Adhesive Joints and Patch Repair

May 2015

Guidance Note
NI 613 DT R00 E

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BUREAU VERITAS

MARINE & OFFSHORE DIVISION

GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine & Offshore Division (the "Society") is the classification (" Classification ") of any ship or vessel or offshore unit or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- "prepares and publishes Rules for classification, Guidance Notes and other documents (" Rules ");
- "issues Certificates, Attestations and Reports following its interventions (" Certificates ");
- "publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as " Certification ".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as " Services ". The party and/or its representative requesting the services is hereinafter referred to as the " Client ". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisement given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisement is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - **It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisement or cause to modify its scope.**

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out.

ARTICLE 3

3.1. - **The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are a collection of minimum requirements but not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.**

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - **The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.**

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - **The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.**

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- "reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- "conducts surveys at the place of their construction;
- "classes Units and enters their class in its Register;
- "surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - **The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.**

5.2. - **The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.**

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - **The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder.**

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - **If the Services of the Society or their omission cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee. These limits apply regardless of fault including breach of contract, breach of warranty, tort, strict liability, breach of statute, etc.**

The Society bears no liability for indirect or consequential loss whether arising naturally or not as a consequence of the Services or their omission such as loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - **Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.**

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - **Overdue amounts are increased as of right by interest in accordance with the applicable legislation.**

8.3. - **The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.**

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- "Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit ;
- "copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- "the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, may be passed on to IACS (International Association of Classification Societies) according to the association working rules;
- "the certificates, documents and information relative to the Units classed with the Society may be reviewed during certificating bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France, or to another Court as deemed fit by the Society.

12.3. - **Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.**

ARTICLE 13

13.1. - **These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement. They are not varied by any purchase order or other document of the Client serving similar purpose.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.

BV Mod. Ad. ME 545 L - 7 January 2013

GUIDANCE NOTE NI 613

NI 613
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Section 2 Bonding System Assessment

Section 3 Adhesive Joints Design Assessment

Section 4 Adhesives

Section 5 Surface Preparation

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SECTION 1 GENERAL

1 General

1.1 Application

1.1.1 This Guidance Note gives requirements and recommendations for the assessment of adhesive joints and patch repair.

This Guidance Note applies to multi-materials adhesive joints:

- Composite/Composite (secondary bonding)
- Metallic/Metallic
- Metallic/Composite.

This Guidance Note applies only to adhesive joints or patch repair, not participating in ship's structural, watertight and fire integrity.

1.2 Objective

1.2.1 The objective of the Guidance Note is to provide a technical support to shipyards, designers, surveyors, etc involved in bonding and patch repair activities.

2 Definitions

2.1 Rules

2.1.1 Rules means Rules to comply with as specified by this Guidance Note.

2.2 Assessment

2.2.1 Assessment, which is performed on a voluntary request of the shipyard, means the review by the Society of documents, procedures or other items verifying solely their compliance with this Guidance Note, or other referential if relevant.

2.3 Adhesive joint

2.3.1 An adhesive joint is a mean allowing to sustain two surfaces together permanently under loads via a polymeric material layer by either chemical or mechanical interfacial forces or a combination of both.

Pieces (or adherents) which are to be bonded, may be made the same material or not, and the result of this connection is called adhesive assembly.

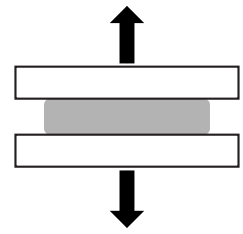
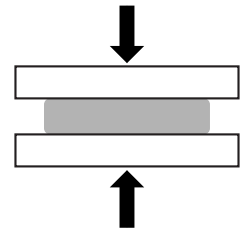
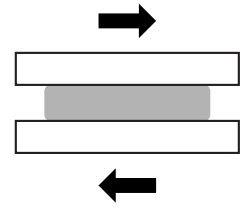
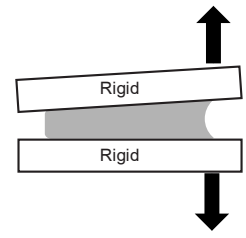
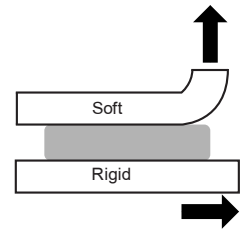
2.4 Patch repair

2.4.1 A Patch Repair is a solution, composed of a composite patch, to repair an existing metallic or composite structure. The composite patch is bonded on the damaged structure area.

2.5 Type of loads

2.5.1 The different types of loads applied on an adhesive joint are indicated in Tab 1.

Table 1 : Type of loads

Tension	
Compression	
Shear	
Cleavage	
Peel	

3 Environmental conditions

3.1 General

3.1.1 In general, environmental service conditions are to be the following:

- temperature: – 25°C to 55°C
- humidity: 95% at 55°C
- salt mist content: 1mg/m^3.

Others values may be considered if they are duly justified.

Protection against UV light and/or chemical aggression is to be applied when relevant.

Application conditions are to be defined following requirements in Sec 2.

4 Adhesive joints risk level classification

4.1 General

4.1.1 In order to differentiate the type of application and to adapt consequently the level of survey by the Society, 3 types of bonding applications are defined:

- Class A: Low risk
- Class B: Medium risk
- Class C: High risk.

The adhesive joints risk level classification shall be approved by Society.

4.2 Class A (Low risk)

4.2.1 Class A adhesive bonding are intended to cover all type of adhesive bonding application for which deficiencies in service will not affect ship's mission in any way (safety, sailing, economic…) and equipment weight less than 5 kg.

4.3 Class B (Medium risk)

4.3.1 Class B adhesive bonding are intended to cover all type of adhesive bonding application for which deficiencies in service could generate minor impact on ship's mission but without any consequence on ship's structural and watertight integrity, on passengers or crew safety and health, on vessel ability to sail.

B class includes devices fitting of weight between 5 kg and 50 kg bonded on deck or on bulkhead located less than 1m in height, in spaces accessible to public.

4.4 Class C (High risk)

4.4.1 Class C adhesive bonding are intended to cover all type of adhesive bonding application for which deficiencies in service will affect ship's mission in any way (safety, sailing, economic…) and equipment weight greater than 50 kg or on a bulkhead located greater than 1 m in height, in spaces accessible to public.

It concerns all adhesive bonding applications which could compromise ship's essential services including primary and secondary service.

Note 1: Essential service means a service necessary for a ship to proceed at sea, be steered or manoeuvred, or undertake activities connected with its operation, and for the safety of life, as far as class is concerned.

Primary essential services are those which need to be maintained in continuous operation.

Secondary essential services are those which need not necessarily to be in continuous operation.

5 Risk assessment consideration

5.1 General

5.1.1 Attention is drawn on Class C adhesive bonding.

This Guidance Note is intended to cover all possible type of adhesive bonding applications by giving a scope and a methodology leading to assessment by the Society.

But project feasibility will remain subject to the Society's prior agreement due to the necessary consistency of the design and durability justification.

6 Additional consideration

6.1 Flag Administration requirements

6.1.1 The attention of Ship-owners, Shipyards and Designers is drawn on the fact that compliance to the requirements of this Guidance Note is not necessarily sufficient to satisfy Flag Administration requirements.

The interested party (Ship-owner, Yard or Designer) have to ensure compliance with any requirements issued by Flag Administration (mainly fire safety requirement).

7 Bonding coefficients

7.1 General

7.1.1 Bonding coefficient depends on three parameters:

- risk level classification (see [4])
- type of adhesive (see Sec 4)
- environmental conditions in service (see [3]).

At each parameter is associated a weighting factor, from 0 to 2, defining the bonding coefficient, see Tab 2.

The total bonding coefficient for an assembly is the sum of the three bonding coefficients corresponding to each parameter, total between 0 and 6.

Bonding coefficient is used to define the analysis type for the design, see Sec 3.

Table 2 : Bonded joint classification

Risk Level Classification	Class A	Class B	Class C
Adhesive behaviour law	Rigid	Medium	Soft
Environmental conditions in service	Technical area Protected	Air cooled area	Exposed, machinery space,...
Bonding coefficient	0	1	2

8 Adhesive behaviour law

8.1 General

8.1.1 An adhesive is considered **"**rigid**"** when the behaviour law is linear, with a tensile elongation at break lower than 10%.

An adhesive is considered "soft" when the behaviour law is non-linear with a tensile elongation at break higher than 100%.

For intermediate values, adhesive may be considered "medium".

9 Rules

9.1 References

9.1.1 In addition to the requirements of this Guidance Note, the various elements of adhesive joints design are to meet the applicable requirements of the following Rules and Rule Notes:

- NR467 Rules for the Classification of Steel Ships
- NR500 Rules for the Classification and Certification of Yachts
- NR396 Rules for the Classification of High Speed Craft
- NR490 Rules for the Classification of Crew Boats
- NR445 Rules for the Classification of Offshore Units
- NR216 Rules on Materials and Welding for the Classification of Marine Units
- NR600 Hull Structure and Arrangement for the Classification of Cargo Ships less than 65m and Non Cargo Ships less than 90m
- NR566 Hull Arrangement, Stability and Systems for Ships less than 500 GT
- NR546 Hull in Composite Materials and Plywood, Material Approval, Design Principles, Construction and Survey
- NR320 Certification scheme of materials and equipment for the classification of marine units.

10 Documents to be submitted

10.1 Plans and documents to be submitted for assessment

10.1.1 In the scope of a bonding application assessment, requested to the Society, all the plans and relevant documentations are to be gathered in the following documents:

- Bonding File: see Sec 2, [2.4]
- Manufacturing, Testing and Inspection bonding plan: see Sec 2, [2.5].

All plans and document specifying the adhesive joint or patch repair are to be submitted for assessment to the Society.

In addition, when direct calculation analyses are carried out by the designer according to the rule requirements, they are to be submitted to the Society for information.

10.2 Additional documents

10.2.1 The Society may request the submission of any additional documents found relevant for the assessment of the adhesive joint.

SECTION 2 BONDING SYSTEM ASSESSMENT

1 General

1.1 Introduction

1.1.1 According to ISO 9000 standard series, adhesive bonding is to be considered as special process, the results of which cannot be fully verified by subsequent inspections and testing. Processing deficiencies may become apparent only in service due to the lack of reliable and / or cost effective non-destructive examination methods.

In order to establish confidence in adhesive bonding fabrication and reliable in service performance, continuous monitoring and/or compliance with documents procedures is required to ensure that the specified requirements are met.

The tasks and responsibilities of each personnel involved in all related activities need also to be clearly defined.

1.2 General approach

1.2.1 Many factors could influence final properties of adhesive bonding joints during all process steps (from adhesives storage, adherent preparation, to adhesive application and final assembly, etc…).

Methodology for bonding joints assessment under BV Mode I survey scheme (See NR320) is particularly appropriate in the case of adhesive bonding process.

Under this scheme, the Society delegates partial or full powers, under its supervision, for certain phases of inspection and testing during adhesive bonding process, as stipulated in this Guidance Note.

1.3 Parties involved and their main duties

1.3.1 The parties identified are:

a) the shipyard (including bonding coordinator, bonding operators or any subcontractors)

b) the adhesive manufacturer

c) the Administration, or the Recognised Organisation

d) the Classification Society

e) the ship-owner.

1.3.2 The shipyard main duties:

- Any shipyard which uses bonding as assembly technique must appoint a coordinator (defined hereafter as Bonding Coordinator) responsible for the quality of assembly and if possible acting independently from the company management (cost) and from the manufacturing management (delays).
- The shipyard enforces the MTI Bonding Plan and checks that associated procedures are met.
- The shipyard ensures that any other person of his staff (bonding operators…) involved in bonding applications are sufficiently qualified for their activity perimeter and maintain their level of qualification with adequate and regular training program.
- The shipyard is fully responsible for any subcontractor involved in bonding applications. A written document may be established specifying the tasks delegated by the shipyard to the Subcontractor. This document is to be signed by both the shipyard and the Subcontractor.
- The shipyard ensures that the Quality Assurance system is addressing all aspects regarding bonding activities, including non-conformities and their relevant corrective actions.

1.3.3 The Bonding Coordinator main duties:

- The bonding coordinator is the cornerstone of all bonding activities in the shipyard and the preferred entry point of all other parties especially for the Classification Society (Surveyor at yard and Local Plan Office).
- Depending on the level of risk of the bonding applications implemented in the shipyard, the Bonding Coordinator must have a specific level of qualification in bonding technologies in order to be able to perform properly his job and ensure the responsibilities related to his function.

1.3.4 The adhesive manufacturer main duties:

- The adhesive manufacturer provides the adhesive and any other associated materials, selected to ensure the reliability of the in service bonding application.
- The adhesive manufacturer provides Technical Data Sheet, Material Safety Technical Data Sheet, technical guide for adhesive application and any other relevant technical documentation which can justify the reliability of the in service bonding application (for instance, any previous similar application or some testing results duly documented whom may have been performed previously…).
- The adhesive manufacturer advises and assists the shipyard & other parties if needed.

