may 1994.
3) Fax J. Rusborg (FORCE Institute) to CJ Houghton, 15.12.94
4) Baltzersen Ø., Moursund B., Melve B., Bang J.: "Ultrasonic Inspection of Adhesive Bonded Coupler Joints in GRP Piping Systems", Journal of Reinforced Plastics and Composites, Vol. 14, July, 1995.
5) M.F. Markham: "Investigations of errors in ultrasonic thickness meters for use on glass reinforced plastics", Brit. Journal NDT, pp. 187-190, July 1981.
6) Report No. GVK 95-94, "Adhesively bonded and laminated joined glass fibre reinforced pipe systems", G.A.M. van den Ende, E. Kokmeijer, P.P. van'tVeen, April 1995

ANNEX D

RADIOGRAPHY

D.1 MAIN DETECTABLE DEFECTS

- Incorrect wall thickness or fit between male and female adherends
- Some voids, delaminations and lacking adhesive
- Axial misalignment
- Internal excess of adhesive

D.2 LIMITS OF DETECTABILITY

Radiographic testing has been demonstrated by several researchers and on various offshore installations, particularly on small diameter piping systems. A summary of detectable defects follows:

DEFECT TYPE	DETECTABLE SIZE (1)	METHOD [SOURCE]	PIPE DIA./ DEFECT DEPTH	COMMENTS
Wall thickness variation, (e.g. of repair lamination), Water ingress, Scale build-up	ca. 2 mm thickness variation detected <3 mm thick zone between original pipe wall and laminated repair <<20 mm (barium sulfate scale)	Ir 192 source with Agfa D7 film, exposure time = 40% of steel [1]	200 mm/inner surface, outer surface - outer surface - inner surface	TIME TO TEST 200 mm LAMINATED REPAIR = 0,25 HRS
Voids (in dry pipe)	detectable, but not quantified	160 kV X-ray, Andrex CMA 16 with CMA 357 control and 2 mm copper filter, energy=120-130 kV at 4 A exposure=1,5-2,5 minutes	100 mm/	
Cracks in thermoplastic lining, Voids (bondline)	detectable, but not quantified <2,5 mm dia. hole (=6% of wall thickness in direction of radiation)	Andrex CMA-208, 200 kV/8mA. Used 60-70 kV, 10 mA, 2,5 min. exposure, and 700mm FFD [2]	200 mm	holes drilled tangentially on bondline
Crack	detectable, but not quantified	not known	/35 to 55 mm thick section	GRE tee
Cracks (through wall)	detectable, but not quantified	160 kV X-ray source	/20 mm thick section	

Notes: (1) Minimum detectable defect diameter is given (unless otherwise noted).

It can be seen from the above that radiography is quite useful for detecting wall thickness variations, water ingress, scale build-up and some voids and areas lacking adhesive in pipe sizes of ca. 200 mm. Areas of poor adhesion, i.e. "kissing bonds" will not be detected by this method. Experience with large wall thickness is limited for the offshore GRP pipe applications; however, this method has been used in various thick-walled aerospace applications. The limits for good resolution of thicker-walled pipes are not yet quantified.

The major limitation is the time and cost associated with needing to photograph several cross-sections in order to get a comprehensive picture of the defects in a given area (e.g. joint). It is hoped that "real-time" equipment now becoming available will address this limitation.

D.3 GENERAL

Radiographic testing (RT) measures local differences in radiographic attenuation which are primarily caused by differences in thickness and density. These differences can provide an indication of defects. However, only one cross-section can be seen at a time. Usually this cross-sectional picture is captured on x-ray film. However, equipment is available which allows a "real-time" image from several cross-sections to be captured on video film.

RT is not sensitive to surface roughness, but it is sensitive to the orientation of the defect. It is relatively easy to perform onshore, while it is somewhat more complicated on offshore installations due to closing-off of the test areas for unauthorized personnel.

Polymer composites consist mainly of low atomic weight elements, with low radiographic attentuation compared to the elements in frequently used metals. Radiographic test parameters, i.e. tube voltage and exposure time must therefore be adjusted so that as much information as possible can be extracted from the tests. Low to medium tube voltages, typically in the range of 10keV to 50 keV, are reported to be suitable for RT of GRP [4]. RT can be used much as for steel piping once exposure sources and times are changed to match GRP.

From RT results it is possible to determine wall and laminate (i.e. repair) thicknesses. In some cases it has also been possible to determine the winding angle, and voids or lacking adhesive (particularly, where these become filled with e.g. water). In general, however, it is very difficult to detect lack of adhesive without modifying the adhesive by adding heavy elements which act as contrast enhancers. ZnI_2, $BaSO_4$, PbO, and W (at 5 weight percent) function well as contrast enhancers, but manufacturers have yet to include a contrasting agent in their adhesives. Consequently, these enhancers are at present limited to research applications. RT can also detect excess adhesive, particularly when contrast enhancers are used.

Lack of available time windows in project schedules can be a limited factor on the use of radiography (since the area to be inspected is restricted to limit personnel exposure).

