Technology and Science for the Ships of the Future
V. Crupi and V. Bucci (Eds.)

doi:10.3233/PMST250105

From International Standards to Classification Rules: Application on Board Ships of Adhesive Non-Structural Fasteners

Giovanni ROGNONI, [a,1], Giada KYAW OO D'AMORE, [a] Emanuele BROCCO, [b] Luciano STEFANUTTI [c] and Marco BIOT, [a]

[a] *Department of Engineering and Architecture, University of Trieste, Via Alfonso Valerio 7/4, Trieste, 34127, Italy*
[b] *C.S.N.I. Scarl, Corso Perrone 27/R, Genova, 16152, Italy*
[c] *Merchant Ships Business Unit, Fincantieri S.p.A., Passeggio Sant' Andrea, 6/a, Trieste, 34123, Italy*

ORCiD ID: Giovanni Rognoni https://orcid.org/0000-0002-3864-9724, Giada Kyaw Oo D'Amore https://orcid.org/0000-0001-5587-4280, Emanuele Brocco https://orcid.org/0000-0001-7716-0633, Marco Biot https://orcid.org/0009-0009-4674-5618

Abstract. Large ships' outfitting stage is a complex process that requires careful attention to safety and timelines. The simultaneous activity of different personnel introduces a high degree of risk regarding their safety. Excellent coordination among many individuals and installation teams is required. One of the primary risk factors onboard during the outfitting phase is fire. Over the years, various precautions have been implemented to mitigate this risk, from pre-assembling external components to strict control over processes requiring welding or other types of hot work. An alternative to these processes could be the use of semi-structural adhesives. Currently, bonded components are limited to a few secondary elements, typically small in size and non-critical to the ship's safety. The economic incentive for semi-structural bonding on cruise ships is substantial, with increased production capacity associated with many components eligible for semi-structural bonding. One of the limits of using adhesives on board steel ships is the need for specific normative, which poses an obstacle when introducing new solutions. Classification societies require an in-depth study demonstrating adequacy and safety, and removing doubts regarding adhesive solutions' long-term durability. Until 2019, adhesives were approved for specific, case-by-case, non-structural bonding uses. There were no approvals for semi-structural bonding processes. Within this context, the Glu&Nav project was funded some years ago to examine and outline a standardised application process for semi-structural bonded fasteners. The research was carried out through a collaboration between the shipbuilding industry, the university, and the classification societies. The result was the definition of a pre-certification process by a leader classification society, which eventually came into force on January 1, 2021. This paper presents the transition process from the existing regulatory framework to the ratified standard for non-structural bonding, providing detailed insights.

Keywords. Bonded joints, Outfitting, Classification Society, Glu&Nav

[1]Corresponding Author: Giovanni Rognoni, giovanni.rognoni@dia.units.it

1. Introduction

Adhesive joints are widely used in many engineering sectors. Automotive, aerospace, railway, and general construction industries make large use of structural adhesives, which became crucial for these sectors [1, 2]. In shipbuilding and offshore engineering, adhesives have yet to gain the same broad acceptance. The harsh conditions involving contact with water, moisture, and humidity, the reluctance to substitute current technologies, and especially the potential fire risk related to these components, slowed down the adoption of such technology on board.

The possibility of using adhesive bonds to connect ship structures was studied in a series of Ph.D. theses [3, 4, 5]. Adhesives have found diffusion in composite marine structures, being used for structural joints for bulkheads and frames. Delzendehrooy et al. [6] enlisted a series of typical applications of adhesive bonds for pleasure boats, racing yachts, and offshore structures. Other uses of adhesives included the bonding of windows and seat mountings in cruise ships and the assembly of the secondary barrier of membrane-type containment systems for LNG carriers. These applications were mentioned by Weitzenböck [7] who also reported the repair of cracks in aluminium superstructures and the joining of lightweight structures made of composite or aluminium to the steel hull. Applications on unmanned underwater vehicles were presented by Lu et al. [8], while Gaiotti et al. [9] studied a bonded joint to connect a mast on a naval vessel.

Many studies mainly focus on structural adhesives. However, it is not the only way bonded joints can be used on board ships. During the construction of ships and offshore structures, many definitive or temporary joining processes are required, such as outfitting assembly and equipment installation. Most of these operations rely on welding and mechanical joining methods like bolting or riveting. The substitution of these processes with adhesive bonding sounds very attractive. The lack of hotwork would produce smooth surfaces, also substantially reducing the fire or explosion risk. Researches on alternatives to temporary welded joints were carried out within the National Shipbuilding Research Program (NSRP) [10]. Horsmon [11] showed some temporary applications that could be substituted by adhesives, illustrating a series of products that could be found on the market at the time (2015). The design of bonded joints and the definition and issue of a regulation for their semi-structural use on ships were the primary objectives of the project Glu&Nav, presented in this paper.

