

**BONDSHIP**  
**project guidelines**



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## Foreword

This document was produced by the members of the BONDSHIP project. BONDSHIP - *Bonding of lightweight materials for cost effective production of high speed craft and passenger ships* - is a 4.6 M€ GROWTH project funded by the European Commission under the 5<sup>th</sup> framework programme. BONDSHIP is a major European initiative to introduce adhesive bonding into shipbuilding as an industrial process for joining of lightweight and dissimilar materials and structures.

The project ran from April 2000 to June 2003 and had 13 partners from 7 nations: (1) Det Norske Veritas AS (project co-ordinator), Norway; (2) Fincantieri - Cantieri Navali Italiani S.p.A., Italy; (3) Vosper Thornycroft (UK) Limited, United Kingdom; (4) Jos. L. Meyer GmbH, Germany; (5) Alcan Mass Transportation Systems, Switzerland; (6) Sika Technology AG, Switzerland; (7) CETENA S.p.A. - Centro per gli Studi di Tecnica Navale, Italy; (8) Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., IFAM, Germany; (9) FiReCo AS, Norway; (10) University of Southampton, United Kingdom; (11) Délégation Générale pour l'Armement - Direction des Centres d'Expertise et d'Essais, France; (12) NDT Solutions Ltd, United Kingdom; (13) Stena Rederi AB, Sweden.

The guidelines can be considered the main deliverable of the BONDSHIP project. They sum up all the steps necessary to design, build, inspect and repair all types of bonded joints in ships. The guidelines describe a general framework for the safe use of bonded joints. However, they do not provide detailed “recipes” for the user to follow. Hence additional information is needed to successfully use adhesive bonding. There are two parts:

- 1) Code (DNV Report No. 2004-0134)<sup>1</sup>: The objective is to provide general requirements to ensure the reliability and safety of load-carrying bonded joints in ships.
- 2) Recommended Practices (DNV Report No. 2004-0193): This document provides guidance and examples on how to design, produce and inspect an adhesively bonded joint. Furthermore it shall provide the basis for meeting the general requirements laid out in the Code document.

Significant progress was made in BONDSHIP. However, most designers, builders and owners of ships are not aware of the possibilities (and limitations) that adhesive bonding offers. The BONDSHIP guidelines show how to safely introduce bonded joints, first in less critical areas and increasingly also in more critical areas as service experience is gained and confidence in the long term performance is built. By making the BONDSHIP guidelines available to the public we hope to establish a broad user base for adhesive bonding in marine structures – thus paving the way for establishing adhesive bonding as a standard joining process in shipbuilding.

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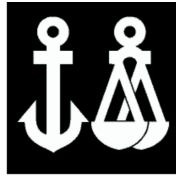
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<sup>1</sup> The main ideas of this report have been published in: Jan Weitzenböck and Dag McGeorge, *The designer's dilemma: How to deal with the uncertainty about the long-term performance of adhesively bonded joints?*, Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, 2004, vol 218, issue 4, p 273-276





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# TECHNICAL REPORT

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## BONDSHIP GUIDELINES: CODE

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## 1 INTRODUCTION

### 1.1 Background

This report is a deliverable of the BONDSHIP project. BONDSHIP - *Bonding of lightweight materials for cost effective production of high speed craft and passenger ships* - is a 4.6 M€ GROWTH project funded by the European Commission under the 5<sup>th</sup> framework programme. The project ran from April 2000 to June 2003 and has 13 partners from 7 nations. BONDSHIP is a major European initiative to introduce adhesive bonding into ship building as an industrial process for joining of lightweight and dissimilar materials and structures.

The guidelines are a summary of the collective know-how and experience of the project partners. The guidelines are split into two parts. Part 1 is the Code part (this document) setting safety relevant requirements. The second part is a collection of recommended practices - how to e.g. select adhesives, design and analyse joints [1]. The present document is a substantially revised and extended version of references [2] and [3]. Reference [4] was a useful reference document in the preparation of these guidelines.

### 1.2 Objective

The objective of this document is to provide general requirements to ensure the reliability and safety of load-carrying bonded joints in ships.

### 1.3 Scope

This document applies to all types of adhesively bonded joints in Ships. The bonded joints can be either structural or non-structural. The document encompasses the design, manufacture and use of bonded joints.