D.4 AREAS FOR FURTHER DEVELOPMENT

- Equipment has recently become available which allows a "real-time" image from several cross-sections to be captured on video film. This has not been used much to investigate GRP piping yet, but should offer significant improvements in radiographic inspection results and costs in coming years.

-Limits of detectability for thick-walled parts need to be determined.

-Results from initial testing have shown that computer tomography (CT), which is a more advanced utilisation of radiographic principles, is suitable for the detection of areas lacking adhesive, and for dimensional control of pipe and coupler. At present, CT cannot be regarded as a field inspection method for GRP pipes. Ongoing research and development work in Australia using this technique aims at the construction of a CT instrument for in-situ testing of wooden poles, and issues related to this application may be very relevant to radiographic testing of GRP pipe joints.

D.5 REFERENCES

1) Investigation of 200mm produced water line, Phillips Pet. Co. Norge, Feb. 1993-July 1994, J. Winkel (unpublished)
2) "Condition Monitoring of Process Equipment Made from Plastic Materials", B. Moursund, 1995
3) Jones T.S., Polansky D., Berger H., "Radiation inspection methods for composite materials", NDT International, Vol. 21, No. 4, August, 1988.

ANNEX E

ACOUSTIC EMISSION TEST METHODS

E.1 MAIN DETECTABLE DEFECTS

- Inadequate structural integrity (may be caused by weaknesses in design, production, material degradation, etc.) Examples: Wrong lay-up on laminated joints, large gaps between dome and cylindrical parts in GRP tanks, underdesigned laminates in areas with multiaxial stresses.
- Delamination growth
- Crack growth in matrix material
- Fibre fracture and pull-out
- Inadequate curing in tanks leading to excessive strains
- Leakages

E.2 LIMITS OF DETECTABILITY

Acoustic emission can be generated by failure mechanisms such as matrix cracking, fibre failure, fibre pull-out, delamination etc. However, it is important to be aware of the fact that an AE test will only identify structurally significant defects, i.e. crack growth in a qualitative manner without sizing defects. Further investigation, e.g. by supplementary NDT, is required in order to classify the defect.

Since the sounds generated from a source have to travel to reach the sensor there is a practical limit for detection, since the sounds will be damped under the detection limit of the equipment if the distance is too large. Due to the anisotropic nature of the composite materials the material damping is larger than in metals. Practical coverage limits from one sensor is a circle of approximately 1 m with the sensor in the center. With fluid filling the limits can in some cases be extended. The damping of the laminates is always tested on site during a standard test in order to have the exact limits for the specific product.

Table E.1: Examples of application of acoustic emission

Product type	Service conditions	Defect found	COMMENTS
Packing support ring in column		Delamination between the support ring and column laminate	Ok after new design of support ring
Drain nozzle in tank		Delamination in the laminated joint between nozzle and tank	
FRP Reactor tank		Internal baffle support did break	Vessel ok after design reconfigurations
Tank 5,5 m high x 4 m diameter, Thermoplastic lined	Tested with water	Leakage	
Flat bottomed tank 8m high x 4 m diam	Hydrochloric acid	Deterioration of laminate	Retest after 2-3 years
400 mm vinylester pipe	Salt water	Delamination in flanges	Renew all flanges

E.3 GENERAL

Stress waves, commonly called acoustic emission (AE), are generated in materials as a result of a sudden, inelastic, local change in stress level, accompanied by inelastic deformation. The phenomenon is well known from the fracture of timber and rock. It is also an industrialised and practical method for NDT of structures like concrete bridges, heat exchangers, steel tanks, aircraft prototypes in all materials, GRP tanks, GRP pipe lines, GRP booms for bucket trucks. Acoustic emission testing of GRP tanks and piping is established as standardised inspection methods in the US industries and many thousand tests have been performed in the past.

Several standards exist which can be followed to test GRP products.The major differences between acoustic emission and other NDT-methods are:

- It is a passive method - the product/component itself generates the sounds used for inspection
- Loading of the product to the standard operating conditions is necessary (e.g. pressurising to nominal pressure or filling to maximum volume).
- At a constant load level it will only detect active and critical material processes i.e. crack and delamination growth, fiber fractures, corrosion attack.

If the product is “silent” at the maximum load it is a sign there are no structurally significant defects present. There might be other defects in the product, but if they are non-propagating they will not generate any sound.

The practical test methods are based on the following principles:
- Loading in steps with periods of constant load
- Zonal location - one sensor covers an area around itself and will be first hit by sound sources in its vicinity.

AE has the advantages of being a passive, global surveillance technique with remote sensing capabilities, which can be used for simultaneous monitoring of an entire structure. It's use has become widespread in quality control of filament wound tanks. It is estimated that several thousand tank tests have been done over the years in the US industries. Also critical pipe systems have been tested.

For composites the typical frequency ranges for sensors and preamplifiers are 100-300 kHz. The technology is thus quite similar to the equipment used in ultrasonics.

For field testing of GRP products special multichannel field equipment is available.

