4 FINAL PUBLISHABLE SUMMARY REPORT

4.1 EXECUTIVE SUMMARY

MOSAIC – Materials On Board: Steel Advancements and Integrated Composites – is a research project funded under theme SST 2012.5.2-3 Innovative structural and outfitting materials for ships including inland ship priority within the 7th Framework Programme for Research and Development of the European Commission. The project was launched on September 2012 and closed three years later, in August 2015. The project, was co-funded by the European Commission within the 7th Framework Programme, was born out of the cooperation of 11 companies/universities coordinated by the Italian research centre CETENA. The project consortium consists of 3 universities (NTUA, IST and UoB), 1 classification society (Lloyd's Register), 2 shipyards (ENP and Fincantieri), 2 institutes and joining technology centres (AIMEN and TWI), 2 research and consultancy companies (AS2CON and CETENA) and a shipowner (DANAOS).

Main objective of MOSAIC is to face one of the most challenging topic of the research in the marine field in the last years i.e. the reduction of the light ship weight (LSW); in fact this is the factor that mainly affects the fuel consumption and the payload capacity of the ship.

The structures of large merchant vessels (tankers, bulk carriers, cruise ships...) in steel are designed to meet the structural requirements for accommodating loads exerted by the marine environment and from operations. These loads, in conjunction with the highly corrosive marine environment, lead to the development of local defects, which, in combination with the ship's light weight and with corrosion, affect mostly the operational and maintenance costs. Therefore the use of better performing and/or lighter ships can advance the shipbuilding industry to more cost efficient and environmental friendly ships.

In MOSAIC this goal has been pursued through two technologies: the use of a special category of high performance steel called HSLA (High Strength Low Alloy) steel and the replacement of steel components with components in composite material.

Although these technologies can potentially achieve this objective of weight savings, the integration of these materials within the steel structure of the vessel is not without hurdles: in particular the welding of HSLA with the other structures in common steel as well as the joining of the composite component with the steel structure of the ship must be carefully designed and tested. For these reasons, MOSAIC paid particular attention to the study of welding procedures/technologies and to the design of hybrid joints (steel to composite) able to guarantee a gradual and effective transition between the composite and the steel through test extensive test campaigns, numerical simulations and analytical calculations.

4.2 SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND OBJECTIVES

MOSAIC – Materials On Board: Steel Advancements and Integrated Composites – is a research project funded under theme SST 2012.5.2-3 Innovative structural and outfitting materials for ships including inland ship priority within the 7th Framework Programme for Research and Development of the European Commission. The project was launched on September 1st, 2012. It had a duration of 36 months and a total budget of 4 million €. Eleven partners from leading European Research Institutions, Shipbuilders, Universities, Shipping Companies and Classification Societies collaborated together to aid the Shipbuilding Industry advance towards more environmental friendly, cost efficient and safer ships.