### 1.4 Basic assumptions and concepts

Long-term performance: This document is based on the assumption that the long-term performance of a bonded joint cannot be reliably predicted from the results of accelerated ageing tests. Therefore, requirements to the resistance of the joint are combined with requirements that limit the consequences of failure of the joint. Furthermore, it must be possible to repair the joint using an approved repair method. This may not be necessary if past service experience documents adequate long-term performance of the joint.

Joint design approval: Numerical analysis cannot reliably predict joint failure without additional large scale tests. While numerical analysis can give extremely useful insights into the behaviour of bonded joints, the approval of joint will only utilise representative tests (as defined in section 2.4) as a cost-effective means of assessing bonded joints. The above applies to new joint designs. Approval of variations of existing design can probably be done on the basis of a numerical analysis, especially when there is in-service experience with the old design.

Production: Adhesive bonding is a complex process with many variables whose interaction is not fully understood. Furthermore, there are currently no NDT methods to measure reliably the adhesion strength of a finished joint. Hence, instead of checking the quality of a joint afterward it



is imperative to establish a quality control system for each individual step of the production process to ensure joints can be produced reliably and consistently. NDT methods can play an important part in the QA/QC of the production processes [6].

## 1.5 Definitions

A **bonded joint** is a joint where adherends are bonded either by placing a layer of adhesive or resin material between the adherends. The primary function of the adhesive is to transfer loads from one adherend to the other. This distinguishes the adhesive from a sealant.

**Quality** is defined as the ability of the bond to meet the functional requirements defined by the designer in the short and long term with the specified level of reliability.



## 2 DESIGN OF ADHESIVELY BONDED JOINTS

### 2.1 Outline

Qualification of the design of an adhesively bonded joint follows the following general approach.

1. The consequences of failure of the bonded joint should be minimised through a formal risk reduction procedure unless adequate long-term performance can be documented from past successful service experience (Section 2.2).
2. The intended operating environment must be accounted for (Section 2.3).
3. Adequate resistance is to be documented using representative tests (Section 2.4).
4. Adequate safety factors are used (Section 2.5)
5. The loads and temperatures that the joint may experience in a fire must be accounted for (Chapter 3).

Guidance Note: It is very difficult to define the terms *structural* and *non-structural* joints. In the context of this document we are not making a distinction between the two. Hence all requirements apply equally to both. However, as experience is growing, it may be possible to relax the requirements for less-critical joints.

### 2.2 Risk reduction

In cases where adequate long-term performance of the bonded joint solution has not been demonstrated by successful in-service experience, possible consequences of long-term degradation and possible consequential damage shall be identified through a formal hazard identification.

The identified hazards shall be reviewed and measures taken to control the risks. Redundancy shall be provided such that the consequences of such failures are limited to economic losses.

Inspection and repair procedures shall be documented.

To limit the probability of severe long-term degradation and hence minimise risk, measures shall be taken to ensure that, among available alternatives, those with unfavourable long-term properties are discarded. This is to be based on accelerated screening ageing tests.

### 2.3 Environment

The following in-service environmental conditions shall be considered when defining the characteristic strength of the joint:

- Humidity
- Temperature
- UV-light
- Chemicals (Chemicals may include fuels, cargo, effluents etc.)



## TECHNICAL REPORT

- Welding

Guidance Note: It may be necessary to allow welding during construction and/or repair of the structure. The use of bonded joints may reduce the possible scope for such work. Hence, a requirement to the joint's ability to accept welding in the vicinity may be a necessary requirement. This requirement can be treated as a requirement to resistance to a specified environment condition (elevated temperature outside the range of normal operating temperature). In addition the effect of thermal contraction or expansion of the surrounding structure shall be considered.

For each environmental condition its variation over time shall be identified, i.e. whether the exposure is permanent, variable or intermittent in nature, whether temperature is cycled through  $\pm 0^\circ\text{C}$  etc.

Unless otherwise agreed all joints shall as a minimum be designed for the following range of conditions:

- Relative humidity: 0 – 95 % \*
- Temperature:  $0^\circ\text{C} - 40^\circ\text{C}$

\* Submergence of the joint under water shall be considered if relevant.