The paper is organised as follows: Section 2 describes the international regulatory framework regarding adhesives in the marine sector. Section 3 outlines the project Glu&Nav, focusing mostly on its development, with a short description of the results of the tensile and shear tests performed on the joints, and concluding with the illustration of the in-situ application on a cruise cabin mock-up. Section 4 presents the standard issued by the Registro Italiano Navale (RINA) as a result of the project outcomes and points out the limitations of bonded joints in relation to their extensive use on board. The paper is closed with a brief conclusion and suggestions for future work.

2. Marine sector adhesive regulatory framework

A challenge shared among all the various fields involving the technological development of ships is the need for approval by authorities and classification societies. Until

2018, classification societies approved the bonding of specific components on a case-by-case basis without any established and shared approvals for semi-structural bonding processes. According to Weitzenböck [7]: "Adhesive bonding is still a relatively new joining process in shipbuilding with limited or no previous experience. Currently, there are very few classification rules or requirements for approval of adhesively bonded joints, which discourages many from considering adhesive bonding as part of their design." The need to standardise adhesive bonding, one of the goals of Glu&Nav, was underlined.

Before starting the project, a state-of-the-art review identified two main guidelines, one from Det Norske Veritas - Germanischer Lloyd (DNV-GL) [12] and one from the ClassNK [13]. The DNV-GL document is a type approval for single products, and the ClassNK guideline is focused on structural adhesives. Curiously, at the same time as our project was in development, the German Maritime Centre was awarded a contract to prepare a study on the development and application of adhesive joints in ship manufacturing. The goal was to analyse the regulations and standards, identifying potential applications and cost savings, and developing a standardised regulation. The activity was carried out in conjunction with the Bureau Veritas (BV); the main results are reported in [14], where the great potential of using adhesives is acknowledged, especially in joining a wide variety of materials. In February 2025, the BV issued the official version of a rule for the certification of structural bonded assemblies of composite materials [15]. The document specifies a series of tests to be performed, depending on the adhesive assembly under inspection. Other general documents and guidelines issued by classification societies and potentially concerning adhesive use are listed in the CertBond project report published in 2023 [16]. Excluding the already mentioned DNV-GL document for type approval [12], the report primarily mentions rules concerning bonded repair of steel structures and testing and certification of materials.

3. The project Glu&Nav

The research project Glu&Nav - "Prodotti e processi innovativi per incollaggi semi-strutturali a bordo delle navi", was co-funded in 2018 by the European Regional Development Fund (ERDF) 2014-2020 promoted by the region Friuli Venezia Giulia, Italy. It followed a previous research project named "Innavin", developed by one of the partners between 2016 and 2018. Two were the principal objectives of Glu&Nav:

- Product innovation: the development of adhesives and bonded joints that can be applied in the shipbuilding sector to reduce outfitting costs;
- Process innovation: design the extensive use of bonding joints in ships' outfitting.

3.1. Project Development

The project was divided into four operational phases. The first part focused on the research for adhesive products for steel structures already available on the market. Some products were identified as potentially interesting: Sika 1277, Sokem MS Polimer HT 4418, SIMP Seal 55 IMO, and an experimental compound from Gurit. All these products already showed characteristics of non-combustibility and low flame spread in accordance with Parts 1 and 5 of the FTP Code [17] relative to their use as defined in this research.

Part 2 was delegated to the end user of the bonded systems, whose task was to define the appropriate use and spaces onboard. A series of semi-structural components that could be bonded was identified, such as supports for electrical appliances, heat detectors, flame detectors, or supports for insulation. The spaces were determined based on their fire class to assess the extent of areas that may be included/excluded from the eligible zones.

The steel joints were designed during Part 3. Figure 1 shows the two fasteners that were eventually chosen as suitable for use onboard. The supports' geometry was partially inspired by the results obtained by the Innavin project and by commercial components already on the market. Both samples are 20 mm long, with a 19 mm M8 threaded bush at their centre. The base diameters are 50 and 30 mm. The supports are made of standard AISI 316 stainless steel.