An example of an idealized acoustic emission wave form and definitions of simple wave form parameters are shown in Figure E.1. Signal analysis is normally based on event counting, ring-down counting, amplitude analysis, energy analysis, event duration and rise time.

Several AE test procedures, including evaluation criteria, have been adopted as recommended practices for testing GRP tanks/vessels [1] and pipe systems [2]. Test equipment which fulfills the requirements given in these practices is commercially available, and some initial tests have been performed on offshore platforms [3].

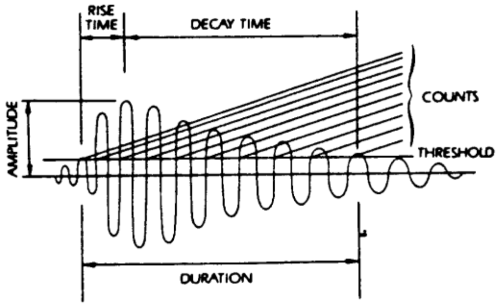


Figure E.1. An idealized representation of an acoustic emission signal and definitions of simple waveform parameters.

Figure E.2. Guidelines for sensor placement during AET of pipe systems [from 2].

Figure E.3. Example of pressurising sequence for proof testing of GRP pipe systems [from 2].

E.4 AREAS FOR FURTHER DEVELOPMENT

For offshore usage there are some aspects that need more focus:
- Development of lightweight instrumentation
- Development of EX-proof equipment to be able to operate in hazardous areas

E.5 INSPECTION PROCEDURE

The testing of a GRP pipe system will include the following operations:

- Identify and place sensors in critical or highly loaded locations of the pipe system, e.g. as shown in Figure E.2 [from 2]
- Calibrate the sensors
- Record background noise
- Load the pipe system by pressurising in accordance with a pre-defined sequence, see Figure 6 [from 2].
- Evaluate results according to the acceptance criteria
- Recommend the pipe system for further use or reject
- Based on zonal location the system will give information where the critical area was (e.g. which channel was most active)

E.6 REFERENCES

1) Standard E1067-89: "Practice for Acoustic Examination of Fiberglass-reinforced Plastic Resin Tanks/Vessels", Annual Book of ASTM Standard, Vol 03.03, Philadelphia, PA, 1989.

2) Standard E1118-86: "Practice for AE Examination of Reinforced Thermosetting Resin Pipe", Annual Book of ASTM Standard, Vol 03.03, Philadelphia, PA, 1986.

3) Melve B.: "Acoustic Emission Testing Trials Onboard Offshore Platforms", Fifth International Symposium on Acoustic Emission From Composite Materials, Sundsvall, 1995.

4) M.J. Peacock, S Stockbridge (DNV Industry INC.), "Commercial FRP Testing - Some Case Histories", Fourth International Symposium on Acoustic Emission From Composite Materials, Seattle, 1992.

5) P. Conlisk, "Design Improvements in FRP Chemical Process Equipment Resulting from Acoustic Emission Examination", Fourth International Symposium on Acoustic Emission From Composite Materials, Seattle, 1992.

ANNEX F

ACCEPTANCE CRITERIA FOR DEFECTS IN ADHESIVE JOINTS AND GRP PROCESS SYSTEMS

F.1 ADHESIVE JOINTS

F.1.1 SCOPE

This discussion of acceptance criteria applies to the adhesive joints schematically shown in Fig. F.1. For laminated (i.e. butt and strap) joints these acceptance criteria only apply to the bond achieved on the laminated surface; the thickness and lay-up of the laminated "strap" must be separately verified by e.g. good quality control procedures and visual inspection. No deviation from manufacturer's recommendations shall be allowed since thickness and proper lay-up are critical for laminated joint strength.

Fig. F1: Different types of joints - a) bell and spigot, b) muff, c) adhesively bonded flange, d) butt and strap, e) taper-taper

F.1.2 ACCEPTANCE CRITERIA

a) General:

These acceptance criteria may be applied during the manufacturing, prefabrication, installation and commissioning, or operational phases (Refer to Parts 3-6).
Recommended corrective actions are listed where appropriate.

The importance of properly following joining procedures and the use of good quality control procedures during fabrication and installation needs to be emphasized. The best way to avoid questions about whether an adhesive joint is good enough is to make it correctly in the first place.

b) Visual Appearance:

- GRP pipe, fitting, and tank defects (cracks, blisters, porosity, etc.) are addressed by Annex A. The acceptance criteria given in Annex A shall apply.

- Fillet appearance shall be as shown in Fig. F2. The fillet should be slightly concave (indicates good filling of the joint and that the adhesive has correct viscosity). A convex fillet shape points to an adhesive problem since the contact angle indicates incompatible materials. Acceptance criteria and corrective actions shall be as given in Table F1.

Table F1: Acceptance criteria for visual inspection of adhesive joints

Defect	Criterion	Procedure
Shaved part not covered with resin/adhesive	Areas larger than 2 cm^2.	Cover area with resin.
Adhesive not filling the joint	Max. 2 cm diameter.	Fill with resin. Larger defects: New joint.
No adhesive showing on the inside	Not accepted.	
Excess of adhesive on the inside	Not accepted. (See Annex A.)	Check filling of joint with ultrasonic inspection or other methods.