Guidance Note: For adhesive selection and production further environmental conditions have to be specified. The production related environmental factors will be addressed in chapter 4. The recommended practices [1] present a systematic approach ("IFAM tables") to specifying all relevant conditions and requirements to the joint in a single exercise.

## 2.4 Representative tests

Tests complying with the following requirements are considered representative.

The fabrication of specimens must be representative of industrial fabrication at the shipyard. Normally, the specimens should be prepared by the shipyard that shall manufacture the real structure. Production shall as far as practically possible be carried out according to the procedures that apply to such industrial fabrication at the shipyard. The following aspects should be given particular consideration:

- Surface preparation of adherends
- Handling before priming
- Priming of the prepared surface
- Preparation of the primed surface before bonding operation
- Environmental conditions during all manufacturing steps
- Curing conditions
- Differences from normal shipyard productions that cannot practically be avoided when small test objects are manufactured.

Deviations from the real joints must be documented to be conservative. Specifically, the mode of loading must be representative of that the joint will experience in the structure when exposed to the operational loads. Peel stresses must be included as relevant. Stress concentrations must be at least as severe as in the real application unless fully accounted for by modelling.



The long-term degradation of the joint strength in the intended operational environment shall as far as possible be represented by the measurements and explicitly accounted for in design. Reversible effects, such as swelling and plasticization, should be accounted for separately from permanent physical and chemical degradation of the joint.

Results from idealised tests may be used directly if they can be shown to be conservative. Modelling may be used to document that the test results are representative for joint geometries differing from the tested configuration. Furthermore, modelling may be used to extend application of test results to loading modes not actually tested. In this way, test results may be applied more widely and the degree of conservatism may be reduced by the aid of modelling.

## 2.5 Safety factors

A safety factor shall be adopted that is commensurate with the uncertainty in predicted long-term joint resistance both due to variability in the state of “as produced” joints and in the effects of environmental exposure they will receive in service and due to unavoidable differences between the tested objects and the components in the real ship.



### 3 FIRE

This section is based on reference [5].

#### 3.1 Fire resistance of bonded joints

The fire resistance of a bonded joint is usually inferior to the fire resistance of the adherend material. When fire resistance is required the joint has also to be designed against relevant fire scenarios. The following information shall be specified:

1. A description of the temperature development in the joint during a fire: e.g. maximum temperature, duration etc. as relevant.
2. Requirements to strength of the joint during a fire
3. Requirements to the residual strength of the joint after the fire

The IMO documents “The International Convention for Safety of Life at Sea” (SOLAS) including the “Code of safety for High Speed Crafts” (HSC-code), is the governing rules for fire safety on board commercial vessels in international trade. They define *load carrying* and *non-load carrying* fire divisions. These two main classes require different treatment.

Guidance Note: The fire reaction (heat release, smoke and toxicity) properties of the adhesive do not represent any decrease in fire safety level. This is not only due to the small areas of adhesive exposed to fire, but also the small amount used compared to other combustible materials used in a ship (paint, decorative surfaces, deck covering, etc).

Guidance Note: If relevant, the effect of the fire extinguishing media on the properties of the bonds shall be considered.

#### 3.2 Non-load carrying fire divisions or elements

It must be demonstrated by fire tests or by engineering/layout that the bonded part(s) of the division will stay smoke and flame tight during the required time. Mechanical fasteners or arrangements can often replace the need for joint strength in a fire situation.

If the division is relying on the structural integrity of the adhesive in order to stay gas and smoke tight, this should be demonstrated by a test. Usually this will require full scale fire resistance testing, but small scale testing can be evaluated depending on the type of joint.

If the bonded elements and the joint itself is part of a load carrying division, but is not a part of the load carrying elements in this divisions (e.g. doors, hatches, fill-in elements, non-critical joints, etc.) these shall be treated as a “Non-load carrying division or element”. It must be clearly demonstrated that:

- The division will maintain structural strength without the adhesive joint and /or the structural strength of the bonded elements for the required time
- The division will remain smoke and flame tight for the required time



### 3.3 Load carrying fire divisions or elements

The bonded joint is load carrying during the fire, and is critical for the function of the division. An element that is carrying local load, but is a part of a non-load carrying division, can still be classified as a load carrying element.