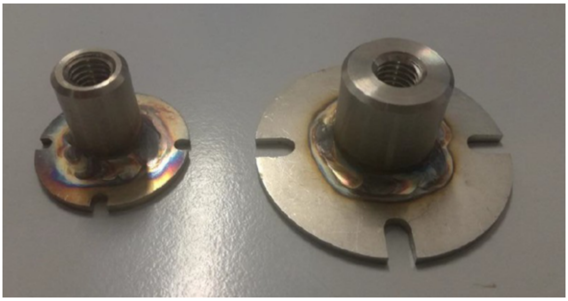


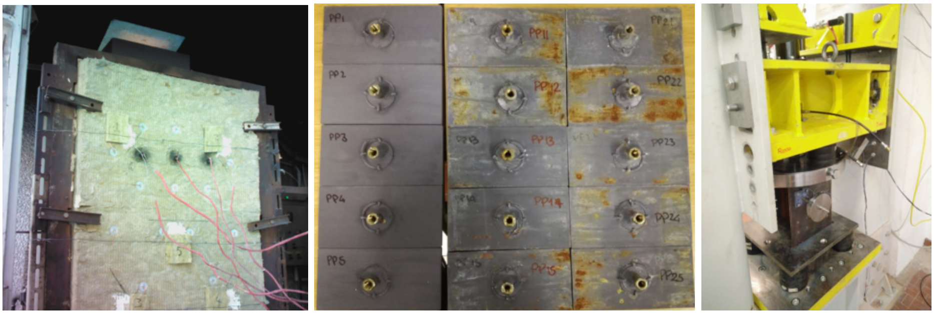
Figure 1. Supports designed for the research

In the last research stage, a series of standard and non-standard experimental tests to be performed on the bonded joints was defined. These tests are indicated in Tab. 1. Eventually, the project concluded with an application of bonded joints on a mock-up representing the steel structure where cruise cabins are mounted.

Table 1. Glu&Nav tests operated on the designed prototypes

Subject	Test perfomed	Motivation
Adhesive	Surface Flammability	Assessing the adhesive compliance with the FTP code
Bonded joint	Salt spray corrosion Climate chamber UV Rays	To simulate ageing due to marine conditions
	Fire	Assessing the compliance with the FTP code
	Tensile stress Shear stress	To define the maximum static operational loads
	Dynamic vibrations	To evaluate the dynamic resistance under load

The request to comply with the FTP code was the critical restriction from the classification societies for the case-by-case approvals issued for products already on the market up to 2021 (Clickbond, Specialinsert). In the project Innavin, the steel fasteners' chemical and physical resistance under salt spray corrosion and climate chamber tests had already been investigated. In Glu&Nav, the UV Rays test was added to include low-temperature applications on open decks. These tests are standard, they are performed according to [18, 19, 20]. Fire tests were carried out to verify the integrity of the boundary or panel in the case of application on fire-resisting surfaces. They were performed in a laboratory oven on 1300x900x5 mm samples of A60 class panel. The panel was made of a steel plate with mineral wool applied to simulate a cruise bulkhead. Three joints were installed on the panel, two of them were bonded and one was welded to have a comparison with the SOLAS standard procedure (Fig. 2a). The test lasted for 60 minutes, giving positive results according to the usual assessment criteria adopted for this test typology. The mechanical tests performed on bonded semi-structural joints are an element of nov-



(a) (b) (c)

Figure 2. a) Set up for the fire test, b) samples used for the tensile and shear tests, c) dynamic test machine)

elty, since no significant restrictions regarding the strength performances of the samples were demanded in the past for the type approvals. The static load tests were performed using a universal testing machine on 60 samples made by a joint bonded to a 140x70x8 mm steel support. A third of the samples were not treated, a third were treated with salt spray corrosion for 7 days (temperature 35°C, sodium chloride concentration of 50 g/l, pH from 6.5 to 7.2) and a climate chamber test for 30 days (5 hours at 75°C and relative humidity of 90%, 5 hours at -40°C), and, on the last third, also a UV rays test was performed according to [20] (Fig. 2b). The dynamic test was based on [21], intended for components and equipment subjected to conditions involving vibration of a harmonic pattern generated primarily by rotating, pulsating or oscillating forces. The underlying idea was to test the bonded joints for assessing their resistance to long-life applications on board. The standard requires a series of frequency sweeps to identify resonances, followed by one or more endurance tests by sweep and at critical frequencies. The dynamic tests were performed on four supports, applying a static load of 1.1 kg to the small ones and 2.8 kg to the large ones. The joints, bonded to a 75x75x8 mm plate, were connected to a vibrating machine (Fig. 2c) that applied a 0.7 g acceleration in all three directions. A frequency sweep from 4 to 100 Hz was performed to identify resonances. Since no peaks were identified in the interval, the maximum frequency (100 Hz) was used to perform the test. The endurance tests lasted 120 minutes, no failures were recorded on the joints investigated.