2 Bonding process assessment

2.1 Assessment main steps

2.1.1 Bonding process assessment may be divided in four main steps:

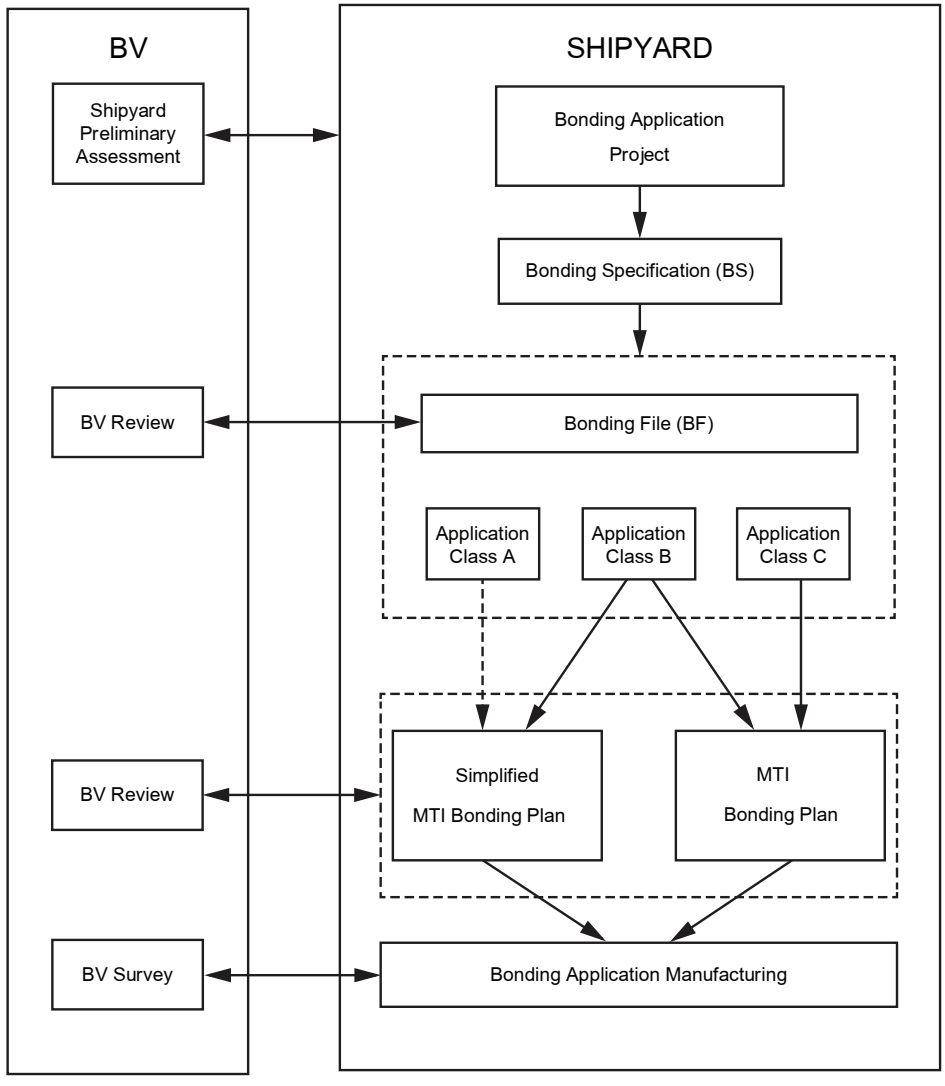
- Preliminary assessment of shipyard
- Bonding File assessment (BF assessment)
- Manufacturing, Testing and Inspection bonding plan (MTI bonding plan)
- Bonding final assessment.

See Tab 1 and flowchart in Fig 1.

Table 1 : General bonding process assessment

Step	
Preliminary assessment of shipyard	The shipyard prepares the general documents on its organization, quality system and experience in order to demonstrate its capacity to achieve reliable bonding operation.
	The Society carries out a preliminary inspection in order to establish an initial diagnosis at yard (SAY).
Bonding File Assessment	Further to the Bonding Specification phase, shipyard submits all necessary technical documents relative to the considered bonding application.
	The Society assesses the conformity of the bonding application design to the requirements of its rules: validation of the bonded joints risk level classification, examination of associated drawings, bonded joints design properties, qualification tests… (LPO+ SAY).
Manufacturing, Testing and Inspection bonding plan	The shipyard provides The Society its MTI bonding plan relative to the considered bonding application process.
	The Society examines the MTI bonding plan and performs inspection of the bonding process (LPO + SAY).
Bonding final assessment	
Note 1: SAY : BV Surveyor at yard LPO : BV Local Plan Office. **Note 2:** Other assessment schemes, based on the same principles, may be considered, to suit particular or specific features at certain shipyards or certain bonding application.	

Figure 1 : General Flow Chart for bonding process assessment



2.2 Shipyard preliminary assessment

2.2.1 This step is particularly necessary for shipyard wishing to introduce adhesive bonding in their assembly methods (e.g. for metallic construction shipyard) and for shipyards not already known by the Society.

Shipyard's assessment is based on a documentary stage associated with a preliminary inspection at shipyard covering following items:

- general shipyard's organization and specific facilities for bonding operation
- quality system and traceability management
- personnel skills and qualification in bonding
- revious shipyard's experience in bonding.

2.2.2 Documentary stage

The following details are to be submitted by the shipyard to the Society:

a) General shipyard's organization and specific facilities for bonding operation:
   - shipyard references: name, address, size and distribution of workforce (e.g. design office, production work staff)
   - production capacity (total number of hull units already built, number of units per year, number of types, sizes)
   - shipyard lay-out showing area assigned to different material preparation, storage site for raw materials (adhesives and all bonded related material, adherent), assembly / bonding unit and hull construction operations and organizational links among them
   - existing equipment related to bonding (process tooling, control and testing equipment, NDT).

b) Quality system / traceability management.

c) Shipyard quality policy (existence of a quality system / ISO certification or equivalent) which should contain the main following items:
   - shipyard organization
   - document control management
   - purchasing management
   - material, products, equipment identification and traceability management
   - production means and process control management
   - inspection, measuring and test equipment management
   - non conformity management
   - corrective and preventive action
   - internal quality audit.

d) Personnel skills and qualification in bonding:
   - shipyard's personnel training policy
   - identification of Shipyard's bonding coordinator and shipyard bonding operator
   - specific qualification in adhesive technology of shipyard's personnel (e.g. certification EWF adhesive bonder / specialist / engineer or equivalent qualification level)
   - training program from adhesive's supplier.

e) Previous shipyard's experience in bonding:
   - compilation, as exhaustive as possible of bonding applications carried out previously by the shipyard describing type of adhesive used, surface preparation and bonding process
   - operating feedback of bonding applications in service.

2.2.3 Preliminary inspection at shipyard

The Society performs a preliminary inspection of the shipyard, to ensure that the information stated in the previous documentary stage is implemented on site.

2.2.4 Shipyard Preliminary assessment report

According to collected information and preliminary inspection at shipyard, the Society may confirm shipyard's capacity to achieve reliable adhesive bonding process or makes recommendations on corrective action which should be implemented by the shipyard to improve its organization.

2.3 Bonding Specification (B.S.)

2.3.1 The B.S. phase consists in gathering all input data considered in first design steps. The aim is to define suitable adhesive system (adhesive + process) according to the considered bonding application and to evaluate the needed level of justification in next design and process steps.

See in App 2, for information, a non-exhaustive list of questions to ask.

This phase should be conducted jointly by the shipyard and adhesive supplier.

This initial phase must allow to draw up a Bonding File suitable for the considered bonding application.

2.4 Bonding File (B.F.)

2.4.1 The B.F. is submitted to the Society for examination and acceptance.

The B.F. shall document the design output in terms that can be verified against design requirements.

Design output consists of drawings, specifications, qualification tests and/or procedures necessary to achieve reliable in service performance of the considered bonding application.

This includes acceptance bonding process criteria for validation as well as specific requirements for safe and proper functioning of the bonded assembly.

Design output documentation shall include specific actions to be taken to address critical design items and to ensure that key characteristics are controlled, with plans for verification and validation as needed.

Table 2 : Content of Bonding file

		Risk Class		
		A Low	B Medium	C High
BV check		SAY	LPO + SAY	LPO + SAY
General arrangement drawing / Associated drawing set		NA	X	X
Considered environmental service condition		X	X	X
Fire safety requirements for the considered bonding application		X	X	X
Design file	Considered design load	NA	X	X
	Considered material mechanical characteristics design values (E, G, nu, behaviour law)	NA	X	X
	Adhesive system breaking strength (σ, τ) measured on test samples representative of real production conditions (environmental, surface treatments, polymerization state…)	NA	(X)	X
	Durability assessment	NA	(X)	X
	Joint geometry specification	NA	X	X
	Calculation method justification	NA	X	X
Process specification file	Adherent surface condition specification before bonding	X	X	X
	Process description	X	X	X
	Process parameters to control / NDT	NA	(X)	X
Repair manual		X	X	X

Note 1:
SAY : BV Surveyor at yard
LPO : BV Local Plan Office
NA : Not applicable
X : Applicable
(X) : Applicable on case by case basis.

2.4.2 Bonding File Content

The Bonding File Content is the following:

- Risk category considered for the bonding applications with associated justification if necessary.
- General arrangement drawing / Associated drawings set for the considered bonding applications (risk Class B and C only) showing location of the assembly onboard.
- Foreseen environmental service condition (T°, H%, chemical agents exposition...) for the considered bonding application.
- Fire safety requirements for the considered bonding application.
- Design file (B and C risk Class only):
  - considered design load (see applicable Rules and/or other if relevant)
  - considered material (adherent and adhesive) mechanical characteristics design value (see Sec 3 and Sec 6) and relevant justification (manufacturer's data, qualification test…)
  - durability / long term performance / ageing / fatigue justification tests (see Sec 6 and App 3)
  - joint geometry specification (bond line thickness, width, length with acceptable tolerances)
  - calculation method justification (see Sec 3).
- Process specification file:
  - adherent surface condition specification (Cleaning and surface preparation) before bonding which allows to achieve material design values
  - process description
  - process parameters to control / NDT.

Content of bonding file is summarized in Tab 2.

2.5 Manufacturing, Testing and Inspection Bonding Plan (MTI Bonding Plan)

2.5.1 General

The MTI bonding plan shall be drawn up by the shipyard's bonding coordinator.

The MTI bonding plan consists in detailing all process steps and all process parameters which need to be controlled (from adhesives storage, adherent preparation, to adhesive application and final assembly etc…) in order to achieve requirements defined in the B.F.

The MTI bonding plan must describe the various operations the shipyard needs to control during bonding operations for the purposes of assessment under the BV mode I survey scheme.

This plan must state the delegate powers limits under the contract between the shipyard and the Society, individuals responsible for accepting tests and various checks, procedures or instructions to be complied with, acceptability criteria, and documents needed to ensure product traceability.

This part offers a general lay-out for drafting an MTI bonding plan, corresponding to the different stages of bonding operation. For each such stage, the shipyard must supply the information stated in the previous paragraphs (individuals responsible for various operations, traceability, and handling of non-conformities).

The MTI bonding plan is submitted to the Society for examination and acceptance. Such examination, accompanied by inspections at the production site or sites, is intended to ensure compliance with the Society requirements and reproducibility of bonding applications production methods.

Periodic shipyard inspections by the Society are intended to ensure that the MTI bonding plan is being applied properly.

2.5.2 Type of MTI

According to the level of risk of the intended applications (A, B, C), two type of MTI may be distinguished:

- Simplified MTI for class A or B applications
- MTI for class C or B applications.

For class B applications, the possibility is left to simplify the MTI, based on previous shipyard experience for similar applications. Such arrangement is subject to prior agreement by the Society.

As a rule, an MTI bonding plan is drawn up for each different type of bonding application in each ship under Society's survey within the scope of this present guidance note.

However, on shipyard request and with Society's agreement, single MTI bonding plans may be established in order to gather similar bonding applications in one or different ships. In this case, MTI bonding plan must contain any specific procedures that have to be respected according to each type of bonding application.

Examples:

- In one ship surveyed by the Society, all bonding applications could be gathered in one single MTI bonding plan
- One MTI bonding plan could be dedicated to one single bonding application which will be used in different ships.

2.5.3 Content of MTI Bonding Plan

Content of MTI Bonding Plan is detailed in App 1.

SECTION 3 ADHESIVE JOINTS DESIGN ASSESSMENT

Symbols

F : Axial load per unit width, in N/mm

V : Perpendicular load per unit width, in N/mm

M : Moment per unit width, in N

l : Bonding length, in mm

E_c : Adhesive Young Modulus, in MPa

G_c : Adhesive Shear Modulus, in MPa

e_c : Adhesive thickness, in mm

E_1, E_2 : Substrate Young Modulus, in MPa

ν_1, ν_2 : Substrate Poisson Coefficients

e_1, e_2 : Substrate thickness, in mm.

1 General

1.1 Application

1.1.1 This Section defines process to assess adhesive joint design.

1.1.2 In the following section, adhesives are assumed isotropic.

1.2 Design procedure

1.2.1 The flowchart in Fig 1 presents the procedure to design an adhesive joint.

2 Design Loads

2.1 General

2.1.1 The rule load considered for the assembly are the loads defined in the applicable Rules for the classification of ship/unit referred in Sec 1.

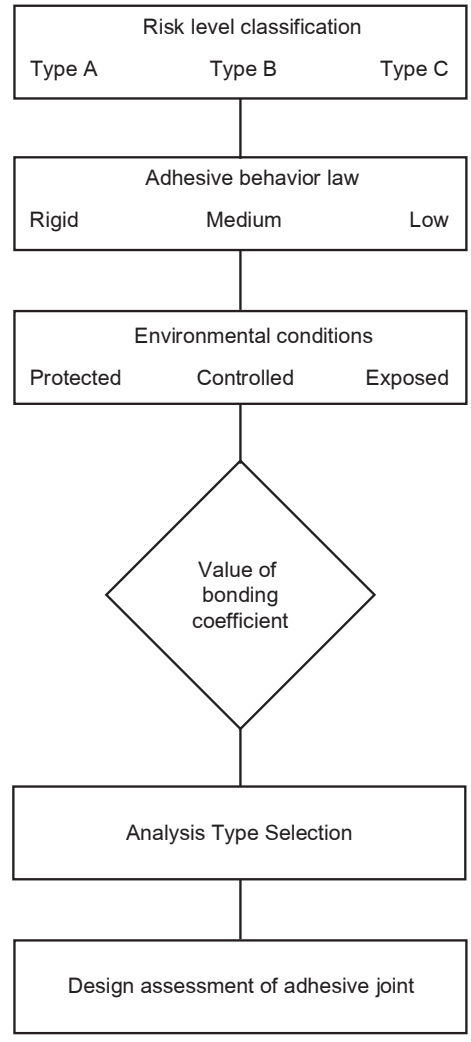
The following categories of loads are considered:

- static loads
- dynamic loads.

2.2 Static and dynamic loads

2.2.1 Static and dynamics loads are to be considered to design the adhesive joint.

Figure 1 : Bonding joint design procedure



3 Analysis type

3.1 Introduction

3.1.1 Four analysis types have been identified to design a bonded joint:

a) Direct analysis

b) Analytic analysis

c) Linear numeric analysis

d) Non-linear numeric analysis.

Depending on the value of the total bonding coefficient, as defined in section 1, analyses can be selected following Tab 1.

Linear or Non-linear Numerical analysis depends on adhesive type.

Table 1 : Analysis type selection

Bonding Coefficient	Analysis Type
0	Direct Analysis and/or tests
1, 2 or 3	Analytic Analysis and/or tests
4 or 5	Linear Numerical Analysis or Non-linear Numerical Analysis, and tests
6	To be discussed with the Society

3.2 Direct Analysis

3.2.1 The average glue stress σ_{da}, in MPa, using the direct analysis is obtained from the following formula:

$$\sigma_{da} = \frac{F}{l}$$

Note 1: In general, the maximal adhesive joint resistance is obtained in shear.