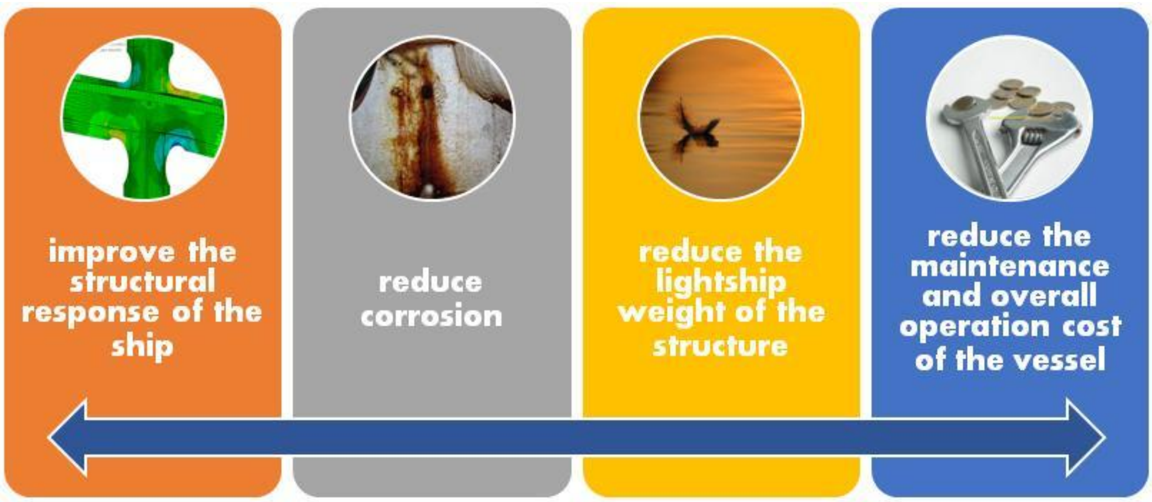
Figure 1 – MOSAIC Partnership

The project MOSAIC had the primary objectives of:

(1) the reduction of maintenance and repair related costs , and
(2) the realization of lighter marine structures and, as a direct consequence,
(3) the reduction of fuel consumption.

Basically the project developed two novel ideas related to ship structures.

- The introduction of High Strength Low Alloyed Steels (HSLA),
- The replacement of specific structural parts of a steel ship with composite materials



HSLA is essentially a category of steels that can be tailored to offer improved properties such as fracture toughness, improved response to cyclic loads, high strength and corrosion resistance, for specific structural details in order to reduce the risk of crack initiation and propagation in critical areas of ships.

Today's passenger ships, container ships and bulk carrier are increasingly large and complex structures. The presence of large openings or variations in longitudinal structural continuity can trigger the formation of fatigue cracks, whose propagation to the surrounding structure can lead to catastrophic structural failure. To avoid fatigue initiation structural details are often locally strengthened by inserting thick reinforcements; however, the quantity and thickness of reinforced structure increases the weight of the structure with direct consequences on the efficiency of the vehicle and indirectly on amount of cargo that can be transported. Moreover, for passenger ships and ferries aesthetics and architectural design are very important. The use of additional strengthened steel structure can restrict the design options which are unfavourable for owners and designers of these vessels.

As concerns Composite materials, MOSAIC Project had considered the adoption of composite materials to substitute steel parts in ship design. There have in fact been many research projects, both European and National, which had the aim of defining new composite materials with mechanical and physical characteristics that could be applied in marine design. Main aim of project MOSAIC was to assess the feasibility of using composite materials in ship structures by investigating design, practicality of fabrication, assessment of composites and composite-to-steel joint properties, assessment of composite and joint quality control, performance enhancement and cost. Project MOSAIC did not address statutory issues related to fire & safety which also require further work. The innovation behind MOSAIC is significant. It will move the introduction of composite solutions of a significant step closer to use on board commercial ships.

4.3 Description of main S&T results / foregrounds

- Five suitable HSLA steels were selected, procured and characterised as potential replacements to conventional marine steels.
- Composite materials that were produced with different methodologies were been tested and characterised in full.
- Qualification of welding methods between dissimilar steels and investigation of new welding method - Friction Stir Welding (FSW) for welding HSLA steels with conventional steel (AH36).
- The following tests were performed on similar and dissimilar welded steels with three different welding techniques metal active gas welding (MAG), laser hybrid welding (LH) and FSW:
    - fatigue crack growth test (FCG)
    - fracture toughness testing (FT)
    - corrosion testing
- Design and test of three different hybrid steel to composite joints.
- Use of proper and advanced numerical techniques for the prevision of the mechanical behaviour of the hybrid joints.
- Study of the influence of various design parameters on the hybrid joint performances.
- Identification of the possible failures for the hybrid joints tested in different condition (static test and fatigue test).
- Significant conclusions were drawn out regarding the applicability of a series of NDE methods for tracing defects in these hybrid joints.
- Development, setting and running of the global numerical models necessary for the identifications of the loads to be applied to the local model of the HSLA/composite solutions.
- Developments of appropriate local numerical model of the structural components in HSLA and composite.