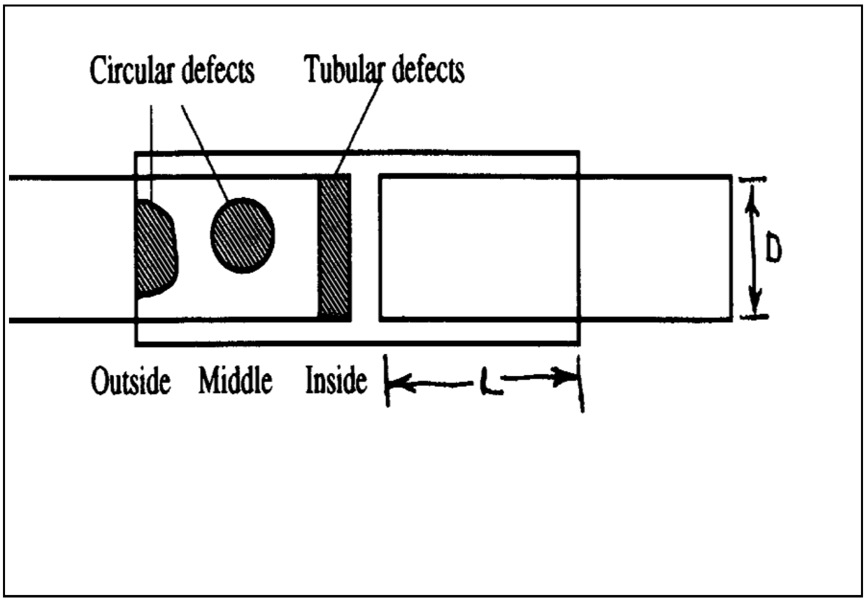
c) Lack of Adhesive or Adhesion:
The following acceptance criteria (see Fig. F3) shall apply when either voids or poor adhesion are present:

Total defect area < 25% of total joint area, and:

(i) the non-defective axial adhesive length is > 20% total joint length,
(ii) any defect intersecting the inside edge of the joint < 30% total joint length (up to 200 mm DN) and < 10% (from 200 to 600 mm DN)

F.1.3 BACKGROUND:
The acceptance criteria given above for voids and poor adhesion (item c) are based on [1] which is limited to GRP pipes with diameters of 150-200 mm, containing room temperature water under static pressures of 10-16 bar. Additional work suggests that this work is more generally applicable as outlined below.

The definition of defect geometry and position in the joint given in Fig. F3 will be used in discussing extension of the acceptance criteria to larger diameters, long term- and dynamic-loading. Note that a minimum of 20% of the joint length must be well bonded for all cross-sections so that no leak paths are formed.



L - overlap length of joint
D - diameter of pipe
t - thickness of pipe, fittings and adhesive layer

Fig. F3. Position and type of the defects in the adhesive joint.

The position of the defect has a large influence on its significance in a typical adhesive joint. The critical crack length is predicted by Finite Element Analysis (FEA) to be ca. 85% of the total joint length (for a 200 mm muff subjected to static pressure loading), with the crack originating at the inside joint edge being most critical [2]. Both experimental tests (on 100 mm muff joints) and FEA show that for short-term loading the joint is quite defect-tolerant [3].

The unstable joint containing the most critical defect (an inside tubular defect covering 85% of the joint) still burst at 2.2 times the design pressure. The experimental and FEA results showed that this joint type can pass the short-term loading criteria (3 x design pressure) with a defect (at least 30% of the total bonded area) located anywhere in the joint.

An extension of the above FEA work to larger diameters (up to 600 mm) has been made by deriving an average shear stress from internal pressure (biaxial loading) and axial loading (e.g. temperature loads), which give different stress distributions with respect to peel stresses. This value can then be used to calculate the overlap lengths needed in joints of varying diameters, which in turn can be compared with manufacturers' actual joint lengths. It is seen that the safety margin decreases for many manufacturers' products as diameter increases. This result is the justification for modifying the acceptance criteria [1] by imposing a tighter limit for the 200-600 mm diameter range. The applicability of the acceptance criteria can also be seen by considering a failure of a severly-misaligned (2.5^o), 600 mm DN, taper-taper bonded joint. This 20 bar joint failed due to misalignment and very poor surface preparation prior to bonding. Interestingly, it failed during pressure testing at 16 bar even though there was a signifcant lack of adhesion (i.e inside tubular defect of 90-95%). If this failure were scaled to match the 85% defect noted above, the burst pressure would likely have corresponded (or been only slightly less) than for the 100 mm muff joint. Thus, the acceptance criteria given above should be conservative for static, short-term loading of large diameter joints.

Dynamic loading has been applied to various 25 bar, 100 mm joints, pipes, and fittings [4,5]. These studies have produced indicative fatigue curves at both 25 C and 95 C. For PN muff joints typical P-N values are 10^4 cycles at 70 bar and 10^5 cycles at 60 bar, while bell and spigot joints typically endure 10^3 and 10^4 cycles at the same pressures. Temperature does not appear to significantly shift the fatigue curve.