3.3 Analytic Analysis

3.3.1 Shear stress only

The maximal glue shear stress τ_{aa}, in MPa, using the analytic analysis, is obtained from the following formula:

$$\tau_{aa} = \frac{Fwl}{4}\left(\frac{\cosh w}{\sinh\frac{wl}{2}} + Y \times \frac{\sinh w}{\cosh\frac{wl}{2}}\right)$$

$$w = \sqrt{\frac{G_c}{e_c} \times \left(\frac{1}{E_1 e_1} + \frac{1}{E_2 e_2}\right)}$$

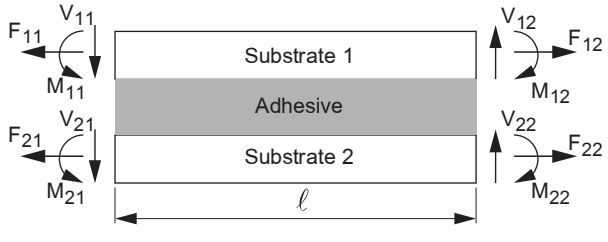
$$Y = \frac{|E_1 e_1 - E_2 e_2|}{E_1 e_1 + E_2 e_2}$$

3.3.2 Shear and Peel stresses

The principle is based on the definition of forces and moments applied on the substrate-adhesive sandwich, (See Fig 2).

Elementary forces and moment can be estimated using Hart-Smith method.

Figure 2 : Elemental sandwich forces and moments



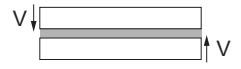
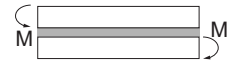
The maximal shear and peel stresses are given by formulas in Tab 2. The substrate1, as defined in Fig 2, is to be the substrate with the smaller thickness.

Any combination of tension, shear and bending moment loading can be applied with the resulting peak shear stress calculated using superposition of the component stresses.

The semi-analytic method developed by Bigwood and Crocombe may also be applied for shear and peel stresses to analyse stresses evolution along the joint.

All stress justifications are to be submitted to the Society for information.

Table 2 : Shear and peel stresses

Loads	Shear stress	Peel stress
	$\tau = \frac{-\alpha_1 F}{2\sqrt{\alpha_1 + \alpha_2}}$	0
	$\tau = \frac{-3V}{4e_1}$	$\sigma = \frac{-\sqrt{2}\beta_1 V}{\sqrt[4]{(\beta_1 + \beta_2)^3}}$
	$\tau = \frac{3\alpha_1 M}{e_1\sqrt{\alpha_1 + \alpha_2}}$	$\sigma = \frac{\beta_1 M}{\sqrt{\beta_1 + \beta_2}}$

Note 1:

$$\alpha_1 = \frac{G_c(1-\nu_1^2)}{E_1 e_1 e_c}$$

$$\alpha_2 = \frac{G_c(1-\nu_2^2)}{E_2 e_2 e_c}$$

$$\beta_1 = \frac{12 E_c(1-\nu_1^2)}{E_1 e_1^3 e_c}$$

$$\beta_2 = \frac{12 E_c(1-\nu_2^2)}{E_2 e_2^3 e_c}$$

3.4 Numeric Analysis

3.4.1 Finite Element method

The numerical approach is based on the Finite Element Method. The model is to be composed of the assembled structures, and is to include the bonded joint

a) Meshing

The mesh is to be defined using shell elements and/or solid elements for adherents and solid elements for the glue, with or without mid-side nodes.

Meshing is to be carried out following uniformity criteria among the different elements.

Most of quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length does not exceed 2. Some of them may have a ratio greater than 2, but not exceeding 4. Their angles are to be greater than 60° and less than 120°. The triangular element angles are to be greater than 30° and less than 120°.

The number of nodes and elements is to be such that the stiffness and inertia of the model properly represent those of the structure, and the distribution of loads among the various load carrying members is correctly taken into account.

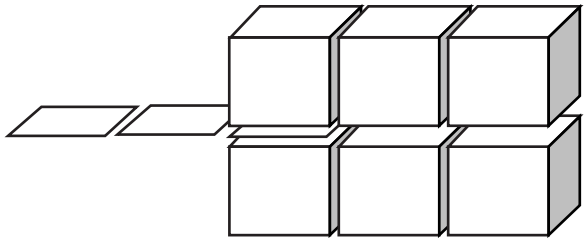
The structural modelling is to be accurate; the mesh dimensions are to be such as to enable a faithful representation of the stress gradients.

In case of local meshing, the mesh area is to be extended and not reduced to the computed part.

The two main reasons for extending the finite elements model are the following:

- the extension of the 3D mesh
- how to model the transition between the shell elements and the solid ones. As shown in Fig 3 the shell elements must be extended inside the solid mesh in order to correctly transfer the rotation degree of freedom of the shell elements to the solid elements.

Figure 3 : Shell / solid connections



Bonded joint is modelled using at least 3 solid elements in the thickness for linear finite elements. If quadratic elements are used, less than 3 elements could be considered.

b) Net scantling

All steel elements are to be modelled with their net scantlings thickness if applicable.

c) Post-processing

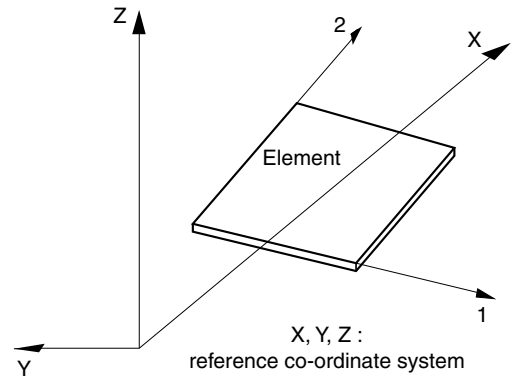
Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 4. The orientation of the element co-ordinate system may or may not coincide with the global coordinate system.

The following stress components are to be calculated at the centroid of each element:

- the normal stresses s12, s12 and s12 in the directions of element co-ordinate system axes
- the shear stress t12, t23 and t13with respect to the element co-ordinate system axes.

Stresses are calculated for each element. The values of these stresses are to be used for carrying out the checks required.

Figure 4 : Reference and element co-ordinate systems



3.4.2 Linear approach mean that material used are defined by a linear elastic law.

In linear elastic model, the material's behaviour is defined by the equation:

$\sigma = E \varepsilon$

where:

σ : Stress in MPa

E : Young's modulus in MPa

ε : Strain.

Finite Element codes typically require two parameters for the definition of the metallic material:

- Young's modulus
- Poisson's ratio.

3.4.3 Non-linear

Non-linear analysis means that the sources of non-linearity are:

- material (hyperelasticity, …)
- geometry (large displacement, …)
- contact…

Adhesives are to be modelled with an appropriate adhesive law but if this law is not available, the adhesives can be modelled with an equivalent elastic law.

This assumption is to be justified by tests on the strain range to be used for the application.

Adhesive failure mode is the critical mode of the bonded joint.

Cohesive element may be used to simulate the bonded joint. But additional tests are to be performed because debonding phenomena are usually characterized by the simultaneous actions of normal and tangential stresses. For the determination of the cohesive parameters, it is necessary to use tests that isolate these debonding modes.

The Double Cantilever Beam test (DCB, see Fig 5) is characterized by a pure normal debonding whereas the End Notched Flexural test (ENF, see Fig 6) produces a pure shear debonding. The DCB test will be used to find the normal cohesive properties whereas the ENF test will be used to calculate the shear cohesive properties.

Figure 5 : Double Cantilever Beam test

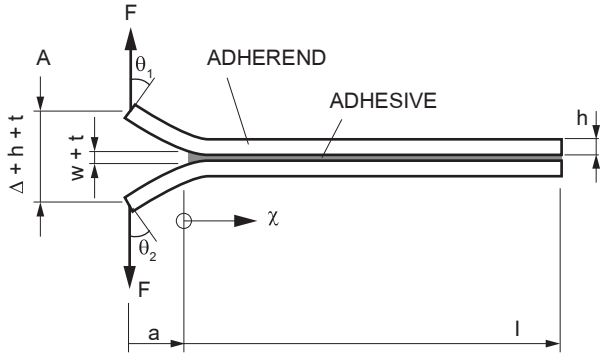
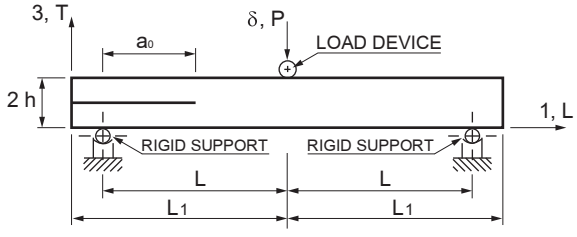


Figure 6 : Notched Flexural test



4 Safety coefficients

4.1 General

4.1.1 Bonded joint design is to achieve the following minimum safety factor SF:

$SF = \alpha\, C_V\, C_F\, C_A$

where:

$\alpha = 2,4$

C_V : Partial safety coefficient taking into account the ageing effect of the adhesive

- $C_V = 1,6$ for exposed joint
- $C_V = 1,2$ for protected joint

C_F : Partial safety coefficient taking into account the type of loads

- $C_F = 1,6$ for dynamic load (impact,…)
- $C_F = 1,2$ for static load

C_A : Partial safety coefficient taking into account the adhesive behaviour law

- $C_A = 1,2$ for rigid adhesive
- $C_A = 1,4$ for medium adhesive
- $C_A = 1,6$ for soft adhesive.

5 Criteria

5.1 General

5.1.1 Adhesive stresses are to comply with the following formula:

$$\frac{\sigma_{adh}}{\sigma_{computed}} \geq SF$$

where:

σ_{adh} : Adhesive system breaking stress measured on test samples representative of real production conditions (environmental, surface treatments, polymerization state…) See Sec 6

$\sigma_{computed}$: Stress computed following see Article [3]

SF : Safety Factor defined in [4].

6 Joint design details

6.1 Joint design details

6.1.1 Typical adhesive joint details are shown in Fig 7 for single overlap and in Fig 8 for double overlap.

In order to avoid or limit peel in adhesive joint, the following solutions, (see Fig 9) may be applied:

The Society could require a mechanical connection in addition to the adhesive joint if deemed necessary.

Figure 7 : Single overlap

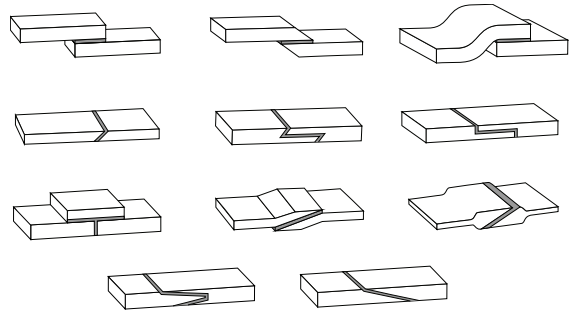


Figure 8 : Double overlap

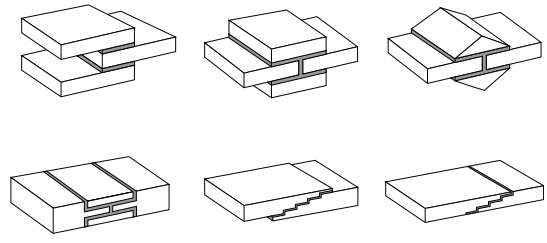
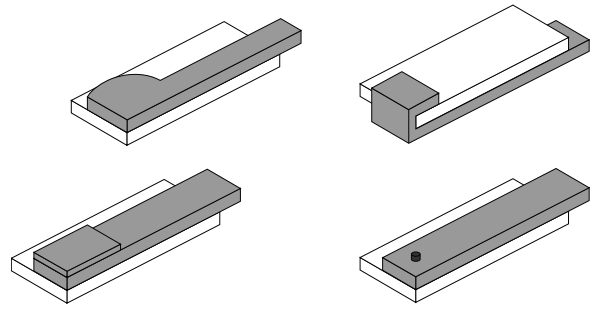


Figure 9 : Peel stress reduction



SECTION 4 ADHESIVES

1 General

1.1 General

1.1.1 A large number and variety of adhesives have been developed by manufacturers to provide solutions for joining an equally wide variety of materials. Therefore, it should be understood that no universal adhesive exist.

Adhesive materials are not to be considered alone but as part of an adhesive system in the sense where final mechanical characteristics of the assembly depend on the following parameters:

- type of adhesive family.
- type of the components to be bonded. as well as their surface preparation
- geometry and thickness of the bonded joint
- curing process of the bonded joint.

Adhesives are generally divided in two categories as:

- structural, where load-bearing properties are needed.
- non-structural or semi structural used for low load-bearing applications. Potting materials and sealants material are also included in this class.

It should be noted that there is no consensus on the exact definition of structural adhesive.

For guidance only, structural adhesives are often described as those achieving more than 7 MPa shear stress in standardized lap shear tests.

Other classification methods could be considered for adhesives as:

- the curing mode like reaction adhesives, solvent adhesives or melt adhesives
- the strain capability of the joint after curing (rigid, flexible)
- the adhesive form: film, liquid, paste, single or two components
- the chemical family of the adhesive, even if it should be noted that some hybrid products exists, sharing properties of different polymer families.

It is the latter classification method which was retained in this guidance note with following main families :

- epoxy-based adhesives
- polyurethane-based adhesives
- acrylic-based adhesives
- silicon
- MS polymer
- others.

2 Adhesive families

2.1 General

2.1.1 The present article gives general information about the main adhesives generally used in marine environment in order to create a permanent connection between parts of same or different materials including:

- metallic material (steel, aluminium, stainless steel)
- composite material
- glazing material (mineral glass, PolyMethylMethAcrilate, polycarbonate)
- others.

2.2 Epoxy-based adhesives

2.2.1 The main features of epoxy-based adhesives are the following ones:

- this thermoset family is one of the most common and one of the most efficient in the range of structural adhesives
- rigid bond and strong mechanical properties depending on formulation (mainly hardener type) and curing mode
- available in single, two components or film form
- good adhesion to many different substrates (composite, metallic substrates, wood…).

2.3 Polyurethane-based adhesives

2.3.1 The main features of polyurethane-based adhesives are the following ones:

- large family with different properties
- flexible or semi flexible bond with moderate mechanical properties depending on product form (single, two components or melt).