- Use of advanced FEM techniques for the study of: adhesive failures, composite failures, fatigue assessments and fatigue crack growth rate estimation.
- Identification and application of the procedures/rules necessary for the assessment of the HSLA and composite structure.
- Identification of techniques used for the design of large scale subassemblies.
- Design and assessment of the connection between the composite structure and the pre-existing steel hull by means of hybrid steel/composite joints.
- The weight estimation and comparison demonstrated the beneficial effect due to the use of HSLA and composite components.
- Design of large scale subassemblies.
- Test of large scale subassemblies.
- Comparison between numerical analysis results and experimental results aimed at the calibration of the numerical model.
- Large scale test with S690 insert plate showed a lower crack growth rate gave better fatigue performance than the specimens with AH36 insert plate. Although additional testing are needed it is possible to state that HSLA seems to be an effective solution for the improvement of fatigue resistance of marine structures.
- The life cycle cost and performance assessment clearly showed the importance of considering the whole life cycle when evaluating the performance of the proposed solutions.
- Even though both material concepts have higher initial costs than the currently used conventional steel, their total life cycle costs appear to be lower, especially due to the savings in operational costs in the case of a more lightweight structure.
- Currently the proposed solutions show an equal or higher risk in all life cycle stages compared to the current solution of conventional steel.
- HSLA show similar performance to conventional steel with regard to environmental impacts in construction and end of life stage. However if less material is used, that leads to emission savings, especially during the operational stage. The same applies to composite materials, where the emission savings during the operational stage outweigh the increased impacts in the other stages.
- Concerning the corrosion experiments, no significant differences are observed for the corrosion behavior among the different combinations or welding techniques. Moreover, it is quite evident that the corrosion pattern is different for HSLA (pitting), and the corrosion rate is slightly lower for S690, and for the welds where S690 participates, mainly the FSW.
- From the perspective of shipyards and universities, HSLA balcony openings represent the most business and research attractive case followed by misaligned hopper plates.
- The highest level of general interest of interview respondents is expressed for the case of composite balcony gangways (overhangs), followed by composite balcony openings, with bow enclosure taking the last place on the scale of business attractiveness.
- The Guidelines developed in the project provides a concrete and straight to the point technical information to a novice entering the use of not only of the application cases analysed in the project but of the general use of HSLA and composites in shipbuilding.
- Workshop and Stakeholders' forum to discuss and agree the business and regulatory implications of introducing HSLA steel and/or composite components in marine structure.
- Tentative to define the regulatory framework for the findings of the project.