The effect of long-term loading (ASTM D2992 cyclic, 25 cycles/min.), temperature (95 C), and defects (nominally 50% inside tubular and oil-contaminated adherends) on the recommended acceptance criteria can be seen from unpublished data made available by Statoil. This data shows a short-term weeping pressure of 90 bar and a short-term burst at 95 C equal to 72 bar for the 200 mm bell and spigot joints tested. The effect of adding the 50% inside tubular defect was a drop to 44 bar short-term burst at 95 C. The non-defective joints withstood a minimum of 22,538 cycles from 0 to 35 bar at 95 C, while the joints with 50% inside tubular defects withstood a minimum of 117 cycles. The effect of oil-contaminated surfaces was intermediate, since reasonably good bonding occurred on most specimens. Subsequent sectioning of the failed specimens showed that rather than the nominal 50% inside tubular defect, some portions of the defect covered up to 93% of the joint insertion length. A leak path was thus easily formed once the adhesive on the outside of the joint failed.

It should be noted that even with such a severe defect at elevated temperatures, the adhesive joint was able to withstand more than one hundred cycles at 1.75 times its design load. Consequently, the recommended acceptance criteria are considered to be conservative.

F.2 DELAMINATIONS AND IMPACT DAMAGE

Delaminations should not be built into a new system. However, if they are found late in the project or in installed systems they may be accepted. The delamination should not go out to any open surface. For straight portions of the pipe, delaminations does not influence much on the stiffness and strength. However, in bends and other places with bending stresses the delaminations shall not be accepted.

F.3 GRP PROCESS SYSTEMS

F.3.1 SCOPE

This section provides acceptance criteria for aspects of GRP process systems that are not covered elsewhere in this document.

F.3.2 ACCEPTANCE CRITERIA

a) <u>Penetration of the process media through the barrier layer</u>:- None.
The structural laminate shall not be exposed to the process medium. The chemical barrier layer must be thick enough to compensate for:

- material depletion caused by corrosion/ erosion
- preventing loss of mechanical performance not arising from material depletion
- depth of cracks and blisters

b) <u>Cracks in the thermoplastic lining of dual laminate (lined GRP) constructions</u>:
crack depth < 10% of thermoplastic wall thickness.
c) <u>Debonding between a thermoplastic lining and the structural GRP</u>: - None.
d) <u>Cracks in non-reinforced thermoplastic pipes</u>: - None

For process units classified as "Critical", and where the process conditions are aggressive to the material, immediate action is generally recommended (e.g. material evaluation, additional inspection, repair or replacement). For process equipment classified as "General" and containing non-aggressive process media, a postponement of action until the first convenient opportunity may be acceptable. It is often desirable that repair or replacement is performed during the following maintenance shut-down. In some cases, a temporary solution based on structural reinforcement, or restrictions i operating conditions may be acceptable, but only if consequence analysis supports such action with regard to safety, operational feasibility, process regularity, costs and materials technology.

F.4 AREAS FOR FURTHER DEVELOPMENT

The effect of simultaneous bending and pressure loading of piping systems needs to be further investigated. Although the acceptance criteria given above for bonded joints is believed to be conservative enough for pressure loading to also allow for bending, the amount of allowable bending should be quantified.

F.5 REFERENCES

[1] Report No. GVK 95-94, "Adhesively bonded and laminated joined glass fibre reinforced pipe systems", G.A.M van den Ende, E. Kokmeijer, P.P van 't Veen, April 1995

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ANNEX G

DIFFERENTIAL SCANNING CALORIMETRY (DSC) AND BARCOL HARDNESS TESTS

G.1 MAIN DETECTABLE DEFECTS

- Improperly mixed or cured adhesive in bonded joints (DSC)
- Improperly mixed or cured laminate in laminates or laminated joints (Barcol)

G.2 GENERAL

DSC is a quantitative , accurate and relatively fast semi-non-destructive technique which is based on the measurements of thermal changes related to phase transitions and chemical reactions, such as the curing of thermosets. The method was used in Norsk Hydro's Brage project for control of the degree of cure of two-component epoxy adhesive in bonded GRP pipe joints. Small samples can be cut from the external adhesive seams of the joints for measuring the glass transition temperature, Tg, by DSC analysis.

Barcol hardness is a similar method for measuring the degree of cure in e.g. vinylester laminates or laminated joints.

G.3 INSPECTION PROCEDURE

DSC testing shall be performed in accordance with Part 2, Section 4.3.2 of Ref. [2]. Barcol hardness testing shall also be performed in accordance with Ref. [1].