2.4 Acrylic-based adhesives

2.4.1 The main features of acrylic-based adhesives are the following ones:

- Very large family with very different properties. They could be thermoset or thermoplastic polymers.
- Structural acrylic adhesives are thermosets with two main sub-families:
  - modified acrylic range (basic polymethylmethacrylate resin grafted with elastomers).
  - anaerobic adhesives mainly used for fastener locking braking applications of threaded metallic pieces and metallic cylindrical assembly.

2.5 Silicone adhesives

2.5.1 The main features of silicone-based adhesives are the following ones:

- Family characterized by basic poly-siloxane structure (Si-C and Si-O linkage) which is responsible for their unusual combination of organic and inorganic chemical properties.
- Used primarily as elastomeric adhesives and sealants, silicone adhesives are now known for their ability to withstand large variations in temperature and to resist to UV.
- Different curing mode as poly-condensation (RTV: Room Temperature Vulcanizing) or poly-addition (HTV: High Temperature Vulcanizing).

2.6 MS polymer

2.6.1 The main features of MS Polymer adhesives are the following ones:

- MS Polymer is Silane Modified polymers which represents a compromise between the polyurethanes and the silicones.
- Single component curing mode: after applying, curing at room temperature with air humidity.
- Two components curing mode: mixing of single component and activator.

2.7 Other adhesives families

2.7.1 Other families like polyester, vinylester or phenolic adhesives with properties similar to resin used in composite building could be considered.

3 Adhesive properties

3.1

3.1.1 For information only, some general adhesive's properties are described in Tab 1 and Tab 2.

4 Homologation of adhesive material

4.1 General

4.1.1 The purpose of the homologation, by the Society, of adhesive materials is to check the compliance of the characteristics of the used materials with the requirements of the relevant Rules of the Society.

The procedure to be followed for the homologation of adhesive materials is described in App 4.

4.2 Equivalent adhesive material homologation process

4.2.1 On a case-by-case basis and particularly when adhesive materials used for bonded joints are known by the Society (type of adhesive material and supplier, previous homologation), specific mechanical tests on adhesive materials may be considered as equivalent to the adhesive material homologation process.

Table 1 : Adhesive properties - Epoxy & Polyurethane (given for general guidance only)

Adhesive family	Epoxy-based			Polyurethane based		
Form available	Single component Pastes or liquids	Two components Pastes or liquids	Film supported (fabrics, frames which allowed thickness calibration) / Film Unsupported (no thickness calibration)	Single component Pastes	Two components Pastes or liquids	Melt polyurethane solid (Granules, sticks.)
Hardening mode	Adhesive in liquid or paste form and already contains the hardener which reacts by the action of heat (T° from 100°C to 200°C).	Mixing a base and a hardener which hardens at RT (or accelerated by heating cycle).	Similar to the chemistry of single component epoxy Curing cycle conveniently performed in an autoclave or oven + vacuum (T° from 90°C to 180°C and pressure from 1 to 7 bars,, vacuum up to -0.9 bars).	At Room Temperature, pasty adhesive which hardens by the action of humidity in the air after application.	Mixing a base and a hardener which hardens by heating or at Room Temperature after application.	By heating the adhesive becomes liquid. After application and cooling, the adhesive becomes solid and hardens under the action of air humidity.
Parameters influencing the hardening	Temperature	Temperature Component ratio Quantity mixed	Temperature Pressure	Air humidity Temperature Adhesive joint width	Temperature Component ratio Quantity mixed	Air humidity Temperature
Handling time		Few minutes to few hours at Room Temperature		Few hours at Room Temperature	Few minutes to few hours at Room Temperature	Few seconds to few minutes at Room Temperature
Complete hardening time	Few minutes to few hours	Few hours by heating cycle to several days at Room Temperature	Few minutes to few hours	Several days at Room Temperature	Several days at Room Temperature	Several days at Room Temperature
Service temperature	- 75°C to + 150°C	- 75°C to + 120°C	- 75°C to + 220°C	- 70°C to + 90°C	- 50°C to + 100°C	- 50°C to + 100°C
Shear strength	20 to 35 MPa	15 to 30 MPa	25 to 45 MPa	1 to 5 MPa	5 to 15 MPa	5 to 15 MPa
Joint flexibility	Rigid (strain < 5 %)	Rigid (strain from 5 to 10 %)	Rigid (strain < 5 %)	Very flexible (strain > 200 %)	Flexible (strain from 30 to 200 %)	Very flexible (strain > 300 %)
Peel strength	2 to 10 N/mm	2 to 10 N/mm	2 to 15 N/mm	4 to 15 N/mm	5 to 15 N/mm	5 to 15 N/mm
Optimum joint thickness	0.05 to 1mm	0.05 to 1mm	0.1 to 0.2mm	0.5 to 5mm	0.5 to 3mm	0.1 to 1mm
Maximum Joint thickness	Few mm	Few mm	0,5 mm	Few mm	Few mm	Few mm
Viscosity	5000 to 1000000 mPa.s	2000 to 1000000 mPa.s		>1000000 mPa.s	5000 to 1000000 mPa.s	
Advantages	High mechanical strength Hardening time No mixing temperature Environment and chemical agents resistance	High mechanical strength Hardening at Room Temperature Environment and chemical agents resistance Gap filing propertie	High mechanical strength Very low shrinkage Thermal strength	No mixing Hardening at Room Temperature Joint flexibility Gap filing properties	Hardening at Room Temperature Joint flexibility Mechanical strength	Handling time Joint flexibility Mechanical strength
Disadvantages	Hardening by heating (> 100°C) Risk of allergies Storage at T° <20 ° C	Hardening time Harmfulness of some hardener	Hardening by autoclave or oven + vacuum Risk of allergies Storage to T° < -20°C Cutting time	Hardening time Storage UV resistance Harmfulness of iso cyanate Do not allow bonding large surfaces	Harmfulness of iso cyanate Components mixing	Store away from humidity Harmfulness of iso cyanate Do not allow bonding large surfaces
Applications	Structural	Structural	Structural	Sealant / semi structural / glazing	Semi structural / structural	Semi structural / structural

Table 2 : Adhesive properties - others (given for general guidance only)

Adhesive family	Silicone	MS Polymer	Acrylic-based adhesives	Anaerobic
Form available	Single or two components	Single or two components	Two components or "No-mix"	Single component liquid
Hardening mode	For RTV silicone, by poly-condensation at Room Temperature and with air humidity (could be accelerated by heat T°<80°C). For HTV silicone, by poly-addition with heating cycle (T° from 120°C to 200°C).	For single component, at Room Temperature and with air humidity (could be accelerated by heating T°<80°C). For two components, at Room Temperature after mixing (could be accelerated by heating T°<80°C).	For two component, at Room Temperature after mixing base and hardener (could be accelerated by heating T°<80°C). For no mix, at Room Temperature, hardening by contact further application of the base on one face and activator on the other face (could be accelerated by heating T°<80°C).	Hardening at Room Temperature, without oxygen and only on metallic surface (catalytic effect of metal ions). Could be accelerated by accelerator or heated T°<100°C).
Parameters influencing the hardening	Temperature Air humidity	Temperature Air humidity	Temperature	Temperature Joint thickness Metal type
Handling time	Few minutes to few hours for RTV silicone. Few minutes to 1 hour for HTV silicone.	Few hours for single component Few minutes to 1 hour for two components	Few minutes at Room Temperature	Few minutes
Complete hardening time	Several days for RTV silicone 30 minutes to 1 hours for HTV silicone	Several days for single component	Few hours at Room Temperature	Few hours
Service temperature	- 75°C to + 250°C	- 40°C to + 100°C	- 40°C to + 120°C	- 50°C to + 150°C
Shear strength	0,5 to 4 MPa	1 to 4 MPa	15 to 30 MPa	10 to 30 MPa
Joint flexibility	Very flexible (strain > 200 %)	Very flexible (strain > 100 %)	Flexible (strain from 30 to 150 %)	Rigid (strain from 5 to 10 %)
Peel strength	5 to 15 N /mm	4 to 15 N / mm	5 to 10 N / mm	Low
Optimum joint thickness	0.5 to 5mm	0.5 to 5mm	0.5 to 1mm	< 0.1mm
Maximum Joint thickness	Few mm	Few mm	0,3 mm (No-mix) to few mm (two components)	0.2mm
Viscosity	>1000000 mPa.s for single component 3000 to 350000 mPa.s for two components	>1000000 mPa.s	5000 to 500000 mPa.s	50 to 3000 mPa.s
Advantages	Thermal resistance	Joint flexibility Tolerance to the surface cleanness UV resistance paintable seal	Mechanical strength Hardening time at Room Temperature Gap filing properties for two components Tolerance to the surface cleanness	Mechanical strength Hardening time at Room Temperature
Disadvantages	Metallic corrosion for single component with acetic base Hardening time	Hardening time	Strong odour	Thin joint Need metal ions
Applications	Sealant / semi structural / glazing	Sealant / semi structural / glazing	Structural	Structural / metallic fastener locking

SECTION 5 SURFACE PREPARATION

1 General

1.1 General

1.1.1 Surface preparation is an important process in the quality scheme of bonding joints. Surface preparation is to be cared to ensure the maximal quality and reliability of the adhesive joint assembly.

Surface preparation is to be in line with bonding manufacturer specification. Any deviation will be subject to agreement society and bonding manufacturer.

This section gives main requirements for preparing the surface before bonding.

Specific shipyard process is to be submitted in order to be validated by the Society.

2 Adherent Material Type

2.1 Steel (Painted or not)

2.1.1 Generally, process to prepare bonding surface is to be the following:

- cleaning and degreasing
- surface abrasion
- cleaning and degreasing
- primer, if any.

2.2 Aluminium alloy

2.2.1 Process to prepare bonding surface is to be the following:

- cleaning and degreasing
- surface abrasion
- cleaning and degreasing
- primer, if any.

2.3 Other metallic adherents

2.3.1 Other metallic adherent type will be reviewed on a case-by-case basis by the Society.

2.4 Composite

2.4.1 Process to prepare bonding surface is to be the following:

- cleaning and degreasing
- surface abrasion
- cleaning and degreasing.

2.5 Glass

2.5.1 Process to prepare bonding surface is to be the following:

Cleaning and degreasing.

2.6 Other

2.6.1 Other adherent type (wood, …) will be reviewed on a case-by-case basis by the Society.

3 Surface preparation

3.1 Cleaning and degreasing

3.1.1 Knowing the characteristics to which a cleaner must comply with, it is important to make the more convenient choice and get the best bonding solution after surface treatment:

- cleaner must be able to remove all that is soluble in water (dirt, salts, etc..) and also insoluble in water (dirt, oil, grease, etc..) from the surface
- cleaner should evaporate or be removed quickly without any residue
- cleaner must not damage the materials to be bonded. That is, as a general concept, not to generate corrosion of metals, for example
- cleaning product is to be harmless to health and environment.

There are two major families of cleaners:

- Organic: alcohols (isopropyl) and acetone are the most common
- Aqueous: Alkaline (pH> 9) cleaners are recommended because they can remove hydrocarbon derivatives, soaps and metal salts. Non-ionic detergents also give good results.

Cleaning and degreasing must be made with a lint-free cloth and the wiping action should be applied only in one direction, without rubbing. After each wipe the cloth should be refolded to expose another clean area ready for wiping the surface.

3.2 Surface abrasion

3.2.1 Different methods which can be used to prepare bonding surface are:

- grit blasting (only for metallic adherent)
- bristle blaster (only for metallic adherent)
- sand paper.

Needle gun is not recommended, surface treatment is not sufficient for adequate bonding.

The selection of the method used for the preparation of a surface will depend on:

- state of the surface
- dimensions of the surface to be prepared
- specific readiness required
- requirements relating to particular operating conditions.

Surface abrasion can be carried out wet or dry. The following sequence is recommended:

- perform abrasion in one direction, until the entire surface has been slightly and uniformly scarified
- perform abrasion in the direction perpendicular to the last, until all traces of the process are eliminated
- perform abrasion by means of a circular movement until removed, again, all traces of the previous point, and until surface looks uniform
- remove loose material, cleaning with solvent and a clean lint free cloth
- glue or perform other processing of surface modification.

3.3 Primers

3.3.1 Primers are products, mostly liquids, which are applied to an adherent prior to application of an adhesive, paint or sealant. The reasons for using them are the following:

- protection of the surface after a treatment
- modifying the surface free energy by providing a more easily wettable surface than the original adherent
- promoting chemical reaction between the adhesive and the adherent
- dissolving low levels of organic contamination that otherwise would remain at the interface as a weak boundary layer
- inhibiting corrosion of the adherent during service
- serving as an intermediate layer to enhance the physical properties of the joint and improve bond strength
- penetrating porous or rough surfaces to provide better mechanical interlocking
- sealing surfaces from the environment.

Usually, a primer is needed when the adhesive or sealant cannot be applied immediately after surface preparation, when a surface is weak or porous, or when the joint interface requires additional protection from service environments, which is the case in marine environment.

Primers are applied quickly after surface preparation and result in a dry or slightly tacky film. It is generally recommended that they have a dried coating thickness range of tenths of a millimetre. It is necessary to control the primer thickness, since if the primer layer becomes too thick its bulk properties may predominate, and the primer could become the weakest part of the joint.

3.4 Surface preparation tests

3.4.1 Surface preparation may be tested according to one of the following methods:

- Method 1 – Wettability – NF EN 828

  Determination by measurement of contact angle and critical surface tension of solid surface.
- Method 2 – Wetting Tension – ASTM D2578

  Standard test method for wetting tension
- Method 3 – Pull test

  Pull tests are to be performed in the same condition that the bonding. This test consists of applying an upward force and comparing the pulling force with the design force.

SECTION 6 TESTS

1 General

1.1 General

1.1.1 The present Section gives general information on adhesive testing. Depending on the test purpose, some recommended test methods are described without being an exhaustive listing. Other tests methods can be considered if they are relevant.

1.2 Aim of tests

1.2.1 Reasons of testing can be summed up as following:

- materials (adhesives, substrates) and bonding process selection
- design data
- durability assessment
- quality control tests before and during use
- end products control.

1.3 Test type overview

1.3.1 An extensive range of test methods exists for characterizing adhesives and bonded joint.

They can be:

- standardized or not
- with qualitative or quantitative purpose
- performed on bulk specimens or on bonded joint specimens.

The usefulness and limitations of testing methods should be clearly understood before starting a testing program.