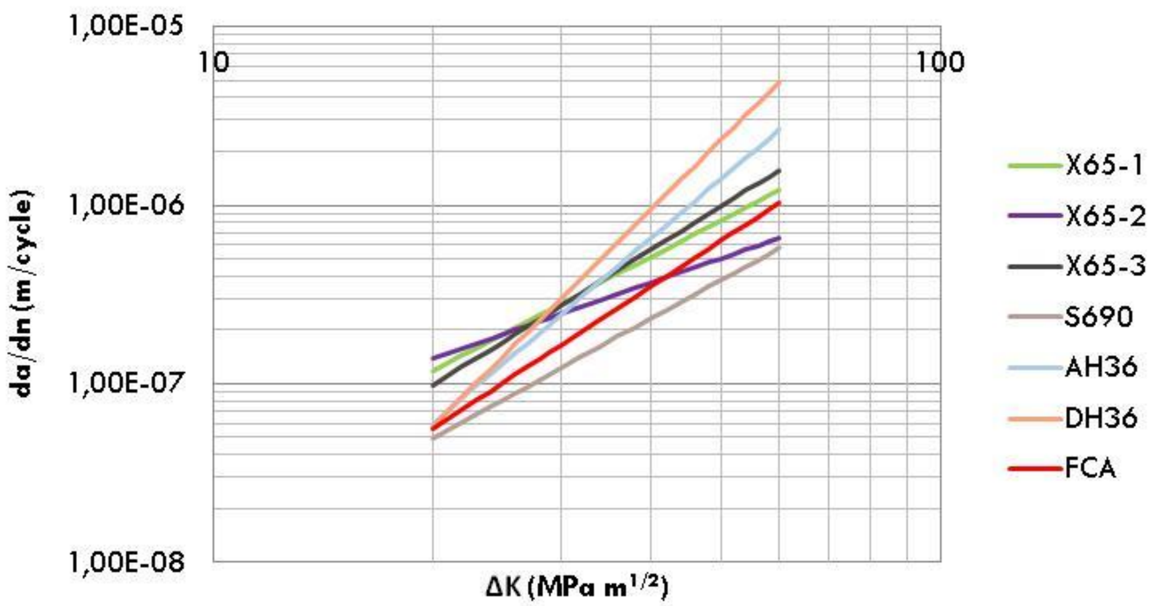


Figure 2 - Testing on different HSLA types

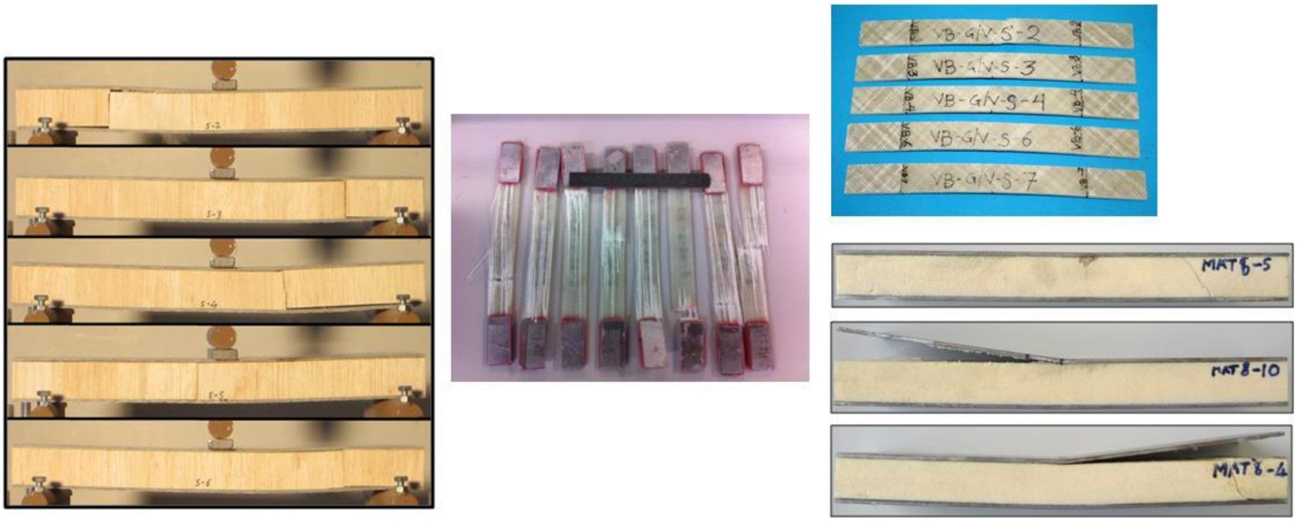
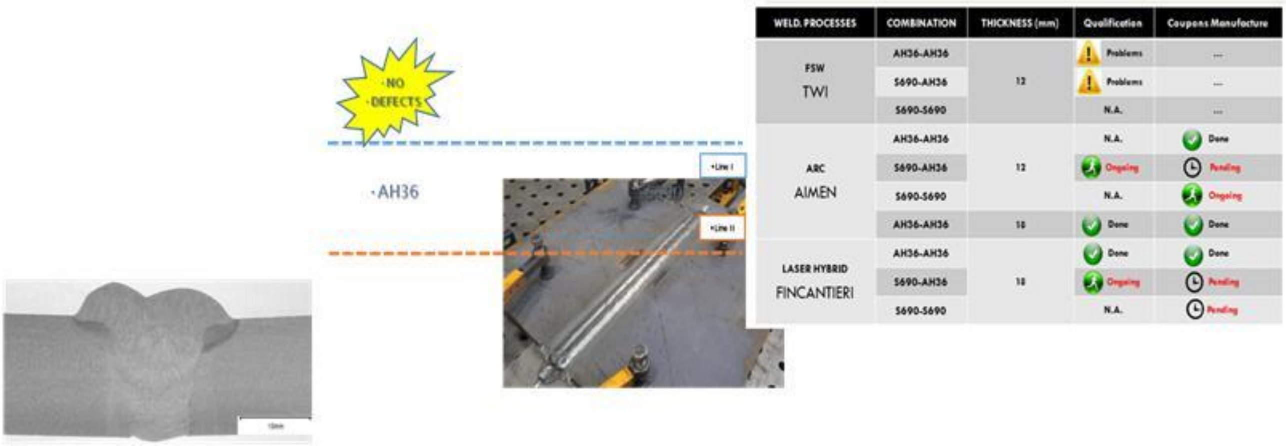