3.2. Tensile and shear stress test results and discussion

The tensile and shear stress test results are shown in Fig. 3. The adhesive selected in the final stage of the project was the SIMP Seal 55 IMO, a monocomponent silyl-modified polymer. The values represent the average of the maximum forces required to cause the failure of the sample. A safety factor equal to 3 was selected to define the maximum applicable load to each support. For this adhesive, the curves obtained from the tensile and shear tests are very similar. For both shear and tensile strength, the maximum load decreases by approximately 28% after ageing in the climate chamber and undergoing the salt spray corrosion treatment. Further ageing in a UV chamber shows a subsequent recovery in strength, attributed to further cross-linking of the adhesive due to prolonged exposure to UV rays, which were able to penetrate the less superficial layers of the material. This increase in strength, however, corresponded with an increased embrittlement of the adhesive.

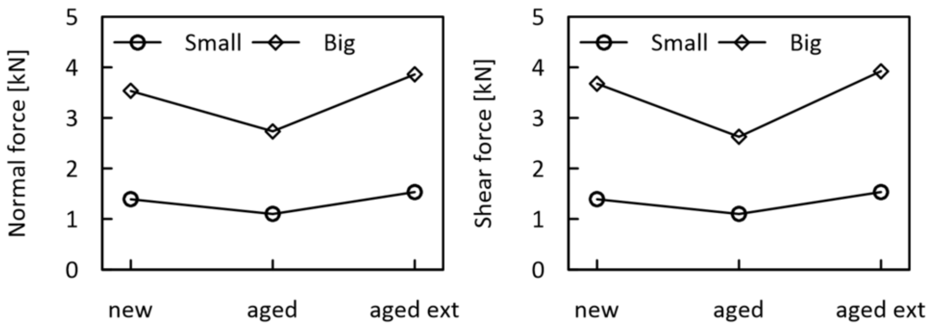


Figure 3. Results of the tensile (a) and shear (b) tests performed on the bonded joints

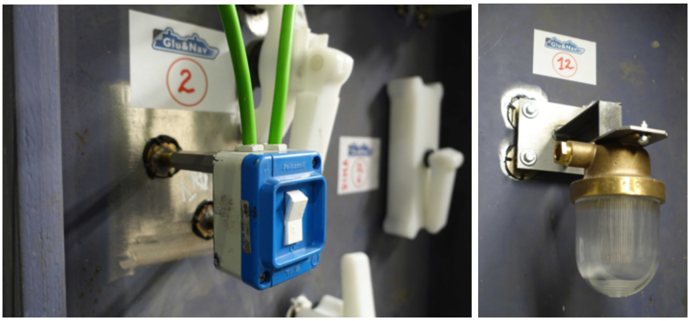
3.3. *In-situ mock-up application*

The research project concluded with an application of bonded joints on a cruise cabin mock-up. Forty objects were bonded to the steel plates. Figure 4 shows an electrical switch (0.5 kg) and a lamp (1.12 kg). The researchers and the classification societies' surveyors inspected the application and made some technical observations, outlining the shared protocol, which represented the base for the standard issued by RINA.

4. The RINA NCC94 Standard and limitations on the use of bonded fasteners

The international standard developed during Glu&Nav covers the certification of semi-structural bonded joints on board steel ships [22]. The origin of this document was discussed and agreed upon among the interested parties: joint and adhesives manufacturers, system applicators, end users, researchers, and surveyors. The tests requested are modelled on those listed in Table 1. The document aims to determine clear rules covering equipment installation on board ships without resorting to case-by-case approval.

While the proposed use of bonded joints in the ship outfitting phase shows promising results, their application poses non-negligible practical limitations to their extensive use on board. The weight that each support can carry is limited, and although the tensile and shear tests showed high maximum loads, the high variability in the results led to the adoption of a safety factor reducing the maximum load to 33%. The positions and spaces where the bonded joints can be installed are restricted to open decks and underdecks, and only for equipment whose failure does not compromise safety or may obstruct escape routes on board.