1.3.2 Standard tests / non standardized tests

The main interest of standardized tests is the possibility of reliable comparison between different testing operators / laboratories. Especially in testing of adhesives, this is conditioned by strict compliance of the used standard procedure, associated if missing, with a thorough documentation on the performed tests parameters (substrates surface preparation or test, environmental conditions or test speed for instance). Therefore even with standardized tests, proper interpretation of results requires sufficient background on adhesive testing.

Standard tests are mainly useful for comparing materials properties and determining the consistency of materials and processes. They are less valuable in accurately predicting the strength of bonded joints. Modified standard tests or specific prototype tests must often be designed for this purpose.

In any case, use of standardized tests or not by every personnel involved in adhesive testing (from laboratory to shipyard operator) should be conducted with the same rigor in order to ensure reproducibility and correct interpretation of tests results for the end user.

1.3.3 Qualitative - quantitative tests

Most of tests can only be used for qualitative / comparative measurement. Only a limited number of test methods are suitable for generating design / quantitative data.

1.3.4 Tests on bulk or on bonded joint specimens

Two approaches coexist in order to determine reliable mechanical properties of adhesives: testing on bulk specimens or bonded joint specimens.

Both options have their own limitations. The choice of the test will also depend on adhesive's form (film, liquid, paste…) and its compatibility with test specimen preparation.

As a rule, bulk tests are more straightforward to perform and they give intrinsic material properties as the specimen is free of any stress concentration (tensile test for instance). However, for specimens' preparation, care should be taken:

- with exothermic reactions for thick adhesive specimens that can cause overheating and residual thermal stress
- content in defects as porosity may affect adhesive failure behaviour (mainly for strain in tensile and less effect for strain in shear).

The other approach is to use specially designed joint / prototype tests. These tests more closely represent reality but with some problems associated to adhesive joint configuration:

- stress distribution is most of the time non uniform due to stress concentration at bond line ends
- accuracy and reliability of displacement measurements as magnitude is often small.

2 Tests

2.1 Physico-chemical tests

2.1.1 Non exhaustive list of testing methods for determining some physico-chemical properties is described in Tab 1.

2.2 Mechanical tests

2.2.1 Non exhaustive list of testing methods for determining some mechanical properties is described in Tab 2.

Table 1 : Physico-chemical tests

Properties	Usefulness	Comments	Standard / test methods
Measurement of Tg or other transition temperature of adhesives	Adhesive selection Quality Control R&D	Both means commonly used to measure transition temperature are DSC (Differential Scanning Calorimetry) and DMA (Dynamic Mechanical Analysis)	DSC: • ISO 11357-2 • ASTM E1356 • ASTM D3418 DMA: • ISO 6721-11 • ASTM D7028 • ASTM E1640
Density	Quality Control	As a general rule, density of adhesives may vary from 0.8 to 1.5 Adhesive manufacturer technical data sheet must indicate density of the product	EN ISO 1675 ISO 1183 NF EN 542 NF EN 543
Viscosity	Adhesive selection Quality Control		EN 12092 ASTM D2556 ASTM D1084 EN ISO 2555 ISO 3219
Pot life	Adhesive selection Quality Control	Characteristic related to 2 component adhesives. Pot life is the time during which the adhesive may be used after components mixing	NF EN 14022 ISO 10364
Filler content	Adhesive selection R&D Durability assessment…	Method used to measure content of mineral fillers or other solid raw material in adhesives. They are used by adhesive manufacturer in order to modify / improve properties of adhesive (viscosity, mechanical, electric, durability, cost…). According to their shape, for example, fillers may even induce anisotropy in the behaviour of the adhesive. Their interaction with moisture and / or metal substrates may also cause effects on durability of adhesive joints	NF EN 1246 NF EN 827 ASTM D5040 ASTM D1489
Water absorption	Adhesive selection Quality Control R&D Durability assessment…		NF EN ISO 62 ASTM D570
Coefficient of thermal expansion	Adhesive selection Design	Parameter to be taken into account in the case of assembly of different materials	ASTM D696 ISO 11359-2
Hardness	Quality control	Comparative method measurement can give an indication of the degree of cure of the adhesive	ISO 868 ASTM C661 ASTM D2240
Adherend surface quality	Adhesive selection Quality control	Comparative methods to be used for adherent surface preparation before bonding	NF EN 828 ASTM D2578 ISO 8296 Pull off test ASTM D3808 Rugosity
pH	Adhesive selection Quality Control R&D Durability assessment	Some adhesive can be acidic or alkaline under influence of moisture with the time. This can lead to corrosion of metallic adherent and decrease durability of bonding joint. pH can be measured only on water dispersion or solutions depending on the type of adhesive formulation	EN 1245 ASTM D3310 ASTM D1583
Resistance to UV	Adhesive selection R&D Durability assessment	For exposed bonded joint	ASTM D412 EN ISO 4892
Resistance to chemicals	Adhesive selection R&D Durability assessment	Adhesive resistance against aggressive media commonly encountered in operating environment is to be specified by adhesive supplier	ASTM D896

Table 2 : Mechanical tests

Tests methods		Standard	Benefits	Limitations
Tensile	Bulk	ISO 527-2 ASTM D638	• Specimen fabrication and testing straightforward • Pure stress state Suitable for design data	• Specimen fabrication: caution for exothermic reaction in thick specimens • Strain to failure dependent on the presence of defects (porosity, cracks)
	Butt Joint	ASTM D897 ASTM D2095 ISO 6922	• Suitable for comparative assessment, adhesive selection, quality control • Specimen fabrication and testing straightforward • Possible for fatigue / creep / environmental testing	• Not suitable for generating design data • Strength sensitive to spew fillet • Sensitive to specimen misalignment • Measurement reproducibility
Compression	Bulk	• Soft adhesives ISO 7743 ASTM D575 • Rigid adhesives ISO 604 ASTM D695	• As a rule, it is assumed the compressive and tensile properties are the same, excepted when hydrostatic stress component influence adhesive's yield and failure	• Test different for soft and rigid adhesives
Shear	Single Lap Joints (SLJ) Double-Lap Joints (DLJ)	ASTM D 1002 ASTM D 3163 ASTM D 3164 ASTM D3165 ASTM D 3166 ASTM D 3528 ASTM D 5868 EN 1465 ISO 4587 EN ISO 9664	• Specimen fabrication and testing straightforward • Suitable for comparative assessment, adhesive selection, quality control • Possible for fatigue / creep / environmental testing	• Not suitable for generating design data (Yields "apparent" shear strength only) • Geometry dependent (adhesive thickness, overlap length…) • Caution of failure mode for proper analysis (peel, adherent yielding…) • Limited to rigid adherents • SLJ: Moderate to high bending moments due to loading misalignment Elevated shear and peel stresses at bondline ends • Double lap / double strap joint tests reduce peel stresses but do not ensure uniform shear stress • Measurement reproducibility
	V-Notched beam (Iosipescu)	ASTM D5379	• Bulk or joint specimen • Suitable for design data • Suitable environmental testing	• Bulk Resin: strain gauges (2 biaxial rosettes) required • Adhesive Joints: difficulties with small deformation measurement • Accurate specimen machining required • Special test fixture required • Unsuitable for fatigue / creep testing
	Arcan (V-Notched plate) Modified Arcan	No standard	• Versatile testing method (tensile / shear loading combination possible) • Bulk or joint specimen • Stress state relatively uniform (improve with modified arcan test) • Suitable for design data • Suitable for fatigue / creep / environmental testing	• Difficulties with small strain measurement • Strain gauges / extensometer required • Accurate specimen machining required Special test fixture required • No existing standard
	Torsion Rod / Butt	No standard	• Bulk or joint specimen • Suitable for design data • Suitable for fatigue / creep / environmental testing	• Torsion facility required • Bulk specimens: Caution for exothermic reaction • Adhesive Joints Small strains - difficult to measure accurately • No existing standard
	Napkin Ring	ASTM E229 ISO 11003-1 NF EN 14869-1	• Stress state relatively uniform • Suitable for design data • Suitable for fatigue / environmental testing	• Torsion facility required • Accurate specimen machining required • Small strains difficult to measure • Bondline thickness difficult to control

Tests methods		Standard	Benefits	Limitations
Shear (continued)	TAST Modified TAST	TAST: • ASTM D3983 • ISO 11003-2 • NF EN 14869-2 Modified TAST: no standard	• Stress state relatively uniform over bondline • Suitable for design data • TAST specimen fabrication and testing relatively straightforward • Suitable for environmental testing	• Difficulties with small deformation measurement (2 extensometers required) • Accurate stress analysis difficult / concentrations present at bondline ends (can be reduce with Modified TAST- special test fixture required or spew fillet) • Limited fatigue capability
	End Notched Flexure (ENF)	No standard	• Mode II fracture toughness • Specimen fabrication and testing straightforward • Suitable for fatigue/environmental testing	• Limited to rigid adherends and adhesives • Special test fixture required • Not suitable for generating design data • Results analysis difficult • Measurements reproducibility
Peel	T peel	ASTM D1876 ISO 11339 ISO 8510-2	• Specimen fabrication and testing straightforward • Suitable for comparative assessment, adhesive selection, quality control • Possible for environmental testing	• Limited to thin flexible adherends • Not suitable for generating design data • Measurement reproducibility • Unsuitable for fatigue / creep testing
	Climbing Drum	ASTM D1781	• Testing straightforward • Suitable for comparative assessment, adhesive selection, quality control for sandwich skins	• Special test fixture required • Specimen fabrication • Not suitable for generating design data • Unsuitable for fatigue / creep / environmental testing
	Floating Roller Method	ASTM D3167 ISO 4578 NF EN 1464	• Specimen fabrication and testing relatively straightforward • Suitable for comparative assessment, adhesive selection, quality control	• Special test fixture required • Limited to rigid-to-flexible adherends • Not suitable for generating design data • Unsuitable for fatigue / creep / environmental testing
Cleavage	Wedge Cleavage (Boeing Wedge)	ATSM D3762 ISO 15107 ISO 10354	• Mode I fracture toughness • Specimen fabrication and testing straightforward • Suitable for environmental testing • Effective comparative method for durability assessment of adhesive and adherents surface preparation • Accurate and reproducible data • Variant method (chip test) for brittle materials	• Limited to rigid adhesives and adherents • Unsuitable for fatigue / creep loading
	Cleavage Strength (Compact Tension)	ASTM D1062	• Mode I fracture toughness • Specimen fabrication and testing relatively straightforward • Suitable for comparative assessment, adhesive selection, quality control • Suitable for environmental/fatigue testing	• Special test fixture required • Limited to rigid adherends • Not suitable for generating design data
	Double Cantilever Beam (DCB)	ASTM D3433 ISO 25217	• Mode I fracture toughness Specimen fabrication and testing straightforward • Suitable for fatigue / environmental testing	• Limited to rigid adherends • Fracture energy vary with length of failure • Special test fixture required • Results analysis difficult • Limited ability for generating design data • Measurements reproducibility
	Tapered Double Cantilever Beam (TDCB)	ASTM D3433 ISO 25217	• Mode I fracture toughness • Specimen fabrication and testing relatively straightforward • Suitable for fatigue / environmental testing	• Limited to rigid adherends • Large specimens required • Not suitable for generating design data Special test fixture required • Measurements reproducibility

Tests methods	Standard	Benefits	Limitations
Dynamic Test	ISO 6721 series (1/12) ASTM D4065 ASTM D4092 ASTM D5023 ASTM D5024 ASTM D5026 ASTM D5279 ASTM D5418	• Alternative and versatile methods (tensile, flexural, compression, torsion) which can used for determining glass transition temperature or generating mechanical properties relatively close from those obtained with static tests • Modulus (E, G) may be obtained as a function of frequency or temperature • Non-destructive methods • Specimen fabrication and testing relatively straightforward • Bulk or joint specimen • Methods which may use specimens prepared for other static tests (tensile bulk, TAST...) • Suitable for R&D, adhesive characterization and selection, quality control	• Unsuitable for soft adhesive • High vibration frequencies may generate self-heating of test specimens this which may lead to biased results

2.3 Durability tests

2.3.1 Assessment of bonded joints durability involves interaction knowledge of particularly complex aging mechanisms.

Causes which can decrease lifetime of bonded joints are mainly mechanical loading combined with environmental factors as temperature and moisture particularly.

No universal method has been yet established to estimate lifetime of bonded joints in service.

Repeated long term testing in the expected environmental conditions is generally considered as the most efficient method but for practical and financial reasons this type of testing is not always possible or cost effective.

These considerations lead to the necessity to define and use others tests methods.

Some standard test methods described in Table 1 and Table 2 may be used. Due to the variety of application cases and specific behaviour of each type of adhesive, other test methods may be used.

Another alternative approach may be the use of accelerated tests methods.

The determination of accelerated tests consists of four steps:

a) Definition of environment in which the bonded application will evolve (temperature, moisture, UV, other chemical media, mechanical load, water, etc)

b) Identification of degradation mechanisms (physical, chemical, combined)

c) Identification of accelerating factors: combined loads (fatigue, static); temperature (isothermal, cyclic); hydrothermal; etc

d) Identification of indicators (residual strength, stiffness, fatigue life, etc.

Once these steps have been performed it is necessary to define a level of application of accelerating factors and a duration of accelerated test representative of the product lifetime.

The methods development to determine the time reduction in function of the level of application of the accelerating factor could be either empirical using as input the environmental factors in tests protocols or analytical using as input the controlling variables (geometry, loading history, material properties, etc.).

2.4 Non-destructive tests

2.4.1 General

The aim of Non-Destructive Tests (NDT) is to confirm if the manufacturing process has not generated defects which could reduce the structural integrity.

Any available NDT methods have some limitation in terms of type of detected defects, depth of inspection, inspected material type. It should be clearly understood that no NDT can provide a quantitative assessment of bonded joint strength.

Defects which are not detectable should be prevented by alternative and suitable quality control methods.

A special attention is to be drawn at the design stage to ensure accessibility of inspection equipments.

Non-Destructive controls and results interpretation are to be performed by personnel with relevant qualifications and with sufficient experience.

The basic principle of inspection is to proceed to a calibration of the NDT method on sounded area. Assessment is based on responses comparison between a sounded area and an inspected area which may contain defects.

The NDT program and defects acceptance criteria are to be defined by the shipyard.

2.4.2 Defects

The main classes of defects which can significantly impair joint strength are described on Tab 3.

2.4.3 NDT Methods

Non exhaustive list of NDT methods is described in Tab 4.

