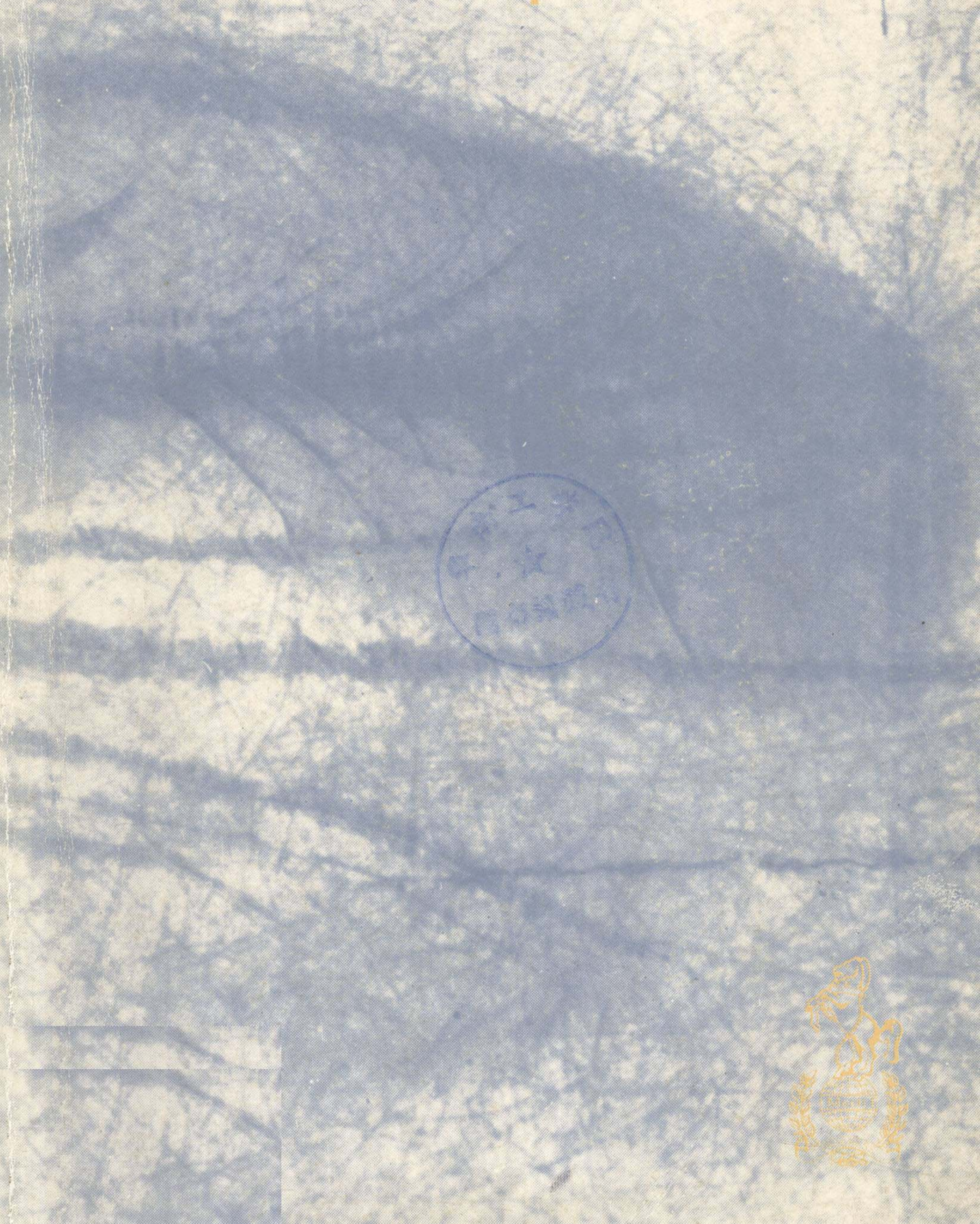
GRP VESSELS AND PIPEWORK
for the chemical and process industries



GLASS REINFORCED PLASTIC VESSELS AND PIPEWORK FOR THE CHEMICAL AND PROCESS INDUSTRIES

A joint one day symposium sponsored by UMIST, the Institution of Mechanical Engineers and the Institution of Chemical Engineers

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R. T. MOLD
BP Chemicals Ltd

INTRODUCTION

In June 1977 a meeting was held at the Rubber and Plastics Research Association (RAPRA) to discuss the need, felt by many in the industry, for the development of design rules to cover GRP piping systems for use in the chemical and process industries. The attendance at this meeting was considerable – which in itself indicated that the need was widely felt – and included many material suppliers, GRP piping fabricators, and users.