Figure 3 - Characterization and selection of composite materials



WELD. PROCESSES	COMBINATION	THICKNESS (mm)	Qualification	Coupons Manufacture
FSW TWI	AH36-AH36	12	Problems	...
	S690-AH36		Problems	...
	S690-S690		N.A.	...
ARC AIMEN	AH36-AH36	12	N.A.	Done
	S690-AH36		Ongoing	Pending
	S690-S690		N.A.	Ongoing
	AH36-AH36	18	Done	Done
LASER HYBRID FINCANTIERI	AH36-AH36	18	Done	Done
	S690-AH36		Ongoing	Pending
	S690-S690		N.A.	Pending

Figure 4 - Tests on different welding techniques

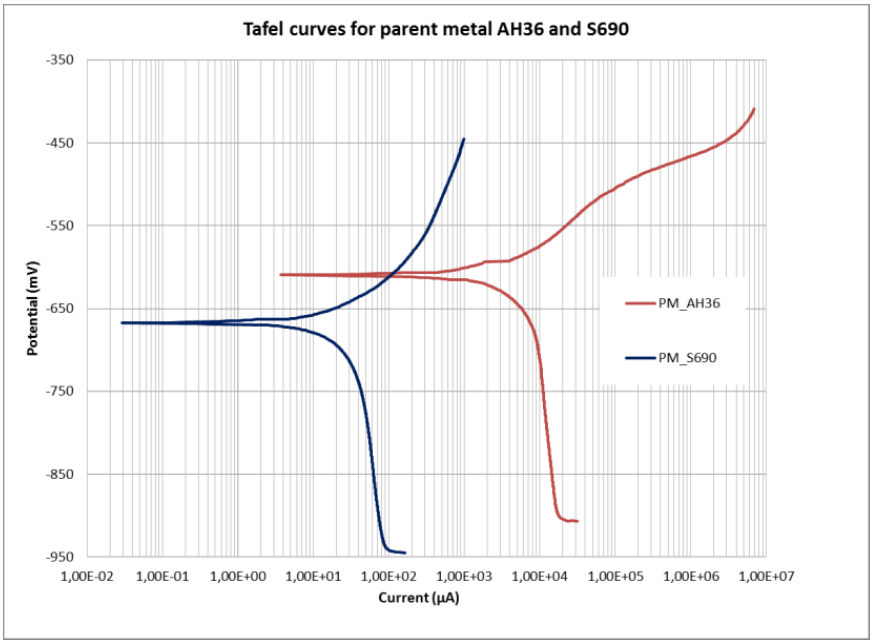


Figure 5 – Corrosion experiments : Tafel polarization curves for Parent Metals AH36, S690

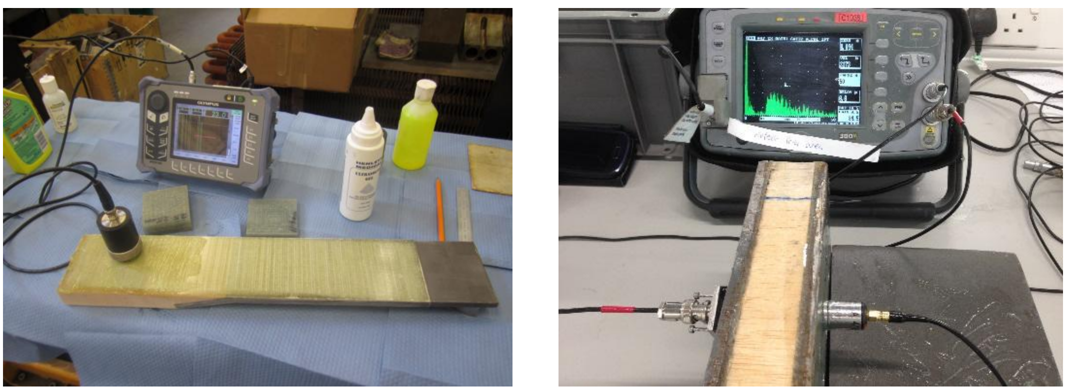


Figure 6 – NDT experiments on hybrid joints.