Table 3 : Type of defects and main causes

Defects type		Main causes
1	Porosity	Loss of volatile product, occurence of gas bubble, insufficient pressure during curing of adhesive
2	Voids or cavities	Concentration of porosity, lack of adhesive during application
3	Debonds between adherends and adhesive	Poor surface preparation, occurence of solid form contaminant as grit, swarf, or peel ply...
4	Poor adhesive polymerisation	Non homogeneous adhesive (poor mixing), non-respect of curing specifications of adhesive (time, temperature)
5	Cracks	High thermal stress not controlled during curing of adhesive

Table 4 : Comparative table on NDT methods

NDT Methods		Advantages	Disadvantages
Visual inspection	• First NDT method to implement prior any other methods • Highlighted surface defects (cracks / disbond), lack / excess of adhesive	• Simple method	• Not sufficient / only highlighted of gross defects
Taping	• Analysis of the acoustic response of a material to a mechanical shock • Manual or automated methods • Highlighted of large volume defects (few mm)	• Simple method	• Results difficult to interpret for manual method (experienced operator depending) • Low depth controlled • Not suitable for complex shapes
Ultrasonic	• Based on the principle of ultrasonic wave propagation (emission / reception) • Highlighted of small volume defects	• Efficient method • Positioning and sizing of defects • Automated method possible	• Not suitable for all material • Personnel qualification
Acoustic emission	• Acoustic analysis of the tested component response by mechanical straining	• Sensitive to the evolution of defects	• Mechanical straining of the component needed
Mechanical Impedance	• Various methods where the structure is excited with relatively low frequency mechanical vibrations and its response to these excitations is measured	• Commercial available instruments	• Comparative methods with difficulties for calibration
Radiography	• An image is formed following differential absorption of X-ray energy by elements present in the component • Enables the volumetric inspection of components	• Efficient method • Positioning and sizing of small defects • Automated method possible	• Expensive method • Personnel qualification • X-rays safety issues
Thermography	• Heating of the element to check / Analysis of emitted temperature • Any discontinuities affect the rate of heat conduction • Highlighted of medium volume defects	• Efficient method • Suitable for large surface	• Low depth controlled / depend on thickness and material type • Poor accuracy / no sizing of defects

SECTION 7 FIRE SAFETY

1 General

1.1 General

1.1.1 The purpose of this section is to detail under which conditions adhesive may be used from the fire safety point of view.

1.2 Fire safety considerations applied to adhesive joints

1.2.1 The fire safety matters should be considered on a case by case basis, depending on the applicable rules, the type of ship and where the adhesive joints are used.

The two main identified criteria are:

a) Fire resistance and structural strength (including smoke and flame tightness, fire insulation),

b) Fire reaction (flammability, smoke and toxicity)

1.3 Test laboratory

1.3.1 As a rule, fire tests are to be carried out in recognized test laboratories (the up-to-date list is issued by IMO every year).

2 Rules and codes

2.1 BV, IMO and other codes

2.1.1 When the Administration of the State whose Flag the ship is entitled to fly has issued specific rules covering fire protection, such rules should be taken into account.

2.1.2 NR467, BV Rules for the Classification of steel ships; NR500, BV Rules for the Classification of Yachts; NR566, BV Hull Arrangement, Stability & Systems for ships less than 500GT.

2.1.3 The international Convention for Safety of Life At Sea (SOLAS).

2.1.4 The international Code for application of Fire Test Procedures (FTP Code) as adopted by Resolution MSC.307(88).

2.2 Requirements in SOLAS

2.2.1 According to SOLAS and BV NR467, the hull, superstructures, structural bulkhead, decks and deckhouses shall be constructed of steel or other equivalent material.

In addition, crowns and casings of machinery spaces of category A as well as stairways frame (in accommodation and service spaces) shall be made of steel.

3 Application

3.1 General

3.1.1 For each application, several points should be taken into account:

- The type of division (A or B class division, no fire class), load-bearing or not.
- The location where the bonding will be used.

Two main cases are identified:

a) Cases where the A or B class of the division may be impaired by the bonding.

b) Cases where the A or B class of the division will not be impaired by the bonding.

3.2 Cases where the A or B class of the division may be impaired

3.2.1 Fire tests on the adhesive

In such cases, depending on the area of adhesive which will be exposed to fire and the location (e.g.: escape route, stairway enclosure), some fire tests may be requested:

a) Smoke and toxicity test (FTP Code, Annex 1, Part 2)

b) Test for surface flammability (FTP Code, Annex 1, Part 5)

3.2.2 Fire test on the structure

In addition, it should be demonstrated that the integrity (smoke and fire tightness, under load if deemed necessary) and fire insulation are maintained for the required length of time. A full-scale test may be requested (see FTP Code, Annex 1, Part 3 and Part 11 for test procedure).

3.3 Cases where the A or B class of the division may not be impaired

3.3.1 In such cases, depending on the area of adhesive which will be exposed to fire and the location (e.g.: escape route, stairway enclosure), some fire tests may be requested:

a) Smoke and toxicity test (FTP Code, Annex 1, Part 2)

b) Test for surface flammability (FTP Code, Annex 1, Part 5).

SECTION 8 PATCH REPAIR

1 General

1.1 General

1.1.1 Composite patch can be bonded on metallic or composite plate to repair:

- corroded area, or
- crack.

This Section is only applied for non-structural patch repair, not participating to hull girder strength.

The criticality of the damage will be evaluated by the Society and possibility to repair will be granted by the Society on a case by case basis.

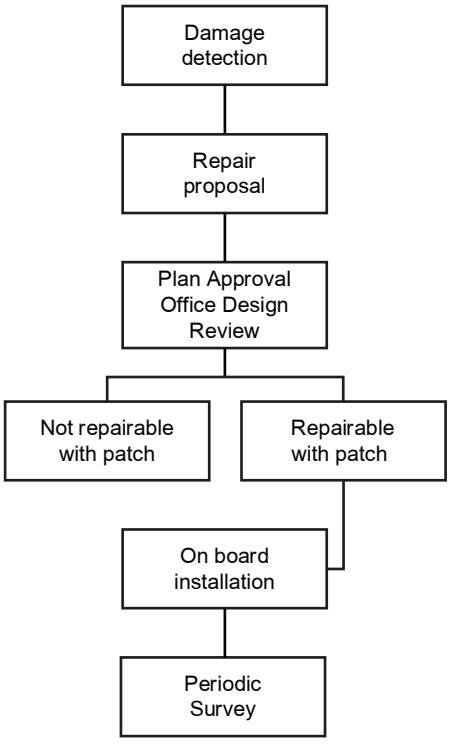
Requirements indicated in the previous sections are applicable for patch bonding, when relevant.

2 Patch repair process

2.1 Flowchart

2.1.1 The diagram in Fig 1 indicates the patch repair process to be applied.

Figure 1 : Patch repair process



2.2 Damage detection

2.2.1 In case of identification of significant corrosion or structural damage detected during an inspection, measures are to be implemented for the repair.

The Society must be informed about:

- type of damage
- eExtent of damage
- lLocation of damage
- cCause of damage, if any.

2.3 Repair proposal

2.3.1 The repair proposal must indicate:

- process to repair
- materials properties for composites
- survey planning
- efficiency of patch repair
- scantling analysis.

2.4 Plan Approval Office design review

2.4.1 Patch repair design reliability is to be assessed by Plan Approval Office to confirm reparability by patch or not.

The reliability parameters are:

a) The criticality of the damage depending on:
   - the size and the accessibility of the crack
   - the corrosion's extended area and thickness reduction.

b) The criticality of the element repaired depending on:
   - the location of the damage onboard
   - the type of damaged structure.

c) The environment of the repair depending on:
   - the type of loads
   - the inspection possibilities
   - the category of spaces.

2.4.2 In case of:

- Low criticality: Repairable with patch
- High criticality: Not repairable with patch
- Medium criticality: additional tests and/or computations may be required by the Society on a case by case basis.

2.5 Patch Repair design assessment

2.5.1 The design assessment justification is to be submitted to the society for review.

All documents, drawings, calculations notes, tests reports allowing the understanding of the patch repair are to be submitted to the Society.

The design will be validated by the Society on a case by case basis.

2.6 Onboard installation

2.6.1 The patch installation onboard is composed of 3 steps:

- surface preparation
- patch application
- curing process, when relevant.

The requirements indicated in Sec 5 for the surface preparation are to be applied.

The laminating method used for the manufacturing of the patch is to be in accordance with NR546.

2.7 Periodic survey

2.7.1 A periodic survey will be defined with the Society on a case by case basis and patch repairs should be easily accessible for visual inspection.

The following Tab 1 gives the typical inspection planning for a patch.

In case of defects of the patch detected before the inspection, the Society should be informed to take a decision.

In general, the types of defects are:

- loss of adhesion to substrate surface
- loss of patch integrity
- crack propagation
- patch failure.

Table 1 : Patch repairs inspection planning

Three months following repairs	Every month
3 to 12 months following repairs	Every 3 months
12 months to 2 years following repairs	Every 6 months
2 years to 3 years	Once a year (ie at 36 months)
More than three years	Normal periodic survey, but should be checked at each survey

3 Certificate

3.1 Classification certificate

3.1.1 In the case of repair by composite patches the Classification Certificate Hull Annex must be amended and the repair verified as acceptable as a "permanent repair" (see [4]).

When a repair is accepted as permanent a "memoranda" will be issued on the Hull Annex which describes the location and type of repair used. This is performed in order to provide transparency to any interested party. In cases where the repair is considered to be temporary, for later permanent repair or later acceptance as a permanent repair a recommendation/condition of class requiring re-inspection may be endorsed.

3.2 Statutory certificates

3.2.1 In the case of repair by composite patches the International Safety Construction Certificate and possibly also the International (or National) Load Line and Cargo Fitness Certificates amongst others must be considered and the repair verified as acceptable.

4 Permanent Repair / Nomenclature

4.1 General

4.1.1 The term **"**Permanent Repair**"** is of cardinal importance in the understanding of the requirements of Class and Statutory Bodies. In order to provide clarity on this a description of repair types follows below.

4.2 Prompt and thorough repair

4.2.1 A **"**prompt and thorough repair**"** is a permanent repair completed at the time of survey to the satisfaction of the attending surveyor.

4.3 Temporary repair

4.3.1 A temporary repair is any repair which is performed in order to allow the vessel to reach a place of repair or to delay permanent/definitive repairs until a specified time - ie next scheduled dry docking.

4.4 Definitive repair

4.4.1 A repair is considered to be definitive when, in the opinion of the attending surveyor, the extent of repair should not require further intervention or additional survey upon completion and the vessel continues to meet with the requirements of the Classification Society and Statutory Bodies. The repair details will be contained in a survey report and the certification is not affected.

4.5 Permanent repair

4.5.1 A repair such as patch may follow plan review (See Sec 1, [10]) and survey (See [5]) be considered as a permanent repair. The reviews leading to acceptance will require to be performed on a case by case basis for each application.

A preliminary certification of the technology shall be achieved demonstrating strength and ageing in accordance with the level of criticality aimed for. The latter phase shall establish the necessary data for the mandatory design review of any patch and survey.

The Process Approval Certificate allows the repair to be considered in general terms prior to plan review and for the repair companies to demonstrate to owners that the repair process is acceptable. Each repair must however be reviewed by the Classification Society prior to works commencing. The PAC should contain such information as the areas of the vessel where the technology may be used, the type of resin used, curing times, steel preparation details, moisture level, temperature ranges of application, types of damages to be repaired, protection of the repair, full details about the components and arrangements of the patches, possibilities of inspections, efficiency of the classical ship survey technology or possibility or alternative method, etc.

Following the accepted application of patch technology for repairs the vessels Classification Certificate (See [3]) will require to be endorsed with memoranda as such repairs are considered to be acceptable and not requiring further survey.

5 Onboard Survey

5.1

5.1.1 Following plan review a letter containing comments will be issued by the society to the owner, operator or manager along with an endorsed copy of drawings used in the studies.

The letter, comments and drawings must be made available onboard to an attending Class Surveyor who will monitor all aspects of the repair as required. It could be considered that this will include verification of arrangements and details, verification of ultrasonic thickness measurements, verification of the correct control of substances such as “use by” dates of resins etc.

In all cases the surveyor will have ultimate responsibility for the acceptance (or not) of the repair in line with the requirements of the Classification Rules and Statutory Regulations.

Recall that at all times however the owner retains full responsibility for the standard of the repair and the society will have no contract with the companies involved in the repair. To this end all communication between repair contractors and the Classification Societies will be made via the owner / operator. Where reference is made to “the owner” this is taken as the person responsible for the operation of the ship on behalf of the legal owner(s) and who is shown to be so on the vessels documentation and as described in the International Safety Management (ISM) Code.

APPENDIX 1 CONTENT OF MTI BONDING PLAN

1 General

1.1 General

1.1.1 This Appendix resumes process general description and all specifications define previously in the Bonding File.

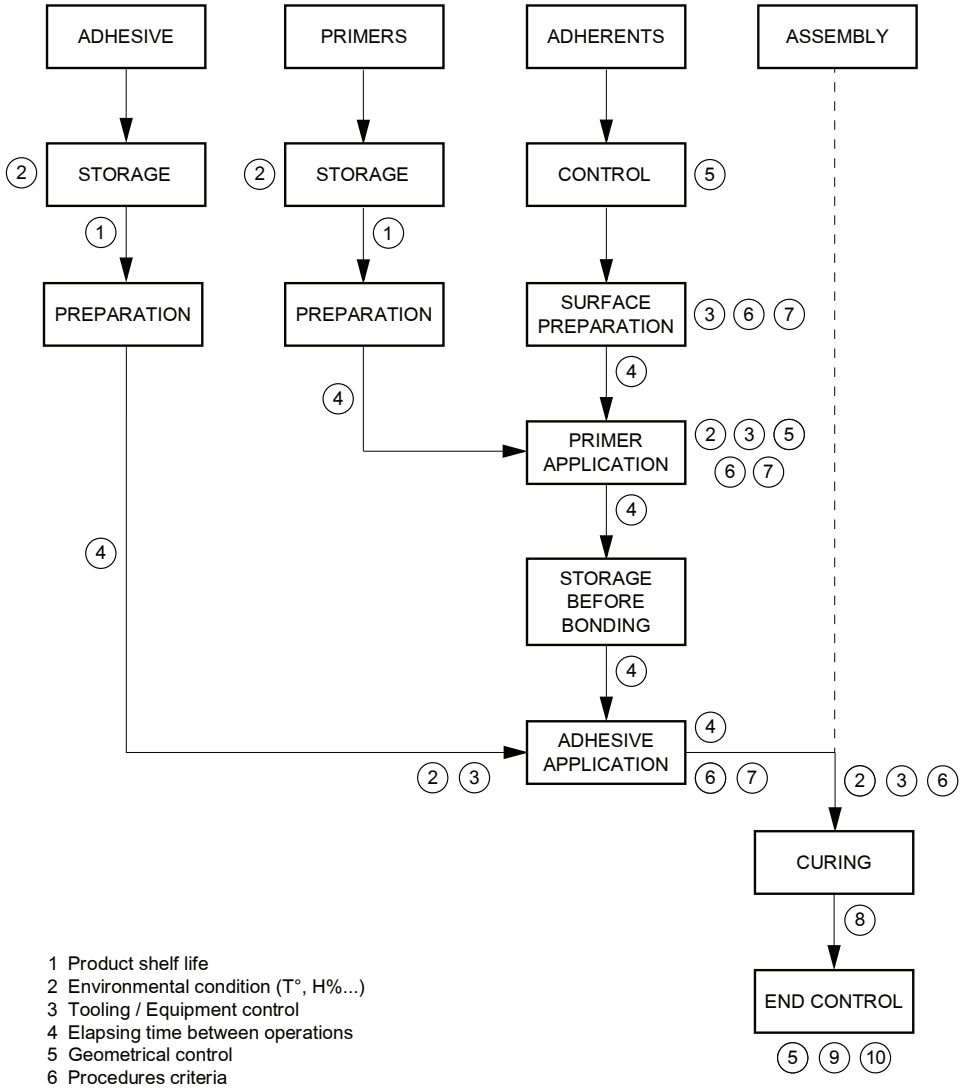
According to the process general description, the shipyard must draw up an exhaustive list of all related materials and various tools and equipment used in bonding process.