A commonly held view, strongly expressed at the meeting, was that the absence of any national or international design code for GRP piping systems was a major cause of the lack of confidence in the material felt by engineers, which resulted in a brake on its wider use. The meeting agreed to set up a multi-sponsored research project, funded jointly by the sponsors and the Government (via the Requirements Boards) to produce a standard for GRP piping systems, in the same way that BS 806, BS 3351, and ANSI B31.3 cover metallic piping systems. It was hoped that this document would eventually be accepted by the British Standards Institution (BSI) as a British Standard.

PROJECT ORGANIZATION

It was recognised that BS 4994 and an existing draft British Standard on GRP pipe give some relevant data for the design of straight pipes under internal pressure. However, these give no guidance on the effect of pressure on other piping components such as bends and tees, or on how to design the piping system to cope with the end loads and bending stresses arising from thermal expansion.

A research project was therefore set up at RAPRA and the National Engineering Laboratory (NEL) to determine stress intensification, flexibility, and pressure stress multiplication factors for tees, bends, and straights of various constructions and sizes. This work, which is now completed, was coordinated and kept under continual assessment by the Design Methods Working Party which included representatives of fabricators, users, and the research establishments. This working party was responsible to the management committee which has overall control of the project on behalf of the sponsors.

A second area recognised as needing very careful consideration was the choice of design strain, or design stress, for the piping system when working in a specific environment. A second research programme was therefore organized – again at NEL and RAPRA – to determine fatigue and creep rupture data for a range of environments and laminates. This work, which is not yet finalized, is being monitored by the Design Stress Working Party which again reports to the management committee.

The Management Committee also recognized that if GRP piping was to become more widely specified by operating companies, quality control techniques were needed that would give the user the same degree of confidence as he could get for metallic piping systems. A third working party covering quality control and non-destructive testing (NDT) was, therefore, set up to review the available procedures and techniques and determine what further work, if any, was required in this field.

A fourth working party has recently been set up to coordinate the work of drafting the proposed code prior to submission to BSI. This group is taking the results of the work of the research programmes and of the other three working parties and, it is hoped, compiling them into a complete and coherent document.

RESEARCH WORK

Bends

In order to obtain data for the stress intensification, flexibility, and pressure multiplier factors for bends, some 13 sets of bends and equivalent straights were tested at RAPRA for both in-plane and out-of-plane bending, with and without internal pressure. About 60 per cent of the specimens were made from glass in the form of chopped strand mat

(CSM), this being considered to be the most common construction for chemical and process industry piping, the remainder being constructed from glass in the form of woven rovings. A wide variation of nominal sizes, bend radii, and glass weight were covered, and smooth and mitred bends were considered. The effect of PVC liners was also included within the programme.

Each set of specimens consisted of two or three samples of bend together with up to three equivalent straights. It was found necessary to strain gauge both the internal and external surfaces in order to take into account the effect of local bending due to variations in stiffness. All this testing is now complete.

Tees

A similar programme to that described above has been carried out by NEL on a range of tees and corresponding straights.

Fifteen sets of tees and equivalent straights were tested, with in-plane and out-of-plane loading of the trunk and compression of the branch being the loading modes covered; in all cases the load was applied through the branch. The samples covered a range of variations of construction, main diameter, branch diameter, and glass weight, and included specimens with PVC liners. Tests were carried out both with and without internal pressure and, as for the bends, strain gauging was carried out on both the inner and outer surfaces.

Fatigue and creep rupture tests

A programme of tests was agreed with the aim of obtaining as much data as possible on the effect of environment on safe design strains for GRP, and also of seeing whether relatively short term tests could give reliable guidance on the long term effects of the contained fluid on the properties of the laminate, and so form the basis of design strain data.

A series of long term creep rupture tests, together with fatigue tests, were therefore carried out on a range of samples. The creep rupture samples were 4 in. pipes, 1 m long, constructed in CSM, CSM/WR, and CSM/FW using both bisphenol and isophthalic resins. Six environments were used to fill and pressurize the specimens. These were water, mineral oil, alcohol, perchloroethylene, dilute caustic soda, and dilute sulphuric acid, and were chosen as being typical of the environments frequently found in GRP piping in the chemical and process industries. Tests were carried out at two temperatures – ambient and 10°C below the heat distortion temperature for the resin.