The following must be presented in addition to the information requested in section 3.1:

- Detailed load and stress analysis of the adhesive joint for all relevant load cases.
- The most critical load case or combination of load cases must be used to find worst-case stresses for the bonded joint.

Two methods for qualification of the bonded joint can be used:

1. Characterise the thermo-mechanical properties of the material, find the allowable temperature limit and measure temperature during large scale test.
2. Apply load during the full-scale fire test.

Guidance Note: Method 1 is equivalent to the philosophy that was used when aluminium was allowed in shipbuilding.

Guidance Note: Method 2 is equivalent to the philosophy that was used when composite structures were allowed in the construction of high-speed crafts.



## 4 QUALITY AND SAFETY

### 4.1 Quality assurance and quality control (QA/QC)

The yard or fabricator shall develop and implement procedures and practises controlling all processes having an effect on the quality of the finished bond.

This section outlines the requirements to the content of such a QA documentation. Detailed requirements are not given as these will depend on the actual joint configuration, choice of materials etc., and will have to be worked out in detail for specific applications. More detailed information will be provided in the RPs [1].

The QA documentation shall address the following topics:

- Joint specification
- Receipt and storage of materials
- Bonding operation including surface preparation
- Inspection and verification
- Quality plan
- Qualification of personnel (see chapter 5)

The QA documentation shall give requirements to all relevant items to a level of detail commensurate with the complexity of the operations and to their influence on the quality.

### 4.2 Health and safety

Adhesives, primers and solvents are chemical substances that require careful handling. However, provided precautions are taken they are safe to use. The following list shows the main safety precautions to be taken (this list has to be modified to adapt to the local requirements):

- Follow safety data sheets provided by the adhesive or paint suppliers
- Follow regulatory requirement regarding maximum allowable concentration of volatile gasses
- Provide protection to workers for skin, eyes and inhalation



## 5 QUALIFICATION OF BONDING PERSONNEL

The bonding operation and quality control shall be carried out by qualified personnel and suitable equipment. Personnel shall be qualified according to the EWF (= European Federation for Welding, Joining and Cutting; <http://www.ewf.be/asp/>) scheme or equivalent. Workers shall be qualified to *European Adhesive Bonder* standard while supervisors shall meet the requirements of the *European Adhesive Specialist*. Personnel responsible for planning and implementing the bonding process in a company shall be qualified *European Adhesive Engineers (EAE)*.

Guidance Note: There are many training facilities in Europe that offer *European Adhesive Bonder* and *European Adhesive Specialist* courses. However, at the time of writing of this document there is only one institute that offers EAE training (IFAM, Bremen, Germany). Hence, for a transition period the lack of formal EAE qualification can be compensated with considerable and relevant experience.

All qualification schemes shall contain the following elements.

- Theoretical training
- Practical training
- Qualification exams, tests etc.
- Certification schemes
- Methods and requirements to maintenance of qualifications:
  - Training
  - Qualification exams
  - Operator joint logbook



## 6 IN-SERVICE INSPECTION

The in-service inspection of bonded joints will be mainly visual inspection of the visible part of the joint:

1. Check for corrosion of the adherend along the bondline (can lead to failure of the joint, but not the adhesive!)
2. Are there (creep) cracks in adhesive?
3. An indirect check for (less critical) joints is whether or not leakage is observed on the other side of the joint.

NDT methods can be used to investigate critical or suspect areas more thoroughly [6]:

- Is the adhesive still in contact with the adherend?
- Are there any defects at the interfaces and what size are they?
- If one can see visual evidence of damage what is the extent of the damage in the joint (e.g. after impact damage)?

Any damage needs to be repaired using an approved repair method.



## 7 REFERENCES

- [1] Jan Weitzenböck, Dag McGeorge and Harald Osnes, *BONDSHIP Guidelines: Recommended Practices*, 2004, DNV Report No.: 2004-0193
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- [6] Richard Freemantle, *Non destructive adhesive bond inspection techniques and guidelines for the BONDSHIP application cases*, BONDSHIP Report Number: 2-24-D-2001-01-4, 2003-06-18

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