(a) (b)

Figure 4. Example of adhesive application on: a) lamp b) electrical switch

A series of practical aspects makes the use of bonded joints challenging, which is why the standard mentions the need for qualified personnel. The bonding of steel supports must be carried out following a specific procedure made up of two subsequent steps: first, the treatment and cleaning of the substrates, followed by the installation of the bonded system; second, the installation of the elements (like those shown in Fig. 4) on the supports and the restoration of primer and insulation. The time between these two phases varies depending on the time needed for the curing of the used adhesive.

Other limitations are related to surfaces: applications on vertical surfaces need retention systems that must remain in position for the entire time required for the adhesive to fully cure. In cases where the surfaces are not perfectly planar, as it happens on ship plating, and more joints are required to support the same object, their length may need to be adjusted to maintain verticality.

5. Conclusion and future work

This paper briefly presents the activity developed during the project Glu&Nav, finalised for the certification of bonded joints for semi-structural applications on steel ships. The publication of an international standard covering the subject paves the way for a future extensive application of bonded joints on board.

Future works on the subject should be aimed at testing the performance of adhesives on real steel structures subject to significant static and dynamic loads typical of ships. A first step may be the extension of the rules, now limited to the installation of equipment which does not compromise safety on board, to a more vast set of elements. The use of adhesives for structural purposes will require time and new compounds appropriately designed for the task. This requires a deeper understanding of the long-term resistance of these solutions in the marine environment. A strategy would be to start with small structural elements, which, in case of failure, would not compromise the integrity of the entire structure, and then gradually increase the use of adhesives for larger hull parts.

References

[1] Marchione F. Structural Adhesive Joints: State of the Art, Challenges, and Future Perspectives. Int J Eng, Transactions C: Aspects. 2025;38(09).

[2] Dillard DA. Advances in Structural Adhesive Bonding, 2nd Edition. Dillard DA, editor. Woodhead Publishing; 2023.

[3] Winkle IE, Cowling MJ, Hashim SA, Smith EM. What Can Adhesive Offer to Shipbuilding? In: The NSRP - 1990 Ship Production Symposium; 1990. .

[4] Hashim SA. Assessment of Adhesive Bonding for Structural Design with Thick Adherends; 1992.

[5] Knox EM. Marine Applications for Structural Adhesives; 1996.

[6] Delzendehrooy F, Akhavan-Safar A, Barbosa AQ, Beygi R, Cardoso D, Carbas RJC, et al. A comprehensive review on structural joining techniques in the marine industry. Compos Struct. 2022;289.

[7] Weitzenböck JR. Adhesives in marine engineering. Weitzenböck JR, editor. Woodhead Publishing; 2012.

[8] Lu F, Liu Y, Sun T, Han L, Wang P, Niu W, et al. Design, modeling and optimization of an adhesively bonded ring joint with U-section for ceramic cylindrical pressure hull of deep-sea underwater vehicles. Ocean Eng. 2024;309:118327.

[9] Gaiotti M, Ravina E, Rizzo CM, Ungaro A. Testing and simulation of a bolted and bonded joint between steel deck and composite side shell plating of a naval vessel. Eng Struct. 2018;172:228-38.

[10] National Shipbuilding Research Program. Report 0528 - Reduction/Elimination of Welded Temporary Attachments; 1999.

[11] Horsmon AW. Adhesives in Shipbuilding. SNAME World Maritime Technology Conference; 2015. .

[12] Det Norske Veritas - Germanischer Lloyd. Adhesive systems; 2016.

[13] ClassNK. Guidelines for Use of Structural Adhesives; 2015.

[14] Center of Maritime Technologies. Studies on the current international situation of Technology related to the development and application of Adhesive joints in ship manufacturing; 2020.

[15] Bureau Veritas. Bonded Assemblies; 2025.

[16] F Santandrea and G G Momm and P Tsokanas and V Rajcic and D Skejic and D Rajnovic and R Petkovic and T Kruse-Strack and S Texeira De Freitas. WG6: Review of certification procedures for bonded structures; 2023.

[17] International Maritime Organization. 2010 FTP Code; 2010.

[18] ISO. ISO 9142:2003 - Adhesives — Guide to the selection of standard laboratory ageing conditions for testing bonded joints; 2003.

[19] ISO. ISO 9227:2022 - Corrosion tests in artificial atmospheres — Salt spray tests; 2022.

[20] ISO. ISO 4892-3:2024 - Plastics — Methods of exposure to laboratory light sources; 2024.

[21] International Electrotechnical Commission. IEC 60068-2-6:2007 Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal); 2007.

[22] Registro Italiano Navale . Rules for the Type Approval of Adhesive Bonded Fasteners for the Installation of Equipement on Board Ships; 2021.