ANNEX H

THERMOGRAPHY

H.1 MAIN DETECTABLE DEFECTS

- Scale build-up (in pipes)
- Major deviations in wall thickness
- Areas in the joint lacking adhesive

H.2 LIMITS OF DETECTABILITY

Various researchers have demonstrated thermography test methods, particularly with small diameter piping systems. Perhaps the most successful applications have been those where the defect enhances the thermal gradients on which this method relies. Examples are scale build-up in, or erosion of, pipes carrying heated media. In addition, some researchers have claimed success in detecting voids in adhesively bonded joints, although resolution is not as good as with ultrasonic or radiographic methods. A summary of detectable defects follows:

DEFECT TYPE	DETECTABLE SIZE (1)	METHOD [SOURCE]	PIPE DIA./ DEFECT DEPTH	COMMENTS
Erosion	5 to 10 mm	AGEMA 900, internal hot water	100mm dia. joint (ca. 12 mm total wall)/7.5 mm from outer surface	
Erosion, thin wall	5 to 10 mm	AGEMA 900, external hot air, internal cold water	6mm wall / ca. 5 mm from outer surface	
Simulated wall thinning	ca. 20 mm width	AGEMA 900, hot water at back surface	15mm thick flat plate/ 1-14 mm (sloping machined slot)	detectable to ca. 10 mm depth from front surface
Lacking adhesive, voids		AGEMA, [1] radiant heating	/15-17 mm (total thick?)	TIME TO TEST 6-8" JOINT (INCL. HEATING) = 0,25 HRS Temp.diff.=ca. 40C (surface temp.=60-65C)
- Lacking adhesive - Impact delaminations	?? ca. 75 x 75 mm delamination	AGEMA 900, radiant heating	50,100,200, 400 mm pipe, bends, tees/?? (200mm thick tee)	400 mm results more difficult to achieve. Temp.diff.=ca. 25C (surface temp.=45-50C)
- Lacking adhesive - Impact delaminations	-detectable, but not quantified -damage caused by 1176 Joule, hemispherical indentor	Agema, radiant heating (1000W)	25 bar, 100 mm dia. GRE bonded coupler/bondline /impact on exterior surface	-difficulties with interpretation and consistency - Visual inspection found 7Joule and 14 Joule damage also.
Lacking adhesive, voids-	20 mm 10 mm	AGEMA 900, hot water	-10 mm thick flat plate/9 mm -10 mm thick flat plate/5 mm	Temp. differential =20 C over ambient temp.

Notes: (1) Minimum detectable defect diameter is given (unless otherwise noted).

It can be seen from the above that voids and areas lacking adhesive can be detected to resolutions of ca. 20 mm and to depths of ca. 10 mm given a 20 degree C temperature difference between the inner and outer surface, although interpretation can be difficult. Areas of poor adhesion, i.e. "kissing bonds" will not be reliably detected by this method. It is possible to detect either smaller or deeper defects by increasing the temperature difference within limits as discussed in H.3. Variations in wall thickness can also be detected, with similar limits of resolution as for voids.

H.3 GENERAL

Various infrared scanning/inspection systems have been developed in recent years by e.g. AGEMA. These systems comprise a portable, high resolution camera, with computer aided condition monitoring program that provide excellent thermal images. This allows non-contact measurements of surface temperatures to be made and imaged for relatively large areas. In addition, polished metal mirrors enable thermal images of less accssible areas to be made. Infra-red (IR) thermography systems have been successfully used offshore to e.g. map scale build-up in piping systems.

The test method entails induced or forced heat (or cooling) to the inner surface with IR inspection applied to the outer surface. As the heat is conducted through the material, defects will become detectable on the outer skin as "hot" or "cold" spots in a thermal pattern. Section H.5 provides recommendations for heating (or cooling) typical small diameter piping systems (<250 mm). Alternatively, the single sided method can be used whereby the IR camera and heat source are located on the same side. In general the single sided method is more suitable for detecting defects close to the surface, and the double sided method is better for deeper defects.

The time in which the heat transfer occurs is crucial. If the heat is supplied too slowly the material's thermal conductivity will allow the temperature to even out through the material (including any defects) so that resolution is reduced.

Because the thermal conductivity is lower for GRP than steel, the resolution and depth of measurement is somewhat limited, but thermal patterns dwell for a longer time. For single-sided measurements, an empirical rule [2] states that the maximum expected ratio between depth position and flaw size is 0,6. When measurements are performed with the heat source and IR camera on opposite sides of the test specimen, the obtainable ratio between depth position and flaw size increases to 1.2. For representative GRE pipe joints (e.g. PN 25 bar/DN 100 mm) flaws in the bondline will typically be located ca. 6 to 9 mm from the external surface, and vary from 0,1 to 1,0 mm in thickness (e.g. adhesive lacking on bondline). These values, compared with the above-mentioned empirical ratio, suggest that bondline flaws can be difficult to detect in practice. One researcher has confirmed this result and found that visual inspection is more effective for finding impact delaminations [3].

H.4 AREAS FOR FURTHER DEVELOPMENT

Further work is needed to determine the upper limits of resolution for GRP wall-thickness, defect size, and depth and to correlate these with applied temperature differences. Particularly bonded joints in the range of 250 mm to 750 mm need to be tested.