The fatigue test specimens were made from flat sheet and were around 1 in. wide and $\frac{1}{4}$ in. thick. These were made of the same constructions as were used for the creep rupture tests and were tested on the same environments. Loading was by repeated tension at constant frequency (25 Hz).

RESULTS

The results of all the testing carried out at RAPRA and NEL are confidential to the sponsors of the programme and, hence, cannot, unfortunately, be given here. The conclusion drawn from them will, of course, become available if, and when, the design code is accepted by BSI for publication.

DESIGN CODE

Work on drafting the code continues, but most of the sections are now complete to the satisfaction of the working party, apart from minor editorial details. The code includes rules for the determination of design strain, design for pressure containment, flexibility analysis, general layout requirements, fabrication, quality control, and inspection. The details of these requirements are also confidential to the sponsors and so cannot be given at this stage. We are confident, however, that when the code is published, in whatever form, it will be accepted as providing a major contribution to the safe and economical design of GRP piping for the process and chemical industries.

2 Inspection authority views

F. E. LAWRENCE
National Vulcan Engineering Insurance Group Ltd

The paper includes brief references to previously emphasised important points of principle regarding materials, design, fabrication, inspection and testing.

Comments are also made respecting proposed revisions to BS 4994, some aimed at clarifying 'grey areas', thus producing a more practical approach to construction and inspection requirements.

Quality assurance principles are discussed, including the relevance of the Pressure Vessel Quality Assurance Board (PVQAB) activities.

INTRODUCTION

Plastics may be reinforced by quite an appreciable number of materials, but the most commonly used is glass-fibre. Glass reinforced plastics (GRP) are plastics materials which have largely withstood the test of time, despite some problems, a number of which have arisen out of a lack of design and fabrication expertise; also an inappropriate choice of lining materials, which have led to operational failures. A further source of failures is mechanical damage – for example, during installation and/or the incorrect supporting of valves, etc.

As already implied, it is essential at the outset that there be a clear understanding among all the parties concerned with regard to the intended use of a vessel or tank at the time it is being ordered. It is further to be borne in mind that once the design concepts have been agreed, information must be accurately conveyed to those on the workshop floor who have the task of producing the product.

Approval of design and drawings should be undertaken prior to commencement of fabrication, which may seem an obvious comment, but experience has shown that this is not always done and can often lead to arguments about the specification later, which gives rise to unnecessary problems.

In his own interests, the purchaser should bring his influence to bear in the foregoing context, because practice shows that orders are normally placed on price alone, prior to the involvement of an inspecting authority and often without proper regard to the adequacy of the design being offered. Once progress has been made, it is extremely difficult to verify compliance with the specification.

CATEGORIES OF VESSELS AND TANKS

It is proposed that inspection and testing requirements for vessels and tanks be inter-related by the establishment of 'categories' taking account of hazards and other factors, such as:

(a) the contents;
(b) knowledge of compatibility of the contact material with the contents;
(c) the design temperature;
(d) the design pressure/vacuum;
(e) the size of vessel;
(f) the geometry and method of supporting the tank/vessel.

Table 2.1 indicates the proposal for suggested 'categories' which will doubtless provoke discussion. It is known that there are some

Table 2.1 Categories of vessels or tank

	Category I	Category II	Category III
Contents (for definition see below)			
Toxic	*		
Highly corrosive	*		
Corrosive	*	*	*
Flammable	*		
Others		*	*
Chemical compatibility of liner with process fluid			
Known long term compatibility based on service experience		*	*

Table 2.1 (*continued*)

	Category I	Category II	Category III
Compatibility based on related performance data	*	*	
Only specimen data (dip coupons) available	*		
Design temperature			
$T < 60°C$ and $T <$ (HDT − 40°C)		*	*
$T \geqslant 60°C$ and $T \leqslant$ (HDT − 40°C)	*	*	
$T >$ (HDT − 40°C) and $T \leqslant$ (HDT − 20°C)	*		
Design pressure and/or vacuum			
Static head only		*	*
$< \pm 5$ mbar		*	
$\geqslant \pm 5$ mbar	*	*	
Size of vessel or tank (capacity)			
$< 10\ m^3$			*
$20\ m^3 <$ capacity $\geqslant 10\ m^3$		*	
$\geqslant 20\ m^3$	*	*	
Geometry and supports			
Flat bottom full support			*
Any other, e.g., legs, skirts, saddles, rings, and frames	*	*	
Other criteria			
If item is critical to plant	*		

Definition of contents classification

Toxic:	The contents, if leaked, could present a significant risk to health of persons exposed.
Highly corrosive:	The contents could severely burn, blind, disfigure or maim an individual.
Corrosive:	The contents could cause damage to the skin or eye.
Flammable:	The contents have a flash point equal to or less than 55°C.
Others:	The contents are not considered to burn, blind or injure individuals or damage the environment.

discrepancies in the table which require correction, but this can more usefully be carried out in the light of public comment. It was certainly not intended that low hazard content vessels of unlimited size and pressure should be constructed without independent design assessment and inspection during manufacture.