This includes:

- adhesives and constituent parts (base resin, hardener, catalyst…)
- adherents
- solvents, chemicals, primers, adherent promoter, various consumables and equipment for cleaning and surface preparation of adherents (peel plies, grit blasting, bristle blaster, sand paper, wipes, gloves, various tools…)
- tools and equipment for applying adhesives
- tools and equipment for assembly operations.

An example of principle scheme for process control is given in Fig 1.

Figure 1 : Example of principle scheme for process control



1 Product shelf life
2 Environmental condition (T°, H%...)
3 Tooling / Equipment control
4 Elapsing time between operations
5 Geometrical control
6 Procedures criteria
7 Manufacturing coupons
8 Destructive testing
9 Visual control
10 NDT

2 Reception, storage and preparation of materials prior to bonding operation

2.1 References

2.1.1 Shipyard documents shall contain the following information for each type of material:

- Manufacturer's name
- Product supplier references
- The Society product homologation references (number and date of validity of type approval certificates)
- Homologation references from another Classification Society (name and same information as in preceding point)
- Supplier's special requirements, including at least:
  - minimum and maximum storage temperatures, minimum and maximum storage hygrometry
  - product packaging for delivery
  - packaging for storage
  - maximum shelf life of product
  - type of checks to be performed on incoming products and properties to be tested by shipyard before use
  - same type of checks to requalify outdated products (tests to be performed, acceptability criteria, length of extended period of use, special conditions for use).

2.2 Storage conditions

2.2.1 Shipyard procedures shall contain the following information on storage sites:

- Location (or locations):
  - geographical position in relation to bonding units, stating variations of temperature and hygrometry that products must undergo when transiting from one to another
  - ventilation conditions, particularly air-replacement rates
  - heating conditions, stipulating means of temperature measurement, recording means, and expected maximum variation (i.e. minimum to maximum temperature)
  - arrangements for measuring hygrometry, giving at least the same information as for temperature, as well as the intended method of calibration of instruments
- Recording means available on storage sites:
  - listing documents related to storage conditions and stored products available on the storage site, and means deployed to ensure that stock managers are informed of arrangements to be made
  - listing documents available on measures to be taken by stock managers, if irregularities occur during storage (e.g. excessive storage temperature or hygrometry)
  - listing documents (and methods of keeping such documents current) to record arrival and departure dates for consignments, with description of any special event that could affect a consignment during storage.

Note 1: Written shipyard procedures must contain copies of consignments during storage

2.3 Reception of raw materials

2.3.1 Shipyard procedures shall state arrangements for to incoming materials, in particular:

- traceability of consignments (references, date of arrival for storage)
- types of inspection of consignments on the basis of supplier requirements (e.g. check on product packaging)
- types of tests performed on incoming consignments, in order to characterise materials
- types of specific tests performed (e.g. compatibility between materials)
- precautions taken when using new materials.

2.4 Supply of materials to bonding units

2.4.1 Shipyard procedures shall cover the following points:

- conditions and precautions to be taken when preparing each material for use
- precautions taken in preparing materials when subject to wide temperature variations before use
- methods adopted to prevent use of products that are exceeded their use-by or fail to conform to supplier or shipyard requirements.

2.5 Traceability

2.5.1 Shipyard procedures must ensure traceability of materials, from the time of reception until the end of production operations.

3 Bonding operations

3.1 General

3.1.1 Site procedures dealing with methods of preparation of adhesives and adherents materials for the bonding operation phase shall provide information indicated in [3.2] to [3.8].

3.2 Bonding environment

3.2.1 Shipyard procedures shall describe the following environmental conditions for bonding environment:

- minimum and maximum temperature and hygrometry
- means of measuring and recording these values
- procedures provided by the shipyard to halt or alter the bonding process when temperature or hygrometry reading exceed limits
- positions of various workstations in relation to one another, in particular precautions taken to prevent the presence of dust at some sensitive workstation caused by other operations.

3.3 Adherent surface preparation

3.3.1 The procedure for surface preparation of the adherents shall describe:

- method of checking before surface preparation that the adherents have been stored in accordance with procedures
- methods, tools and various agents necessary for mechanical and / or chemical surface preparation
- methods, tools and various agents necessary for cleaning surface preparation
- description of each cleaning and surface preparation sequence with minimum and maximum time elapsing between each step
- method of checking after surface preparation that the adherents have been prepared in accordance with procedures.

3.4 Adhesive preparation

3.4.1 The procedure for adhesive preparation shall describe:

- method of checking before preparation that the various technical components of the adhesives have been stored in accordance with manufacturer's specifications and shipyard procedures
- process of preparation of adhesives, defining methods and equipment used to measure various ingredients, component mixing, check viscosity, etc…
- list of criteria for pursuing or halting application after preparation
- precautions taken to comply with manufacturer's specifications on the maximum time elapsing between preparation and application of adhesives.

3.5 Adhesive application

3.5.1 The procedure for application of the adhesive shall describe:

- methods, tools and equipment for application of adhesive (manual or automatic application devices…)
- positioning with traceability
- amounts (weight/surface), thickness of adhesive to be applied, and tolerances
- means of respecting this thickness
- various inspection procedures (e.g. physical examination, measurement of thickness), carried out after bonding operation, and the shipyard reference document for common defects, stating causes and remedies.

3.6 Assembly

3.6.1 The shipyard procedure for assembly shall describe:

- description of all assembly stages with methods, tools and equipment necessary
- mMeans of ensuring contact pressures, immobility of components
- minimum and maximum time elapsing between application of adhesive and assembly stage
- methods of checking dimensions of components and their positioning
- method to control bond line thickness, shape of adhesive bead and tolerance
- method for removal of excessive adhesive
- method to control that bonding will occur on full surface (removal of bubble, good spreading of adhesives…)
- procedures provided by the shipyard when bond line thickness exceeds tolerance limits.

3.7 Curing

3.7.1 The shipyard procedure for curing shall describe:

- methods, tools and equipment necessary to maintain assembly parts in position during polymerisation of the adhesive joints
- condition specification and control methods to achieve required curing rate (T°, H%, pressure...)
- method and equipment for air porosity elimination.
- method for heating if relevant with cures cycles specification
- inspection methods and criteria for checking the curing of the adhesive.

3.8 End control of the assembly

3.8.1 The shipyard procedure shall describe:

- intended inspection methods and NDT after assembly, acceptability criteria for the assembly, as well as remedies for any defects found, means of handling any non-conformities found
- dimensional checks after assembly
- storage conditions specification for the assembly.

APPENDIX 2 QUESTIONARY FOR BONDING SPECIFICATION PHASE

1 General

1.1 General

1.1.1 Items to investigate for Bounding specification phase are listed in Tab 1.

Table 1 : Questionary for Bonding Specification Phase

	Items to investigate	Comments
1	Brief general description of the considered assembly	General arrangement / Principle scheme
2	Is it a single application or does it concerns multiple applications?	
3	What will be the function of the assembly?	Loads transfer or sealing only?
4	Location of the assembly onboard?	Location inboard, outboard, AC space, machinery space…. In service environmental conditions of the assembly? Temperature, humidity, immersion, UV, chemicals agent exposition? Maximum, minimum, average, peak values? Type of exposition (permanent, variable, intermittent..) Location onboard subject to Fire safety requirements? Accessibility for survey and in service survey?
5	Does similar application already exist?	Availability of operating feedback of similar bonding applications in service?
6	Risk assessment of the bonding application in case of failure?	BV requirements: A (low) / B (medium) / C (high) class
7	Which kind of materials are to be joined?	Metallic (steel, aluminium stainless steel…), Composite, Plastic (PMMA, PC…), Mineral glass, Wood Metal to metal / Composite to metal / Composite to composite / Others combination? Corrosion risk? Differential dilatation to consider?
8	What will be the surface conditions of materials to be joined?	Polluted surface, coated surface, flatness, roughness? Possibility of cleaning the surfaces before bonding? Possibility to carry out a surface preparation prior to bonding? Mechanical or chemical surface preparation? Possibility of applying a primer or adhesion promoter prior to bonding?
9	Loading?	Loading nature: shear / tensile / compressive / bending / torsion / peeling? Load type: static dynamic, permanent, variable, intermittent.. fatigue / vibration / chocks Load intensity: Min, Max, frequency Creep behaviour to consider?
10	Where will be implemented bonding operations?	In dedicate shipyard's area, outdoor, in board… Controlled atmosphere (T°, H%, dust…) / non controlled atmosphere
11	Adhesive characteristics?	Adhesive's form: films, pastes, one component / multi components adhesive Rigid or flexible adhesive? Gap filling properties? Adhesive storage consideration? Adhesive pot life?

	Items to investigate	Comments
12	Which production process is considered? Process limitation?	Methods for adhesive application: Manual, automatic? Surface to be bonded? Variability in the thickness of the adhesive joint? Adhesive curing mode consideration? (T°, H%, pressure, curing time..) Can pressure be applied during curing? Can tool be used to maintain for assembly?
13	Are there others operation which could impaired bonding application after curing?	Machining / handling / storage / transport? Other environmental conditions and/or mechanical loading to consider?
14	Health and safety aspect?	Harmfulness, toxicity, flammability Existing regulation regarding the personal protection equipment needed for operators in the working environment?
15	Necessity of specific skills in shipyard work staff for the intended bonding application?	Specific training program?
16	Repair	Possibility to repair in case of failure?

APPENDIX 3 BASIC KNOWLEDGES ON POLYMERS

1 General

1.1 Foreword

1.1.1 The aim of this appendix is to give an overview of the main features of the polymers. Indeed, all adhesives considered in the present Guidance Note are part of the family of polymeric materials.

Compared to metallic materials, the mechanical behaviour of polymers is much more complex to understanding. This is due to the variety of constituent structures of these materials on the one hand but also of behavior's diversity of one same material according to its terms of use on the other hand.

2 Polymer microstructure

2.1 General

2.1.1 Polymers consist of long chains of molecules: macromolecular chains.

These macromolecules are composed of one or several chemical units (monomers) that are repeated throughout the chain of the polymer.

Polymers mechanical behaviour will depend on how macromolecular chains are linked together and their arrangement.

Polymer always contains some various additives, plasticizers, mineral charges… in order to modify their initial properties or to facilitate their implementation.

According to their microstructure, polymers can classically be classified in 3 different classes: Thermosets, Elastomers and Thermoplastics.

2.2 Thermosets

2.2.1 Thermosets consist of macromolecular chains which are linked together by nodes with high energy forces (covalent type) created during polymerization. They form a 3D network where the chains are disordered (amorphous structure) and very few mobile between them.

Because of this cross-linked structure, thermoset are rigid and they cannot melt.

As a general rule, structural adhesives are Thermoset polymers (e.g. epoxy).

2.3 Elastomers

2.3.1 The elastomers are constituted of linear chains linked together by more spaced nodes than for thermoset polymers and which forms an amorphous structure.

Because of this arrangement, the elastomers have a very high deformation capacity. They do not melt but softened with heat.

As a general rule, elastomers are non-structural adhesives (e.g. MS polymer or silicon) and mainly used for sealant application.

2.4 Thermoplastics

2.4.1 Thermoplastic materials are made of macromolecular chains (linear or branched) that are tangled and linked together by weak energy forces (van der Waals forces or hydrogen type).

Chains have certain mobility between them.

Thermoplastics materials can take different microstructure: amorphous structure only or semi-crystalline structure with coexistence of amorphous and crystalline phases in varying proportions.

In amorphous structure, polymer chains are disordered. This type of microstructure does not melt but softened with heat.

In crystal structure, polymer chains acquire an ordered structure. This type of microstructure melts with heat.

Typical example of thermoplastic adhesives are those called "hot-melts" and which are used in packaging. As a general rule, thermoplastic adhesives are non-structural and with very few applications in shipbuilding.

2.5 Adhesives and polymers

2.5.1 The main adhesives families concerned in this guidance note are the following ones:

- Epoxy-based adhesives
- Polyurethane-based adhesives
- Acrylic-based adhesives
- Silicon
- MS polymer
- Others.

It should be noted that due to the possible large variety of formulation and the existence of hybrid products, some adhesives may contain phases whose microstructure belongs to one or the other type of polymer (e.g. epoxy adhesive which contain elastomer phases in order to provide a greater toughness).