H.5 DRAFT INFRARED (IR) THERMOGRAPHY INSPECTION PROCEDURE

H.5.1 Scope:

This test method applies to pipes and tanks, either following prefabrication, installation, or during operation. Methods of heating or cooling of the piping system need to be chosen to match the specific situation, and will often depend on whether the system is in operation or not.

H.5.2 Equipment:

Several types of thermal imaging systems can be used to perform inspections. A system with 0.1 degree C resolution is recommended.

H.5.3 Heating and cooling:

H.5.3.a Installed pipes in normal cold condition mode:

External heating is required for pipes that are installed and carrying a cold substance, e.g. water. The test area (e.g. adhesive joint, pipe wall) must be heated to induce the necessary change in heat variations, and the cold substance needs to flow to ensure a constant cold source.

When the test object has been heated and the heat source is removed, the heat conduction will be towards the cold inner surface of the pipe. Inspection is then performed according to C.5.5. Voids or missing adhesive will show as a hotter areas due to delay in heat conduction.
The outer surface of the pipe should be warmed up at least 10 degrees C above the temperature of the contained fluid for small diameter GRP pipe (< 250 mm). Other temperature differentials shall be chosen as necessary to accommodate other pipe diameters.

H.5.3.b Installed pipes in normal hot condition mode:

External cooling is required for pipes that are installed and carrying a hot substance, e.g. water heated up in a heat exchanger. The area being investigated for defects (e.g. an adhesive joint, pipe wall, etc.) must be cooled down to induce the necessary heat flux variations, while the hot fluid needs to flow to ensure a constant heat source.

When the coolant is removed, the heat conduction will be towards the hot inner surface of the pipe. Inspection is then performed according to C.5.5. Voids or missing adhesive will show as a colder areas due to delay in heat conduction.

The outer surface of the pipe should be cooled at least 10 degrees C below the temperature of the contained fluid for small diameter GRP pipe (< 250 mm). Other temperature differentials shall be chosen as necessary to accommodate other pipe diameters.

H.5.3.c Prefabricated pipes prior to installation and commissioning :

Pipe spools may be tested individually or as partially-installed systems. In this case, they will not typically contain a fluid which can be used as either a heat source or heat sink. Thermography may still be used as inspection method provided that a comparable heat or cooling source is used. For example, a heating coil with 700 Watt capacity max. and 220 Volt variable power supply can be used as an internal heat source for small diameter GRP pipe (<250 mm). The maximum temperature of the heat supply to the material surface shalll be determined from the pipe manufacturer's materials specifications. Surface temperatures of 45-65 C (i.e. temperature differentials of ca. 20-45 C) have typically been used on GRP pipe heated by radiant heaters; these values should be used as a starting point, but should be modified as needed to give sufficient contrast for good defect detection. Care shall be taken (with e.g. thermostat sensors controlling the heating coil and placed close to the pipe surface, and guidance and positioning devices) to ensure that the material will not be overheated and damaged, or directly contacted by the heater. Two thermostat cut-off sensors should be connected in serial with each other and the power supply, since this ensures a double safety against overheating.

H.5.4 Safety procedures:

Care shall be taken to ensure that no harm to personnel or piping systems result from improper heating or cooling.

Guidance and positioning systems shall be tested and found adequate to support the heating element (if used) in a secure position during the operation. In addition to the positioning device a separate safety device shall prevent the coil from direct contact with the GRP material.

H.5.5 IR testing of adhesively-bonded GRP pipes:

If a heating coil is used:

i) Determine pipe inner diameter and set heating coil centralizing device accordingly.
ii) Check that the number of heating coils is correct for the pipe size being tested. (4" to 6" pipe require both elements in serial to reduce the total heating effect. 8" to 10" pipe require full heating capacity with elements in parallel).
iii) Determine the length from the end of the pipe to the joint and fit a stopper on the supply cable at the correct length.
iv) Check that centralizing device is functioning and moving freely at the end of the pipe prior to testing.
v) Test the heating coil at the end of the pipe prior to testing, and that power supply regulator is working.
vi) Insert heating coil with power off and place it the in correct position.

Regardless of heating source used:

vii) Ensure that the area being investigated is heated or cooled as outlined in H.5.3. Heating or cooling shall be uniformly applied to the GRP surface, since non-uniform heat inputs will give false defect indications.
viii) Pipe surfaces shall be dry to avoid false indications resulting from evaporation of water droplets. The effect of nearby warm bodies shall be removed (e.g. with shielding or non-reflective coating applied to the GRP) to avoid extraneous radiation affecting inspection results.
ix) When in position start supplying the heat to the joint and immediately start the temperature monitoring of the joint with the thermographic inspection camera.
x) Inspection is performed until the surface has a temperature of approx. 65 degree C (if internal heating is used). If external cooling is used inspection is performed until the surface has returned to within 20 degrees of ambient temperature.
xi) Inspection results shall be documented during the period of most contrast (typically within the first ca. 10 minutes).

xii) Thermograms of defects shall be stored on diskette, along with one joint without defects for later reference. Report size and location of defects.

H.6 REFERENCES

1) IR-Inspection of Composite Material Pipes, K. Ingebrigtsen.