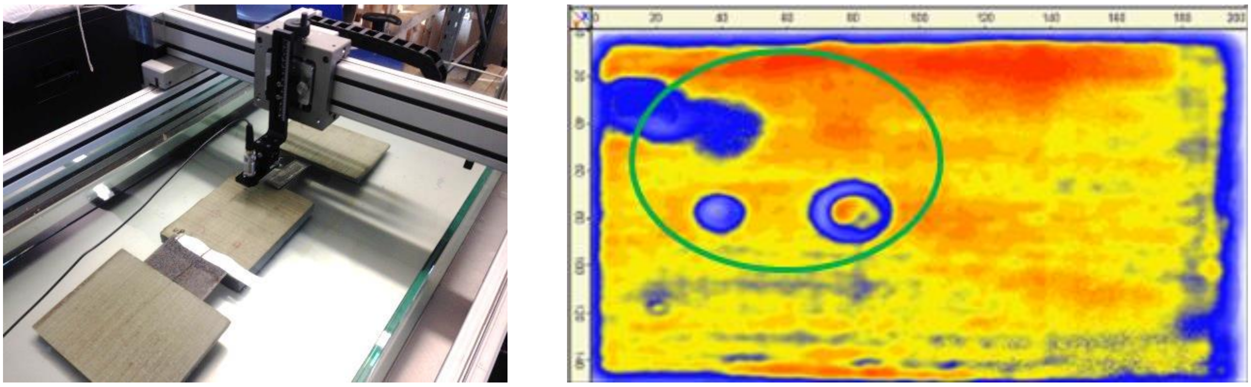


Figure 7 – NDT - Application of UT C-scan to special calibration blocks.