However, when applying the table it should be appreciated that a vessel or tank category is determined by the highest category indication against any relevant line heading, irrespective of any other lower category indications. For example, toxic, highly corrosive, and flammable contents are always of Category 1, irrespective of other parameters. Similarly, vessels and tanks designed for temperatures between HDT – 40°C and HDT – 20°C, and also those for which there is only limited data in respect of chemical compatibility between liner and content should always be Category 1.

The options of Categories 2 and 3 are intended only for vessels and tanks of relatively small capacity and pressure, with content of little hazard, for which some of the more onerous design documentation and inspection requirements may reasonably be relaxed. Category 3 is to be limited to static storage vessels less than $10\,m^3$ capacity and to those containing innocuous substances; all other critical items and vessels containing dangerous materials to be subject to Category 1 scrutiny.

DEFINITIONS

Extensibility is a term which was introduced into BS 4994 at its inception. It is derived from the slope of the stress/strain curve related to a tensile test and its numerical value depends upon the particular laminated construction. This term has now been replaced by unit modulus which is thought to be more realistic, because in fact the term is really $E \times$ thickness.

MATERIALS

In relation to materials, the most fundamental factor to bear in mind is that they are not supplied, as in the case of steel, with relatively uniform predicted mechanical properties. In the contrary, laminates are produced by the fabricator during construction, and strengths may vary substantially regarding a composite. Furthermore, the entire fabrication is exposed to operator-produced imperfections, not just those which may occur in the weld regions, as is usually the case with steel vessels. Construction from individual layers of reinforcement does, however, have the advantage of giving the designer freedom to select a composite best suited to the detailed design requirements.

The mechanical properties of steels, declared by the supplier of the material, are made use of by the vessel designer who employs rules which pre-suppose that they are relatively homogeneous and will satisfactorily withstand an appreciable amount of plastic deformation. In contrast, this is not the case with GRP, which lacks ductility and, consequently, design strain values must be specified and limited to a relatively low figure within the capacity of both reinforcement and the resin system adopted.

The materials specified in the new draft have been extended to take account of developments, and the laminate properties have been revised to incorporate up-to-date information and more recently introduced resin systems. Some of the property values have been increased and some reduced.

DESIGN

Associated with the previously mentioned extension of categories, Table 2.2 provides details of proposed minimum design and drawing requirements. By their very nature these requirements are somewhat subjective and will doubtless promote comment.

There have been quite a number of modifications in the new draft and the following paragraphs draw attention to the salient ones.

Proposals are incorporated to extend the scope of the Standard to include rules for filament wound vessels, rectangular panels, and tanks, and also local loads.

The minimum overall design factor has been increased from 6 to 8, which is believed to recognise practice and is the order of the value normally associated with strain limitation. In itself this makes no difference to laminate requirements, but the revised values of the

Table 2.2 Design documentation and drawing requirements

	Category I	Category II	Category III
Design calculations			
(1) Independent approval required	*		
(2) Calculations to cover:			
(a) hydrostatic loadings	*	*	*
(b) applied pressure	*	*	
(c) applied vacuum	*	*	
(d) wind loads	*	*	
(e) lifting arrangements	*	*	*
(f) supporting	*	*	
(g) seismic loading (if applicable)	*	*	
Drawing requirements			
Vessel/tank general arrangement	*	*	*
Full fabrication drawings showing method of manufacture	*	*	
Installation procedure	*	*	*

component factors from which the overall design factor is determined will themselves make for moderate but significant modification to the derived overall design factor.

An extension has been made to the allowable design temperature range to span −10°C to 110°C, with a cautionary note about applications above 100°C, prompted by lack of data regarding laminate behaviour.