2) Clarke B., Rawlings R.D.,Cawley P., Milne J M: "Non-Destructive Testing of Composite Materials", Course literature, Centre for Composite Materials, Imperial College, London 30 January - 1 February 1990.

3) Condition Monitoring of Process Equipment Made from Plastic Materials, B. Moursund, Norsk Hydro, 1995

ANNEX I

SAMPLE INSPECTION STRATEGY

I.1 GENERAL

This sample inspection strategy is included as a possible guide for those Guideline users who wish to develop a very comprehensive inspection strategy. It is not just limited to seawater, but also includes chemical process plant equipment, and deals with other issues like inspection to extend rated service life . The visual inspection frequencies for critical and non-critical seawater systems in Table 2.3 are generally deemed to be appropriate for GRP seawater systems, as noted in Part 2, Section 1.4. Although many such systems have functioned well with few to no in-service inspections, the recommended visual inspections are neither very time-consuming nor costly.

I.2 RECOMMENDATIONS FOR CONDITION MONITORING OF PLASTIC PROCESS EQUIPMENT

I.2.1 Scope

This strategy covers GRP process equipment currently used with a wide variety of process media, such as ammonia, various acids, sodium hypochlorite, etc. The process equipment includes tanks/vessels, pressure vessels, columns, pipes and fittings, gas ducts, pumps, valves, filters, heat exchangers, and inner linings. A strategy covering only seawater piping and tanks will be a good deal simpler.

I.2.2 Recommendations for inspection

Table I.1 proposes inspection programs based on the likelihood of defects or degradation occuring and the criticality of the system. The interactions between materials and process conditions shall be considered when selecting condition monitoring methods. This is likely to entail a comprehensive materials engineering evaluation that considers the most probable failure/degradation mechanisms (and defects from Part 2, Table 2.1). Relevant NDT methods should be selected while bearing in mind the possibilities and limitations for each method as outlined in Annexes A through H. A combination of several methods may be required in order to achieve safe and cost effective utilization of the plastic process equipment. Inspection intervals are given in Table I.2.

The selection of inspection program shall be based on a thorough evaluation of the consequences of failure. Assessment of the likelihood and severity of failure can be based on previous experience, material properties, design of process units, operating process conditions, etc. This sample inspection program includes the use of destructive testing of material samples to characterize long-term material degradation under the most agressive operating conditions, and as a means to extend GRP equipment past its rated life. Such material samples should be representative of the equipment in-service, i.e. by testing a pipe sample removed from service, or by testing coupons which have been exposed to the same media and stress levels that are seen in service. When the initial materials engineering evaluation indicates that destructive tests are required, the same test methods as those used to pre-qualify the material should be used. It should be noted that even in the chemical industry this level of inspection is seldom required, since suppliers and other users often have extensive experience with GRP equipment in similar applications.

Table I.1 Selection of inspection program

Equipment class	Likelihood and severity of failure		
	High	Medium	Low[1]
Critical	A	B	C
General	C	C	D

Notes:

[1] Seawater systems are typically Program D, and sometimes Program C, since these systems have a demonstrated low probability of failure once comissioned. When failure occurs it is most often limited to weeping (i.e. a low-flow leak through the GRP pipe/tank wall) or leaking gaskets/joints which do not impair function.

Table 2.3 Recommended NDT Methods and Inspection Intervals

	INSPECTION PROGRAM:			
	A	B	C	D
INSPECTION METHODS	-Visual inspection, internal / external - Other NDT (most suitable method for degradation mechanisms) -Destructive testing of material samples exposed to the actual process conditions	-Visual inspection, internal / external - Other NDT (most suitable method for degradation mechanisms) -Destructive testing of material samples exposed to the actual process conditions	-Visual inspection, internal / external - Other NDT (most suitable method for degradation mechanisms) -Destructive testing of material samples exposed to the actual process conditions	-Visual inspection, internal / external
INSPECTION FREQUENCY: * First Inspection (yrs after start of service) * Inspection interval (yrs)	* 0,5-1 * 1-2	* 0,5-1 * 2-3	*1-2 * 0,2 x service life	*1-2 * 0,3 x service life
COMMENTS:	- Inspection interval shall be reduced if results from previous inspection show severe degradation - All inspection methods listed shall be applied during every inspection - Inspection program B can be applied when sufficient confidence in the material and construction performance has been gained. At the earliest, this should be considered after 5 years service.	- Inspection interval shall be reduced if results from previous inspection show severe degradation - All the inspection methods shall be applied during the first inspection, while the following inspections can alternate between destructive and non-destructive methods. - Inspection program C can be applied when sufficient confidence in material and construction performance has been gained. At the earliest, this should be considered after	- Inspection interval shall be reduced if results from previous inspection show severe degradation - Destructive testing is required if the service life has extended beyond the originally estimated service life Inspection. - Program D can be applied to process equipment classified as "General" when sufficient confidence has been gained. At the earliest, this should be considered after 5 years service.	- Destructive testing is required if the service life has extended beyond the originally estimated service life

		3 years service.		