For general guidance only, adhesives can be classed as following:

Table 1 : Adhesives class

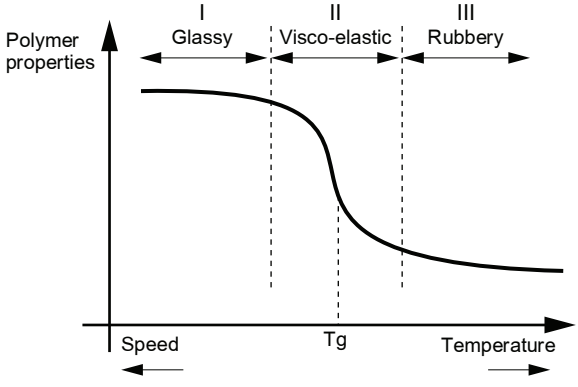
Thermoset	Elastomers	Thermoplastics
Epoxy, polyester, vinylester adhesives Anaerobic adhesives Certain polyurethane adhesives Certain acrylic-based adhesives	Silicone adhesives MS Polymer adhesives Certain polyurethane adhesives	Certain polyurethane adhesives Certain acrylic-based adhesives

3 Temperature effect on polymers

3.1 General

3.1.1 Polymers exist in different states according to the temperature where they are used (see Fig 1).

Figure 1 : Polymer properties vs speed and temperature



3.2 Glassy state

3.2.1 At low temperatures, the mobility of polymer chains is limited. All polymers (thermoset and elastomer) are in solid state and their behaviour is more or less rigid and brittle (glassy state).

In glassy state, mechanical behaviour is mainly elastic type characterized by high modulus and low deformation capacity.

Thermosets are mainly used in their glassy state.

Polymers properties are more or less stable in glassy state but some secondary transitions may modify chains arrangement which can slightly affect some polymers mechanical properties.

3.3 Glass transition temperature

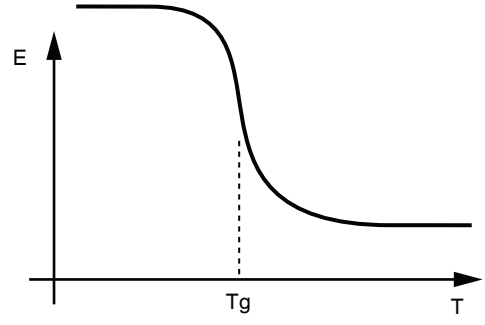
3.3.1 When temperature increases, chains movement become possible according to the polymer nature. Mechanical properties may then evolve more or less abruptly in a gap where is define the glass transition temperature (Tg) (see Fig 2).

Tg is one of the most important features that define a polymer. In this gap, polymers change from a glassy state to a rubbery state, with a visco-elastic type behaviour.

Tg only relates to amorphous microstructure (thermosets and elastomers) or amorphous phases of the semi-crystalline thermoplastics.

When passing this transition, the module can for example decrease by a factor 10 for thermosets or 1000 for some elastomer.

Figure 2 : Modulus vs Temperature



Both means commonly used to measure the glass transition temperature are DSC (Differential Scanning Calorimetry) and DMA (Dynamic Mechanical Analysis). Where Tg is measured, it is necessary to indicate the reference of the test method, since the measured value of Tg may vary from one method to another.

For thermoset, the more polymerized is the polymer, i.e. the greater is the number of chemical links between macromolecules chains, the higher is the value of Tg.

The glass transition temperature may be elevated using curing process at elevated temperature.

The glass transition temperature can be significantly reduced by moisture absorption.

3.4 Rubbery state

3.4.1 In rubbery state, polymers are soft. Amorphous microstructures (thermosets and elastomers) cannot melt if temperature increases but they decompose with heat. Only crystal phases of thermoplastics can melt.

Elastomers are mainly used in their rubbery state.

4 Mechanical behaviour of polymers

4.1 General

4.1.1 The mechanical behaviour of polymers is characterized by a very high apparent diversity. This is due to many parameters which may control polymers behaviour and microstructural modifications that can occur during loading.

The main parameters that can affect the mechanical behaviour of polymers are:

- Type of microstructure polymer (see [2])
- Temperature (see [3])
- Loading time / loading speed / loading frequency
- Others as deformation rate, high pressure, environment (moisture mainly).

4.2 Polymers visco-elastic behaviour

4.2.1 Due to the macromolecular nature of polymers, the response of a polymer to the constraints is usually visco-elastic type (see Fig 3).

Visco-elastic behaviour is an intermediate behaviour between an elastic response and viscous response and characterized with a time / temperature equivalence.

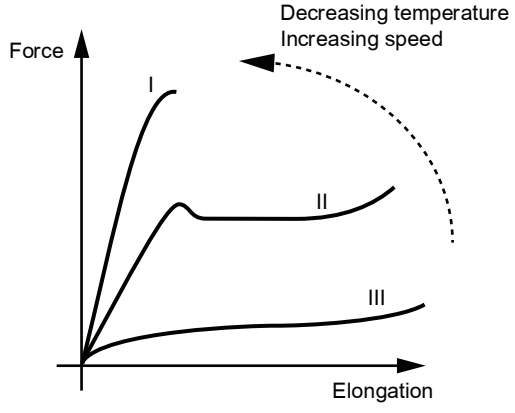
If a load is applied for a short time or if the temperature is low, chains will not have the time to slide to each other. They will just stretch (elastic response).

The elastic behaviour of polymer is preponderant when chains are highly cross-linked as thermoset.

If a load is applied for a sufficiently long time or if the temperature is sufficiently high, chains will be able to stretch and slide relative to each other (viscous response). This will lead to phenomena of creep or relaxation.

The viscous behaviour of polymer is particularly marked for networks weakly or not cross-linked as elastomer or thermoplastic polymers.

Figure 3 : Typical evolution of polymers tensile behaviour according to the temperature or the speed of traction



- Curve n°I: rigid / brittle behaviour

  This behaviour may be considered characteristic for thermoset highly cross-linked or others polymers at high speed or low temperature

  Mechanical behaviour is mainly elastic type, more or less linear, and characterized by high modulus and low deformation capacity

- Curve n°II: ductile behaviour

  Mechanical behaviour more or less ductile (plastic deformation may be possible)

  This behaviour may be considered characteristic for semi-crystalline thermoplastics and for amorphous thermoplastics at intermediate temperature and speed

- Curve n°III: rubbery behaviour

  This behaviour may be considered characteristic for elastomers and for amorphous thermoplastics at high temperature or low speed. Mechanical behaviour is hyper elastic type and generally highly nonlinear.

5 Durability of polymers and adhesive joints

5.1 General

5.1.1 In marine environment, polymers may degrade under the effect of the oxygen in the air, UV rays, temperature, water or other solvents and mechanical stress.

Assessment of bonded joints durability involves knowledge of particularly complex phenomenon. Different mechanisms can interact with each other, each with their own kinetic. Furthermore, these mechanisms may be reversible or not.

5.2 Moisture influence

5.2.1 Moisture is the main factor that decreases bonded joint durability. The different mechanisms that can appear may be:

- Plasticization of the adhesive (reversible phenomenon): the water that has penetrated the polymer network can bind onto hydrophilic sites of the macromolecular chains and break the bonds between chains or the chain itself. These cause an increase in the mobility of the chains and may decrease the glass transition temperature. Plasticization of the adhesive generally leads to a significant decrease in mechanical properties (modulus and breaking strengths) and an increase in ductility.
- Swelling of the adhesive (reversible phenomenon): the breaking of the bonds between the chains results in a loosening of the whole network. This promotes the absorption of new water molecules and an overall swelling of the polymer. For a bonded joint, the swelling may not be homogeneous and may lead to additional internal stresses.
- Hydrolysis of the adhesive (irreversible phenomenon): this is a chemical degradation reaction induced by water. This results in profound modification of macromolecular chains either by cuts of chains or by creation of new bonds between chains or appearance of degradation products. These phenomena generally operate from the exposed surface to the heart of the material, which may result as a heterogeneous character of the ageing through thickness of polymers.
- Interface degradation: the interfacial area is a special area where establish physical or chemical bonds between the polymer and the substrate. Water may condensate in this area by migration from the adhesive and by capillary along the interface. It should be noted that the diffusion of water at the interface is much faster than in the solid adhesive. The presence of impurities on the substrate surface and the existence of differential swelling phenomena between the adhesive and the substrate may cause water concentration gradients and a high osmotic pressure between the interface and the adhesive. For metallic substrates, water can degrade the strength of the adhesive joints through hydration of metal oxyde layers. Corrosion products at the interface are considered a post failure phenomenon. For composite substrates, water can also migrates from the composite itself through the fibres.

For information, distilled water effect is generally considered more severe than fresh water and sea water.

5.3 Temperature influence

5.3.1 An increase in temperature activates the diffusion of the water inside the adhesive and promotes the wet ageing and the interfacial degradation of the bonded joint.

In an environment where the relative humidity is stable, the temperature does not significantly alter the maximum rate of water absorption of an adhesive. The higher the relative humidity in a medium increases, the maximum rate of water absorption of an adhesive increases.

Temperature also affect mechanical behaviour of the adhesive as described in previously (see [3]).

5.4 Others chemicals influence

5.4.1 Others media as solvent or chemicals (fuel, mineral oil, hydraulic fluid, grease, acid and alkaline solutions, etc…) may have similar influence than water according to the nature of adhesives.

5.5 UV influence

5.5.1 Ultraviolet radiations can break macromolecular chains. In almost all bonded joints, adherents are opaque. Only the free edges are exposed to light. As the adhesive layer is most of the time thin, influence of UV radiation may be considered negligible.

Only when adherents are transparent (glazing for instance), influence of UV have to be investigated. For such applications, adhesives specially formulated with UV stabilizers are to be selected.

APPENDIX 4 ADHESIVES HOMOLOGATION

1 General

1.1 Application

1.1.1 The purpose of this Appendix is to give the procedure to be followed for the homologation of adhesive materials within the scope of the present Guidance Note.

These procedures are confined to check the conformity of the adhesives materials with the relevant requirements of the present Guidance Note.

The general requirements for the certification scheme of materials are given in NR320 Certification Scheme of Materials & Equipment, as amended.

1.2 Homologation program

1.2.1 As a general rule, adhesive materials manufactured in series correspond to HBV product within the scope of the certification scheme of materials as defined in NR320 Certification Scheme of Materials & Equipment.

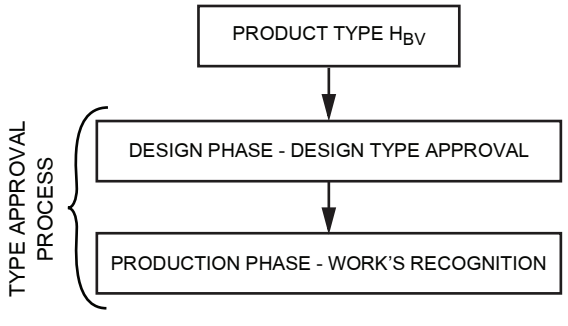
Note 1: HBV products correspond to products manufactured in series, having to comply with design requirements assessed through type approval procedure, and manufactured by works recognised by the Society.

Such products are not required to be certified by the Society individually or per batch. Their compliance with the approved type is solely certified by the manufacturer using his own format of document and marking to allow traceability to the approved type.

The type approval process of raw materials requests the two following successive phases (see Fig 1):

- Design type approval: To review the technical documentation and mechanical characteristics proposed by the adhesive's manufacturer in compliance with the rule requirements (see [2]).
- Work's recognition: To assess the compliance of the adhesive materials manufactured in series with the design type approval (see [3]).

Figure 1 :



1.3 Certificate and responsibilities of adhesive's manufacturer

1.3.1 Upon satisfactory completion of the two phases, a type approval certificate and a recognition certificate are issued by the Society under conditions defined in NR320 Certification Scheme of Materials & Equipment.

2 Design type approval of adhesive materials

2.1 Approval test program

2.1.1 The review of the technical documentation and the type test program are to be carried out within the scope of the design type approval, as defined in NR320 Certification Scheme of Materials & Equipment.

The test program, drawn up jointly by the adhesive's manufacturer and the Society, as well as the minimum required mechanical test results, may be as defined in Tab 1.

Some tests may be dropped from this list, and other additional tests requested, depending on the particular use, or experience acquired, with the materials under approval test program.

2.2 Report and certificate

2.2.1 Technical reports, issued in the forms stipulated in standards indicated in Tab 1, are to be submitted to the Society for examination.

Upon satisfactory completion of the procedure, a certificate is issued by the Society as per the provisions of NR320 Certification Scheme of Materials & Equipment.

3 Work's recognition

3.1 General

3.1.1 The general requirements for the work's recognition schemes are given in NR320.

Table 1 : Minimum tests for adhesives homologation

Adhesives properties / Characteristics	Comments	Test methods/Standard
• Glass transition temperature (°C)	• Method used to be specified (DSC or DMA)	DSC: • ISO 11357-2 • ASTM E1356 • ASTM D3418 DMA: • ISO 6721-11 • ASTM D7028 • ASTM E1640
• Curve of dynamic flexural modulus **(3)** as function of temperature	• Minimum 2 specimens **(1)** • Environmental and loading testing conditions to be specified **(2)**	DMA / dynamic test (See Section 6)
Tensile properties at room temperature **(5)**: • Tensile stress / strain curve • Young modulus (MPa) • Poisson coefficient • Tensile strain at failure (%) • Tensile strength at failure (MPa) • Tensile yield strength / strain **(4)**	• Minimum 10 specimens **(1)** • Loading and environmental testing conditions to be specified **(2)**	ISO 527 ASTM D 638
Shear properties at room temperature **(5)**: • Shear stress / strain curve • Shear modulus (MPa) • Shear strain at failure (%) • Shear stress at failure (MPa) • Shear yield strength / strain **(4)**	• Minimum 10 specimens **(1)** • Loading and environmental testing conditions to be specified **(2)** • Min / max / average values, standard deviation and failure mode to be specified • Cohesive failure required	TAST methods: • ASTM D 3983 • ISO 11003-2 • NF EN 14869-2
• Poisson coefficient	• Deduce from the measurement of the young's modulus and shear modulus at room temperature $v = (G / 2.E) - 1$	calculate

(1) Specimen manufacturing method and geometry of specimen to be specified; specimen curing state according to manufacturer's recommendations.

(2) Loading (test speed or constant strain rate, vibration frequency) and environmental testing conditions (T°, H%), to be specified.

(3) Others dynamic moduli can be used.

(4) Determination of yield strength on case by case basis according to adhesive's mechanical behaviour.

(5) Based on result measurement of dynamic moduli, additional testing in tensile and in shear, at other temperatures is required on case by case according to adhesive's type:

- when adhesive's moduli are not constant (deviation less than 10% tolerated) between
- or when adhesive's glass transition temperature measured by DSC/DMA is close to (less than 20°C),

environmental conditions stated in the present guidance note (see Sec 1, [4]).

For instance, maximum additional testing in tensile and in shear at -20°C / 0°C / 40°C / 60 °C may be required. In case of additional testing at others temperature, reduced number of specimens (5) is required.