Formulae relating to external pressure cases now incorporate D_0 (external diameter) which was previously derived by the general assumption that it was associated with a thickness of 10 per cent of the internal diameter, the results of which produced thicknesses significantly greater than actual values and thus imposed an unwarranted penalty on laminate thickness, requirements.

Additional shape factors have been introduced for domed ends; also a range of factors for semi-ellipsoidal heads as a result of work at UMIST. However it is thought that there may be a possibility of opposition if any reduction in overall strength is involved. In this context concern has also been expressed regarding the danger of being too optimistic about the accuracy of the shapes of ends as they are produced.

The previous rules for the compensation of openings were a source of misunderstanding and they have now been re-written and made more precise, although the actual requirements have not been affected significantly.

Flange types and dimensions have been modified to accord with the draft for GRP process pipework. The original figures have not been without criticism and may be re-assessed. BS 5500 requirements for 'full face' flanges have also been incorporated.

The base/shell inter-section knuckle requirements for vertical cylindrical tanks with fully supported bottoms have been modified to take account of the results of computer analysis of the knuckle and of the omission of a knuckle radius in the design of tanks utilising a fabric backed thermoplastic lining material.

Saddle support design methods have been taken from BS 5500, with a note of caution about ensuring strain limitations in accordance with the general requirements of the specification.

INSPECTION AND TESTS

Table 2.3 shows proposed quality control tests and records, again in relation to specified categories.

The nature of fabrication procedures is sensitive to control and, consequently, construction codes and specifications emphasize the importance of adequate supervision and formal record-keeping, particularly with regard to raw materials and the mixing of substances.

A reputable manufacturer, conscious of the essential nature of production controls and procedures, will have in-house specifications established to cover the fundamental fabrication, laminating, and manufacturing principles to be adopted for the construction of components.

Routine tests will be carried out where necessary to ensure compliance of basic materials, fabricating procedures, and finished test samples with the appropriate standard or specification. In the case of thermoplastic-lined vessels, it is possible to inspect the chemical barrier prior to the application of external reinforcement; indeed, if a conductive resin is

Table 2.3 Quality control: tests and records

	Category I	Category II	Category III
Material records			
Record of resin usage	*		
Record of glass usage	*		
Record of personnel on the fabrication	*	*	
Record of layers and type of glass	*	*	*
Record of cure system	*	*	
Record of post cure (when used)	*	*	
Quality control tests			
Spark test on thermoplastic liners	*	*	*
If adequate documented information on the mechanical properties of the particular resin/glass composite is unavailable production test samples shall be made and tested.	*	*	*
The production test coupon shall be laminated with the vessel or obtained from nozzle cut-outs. The coupons shall then be tested as follows:			
ULTIMATE TENSILE UNIT STRENGTH	*		
unit modulus	*		
lap shear strength	*		
In the case of thermoplastic lined GRP tanks and vessels the fabricator shall also demonstrate the following:			
weld strength	*		
bond strength	*		
visual examination of nozzle cut-outs	*	*	*
ash test on nozzle cut-outs	*		
thickness measurement†	*	*	
Barcol hardness measurement	*	*	*
Quality control records			
Hardness test (Barcol)	*	*	*
Thickness measurement	*	*	*
Nameplate details	*	*	*

Table 2.3 (*continued*)

	Category I	Category II	Category III
Documentation requirements:			
pressure/vac/hydrostatic head	*	*	
ULTIMATE TENSILE UNIT STRENGTH	*	*	
unit modulus	*	*	
lap shear strength	*	*	
weld strength	*	*	
bond strength	*	*	
ash test on cut-out	*		
Independent inspection	*		

† Thickness measured shall not be less than the design thickness.
Particular attention shall be paid to points of discontinuity, e.g. nozzles and end attachments.

applied to the welds, the lining may be checked at any time during its service life.

Detailed fabrication procedures are prepared giving all the stages of manufacture which will be employed, based upon the design and manufacturing requirements for the particular item. While undertaking the various fabrication stages, the materials are usually issued under adequate control in accordance with stage requirements, and fully recorded.

In the new draft there has been a change of philosophy in that laminating procedure and operator approvals are proposed but no formal certification is specified. Test samples may be called for if they have not already been provided, satisfactorily examined, and documented. Emphasis is now given to reviewing and assessing existing documentation and evidence of satisfactory past experience, and it is in a manufacturer's own best interests to ensure that any prototype or other forms of testing are carefully conducted and independently inspected, all tests being properly planned and documented to ensure acceptance.

The requirements for production testing have been made more realistic, and tensile tests are only called for when essential. Initially