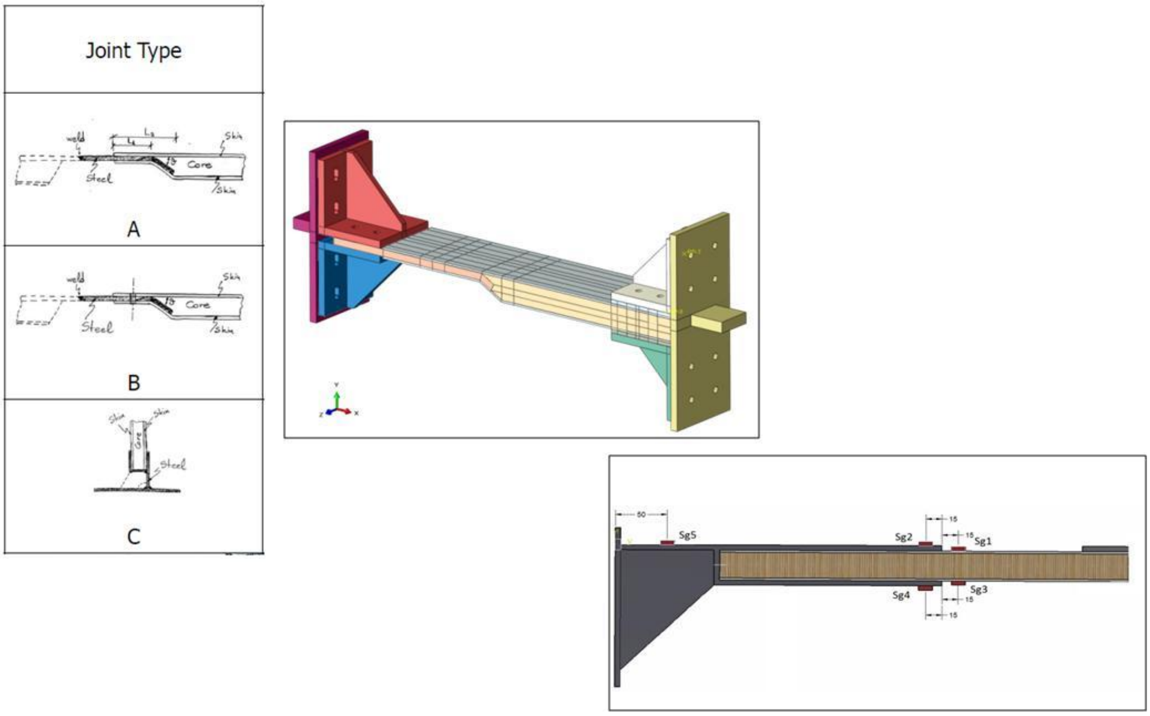


Figure 8 Hybrid joints design

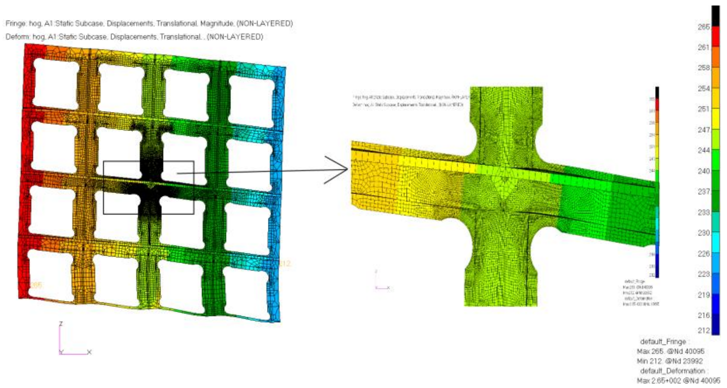


Figure 9 FEM model of Corner opening in longitudinal bulkheads

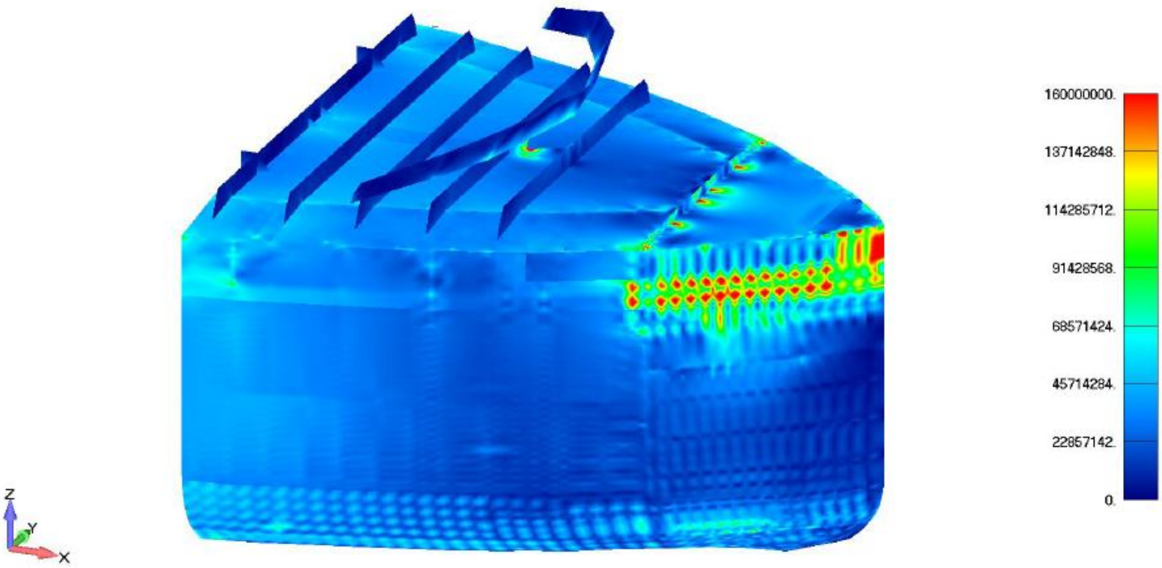


Figure 10 - Bow enclosure FEM model

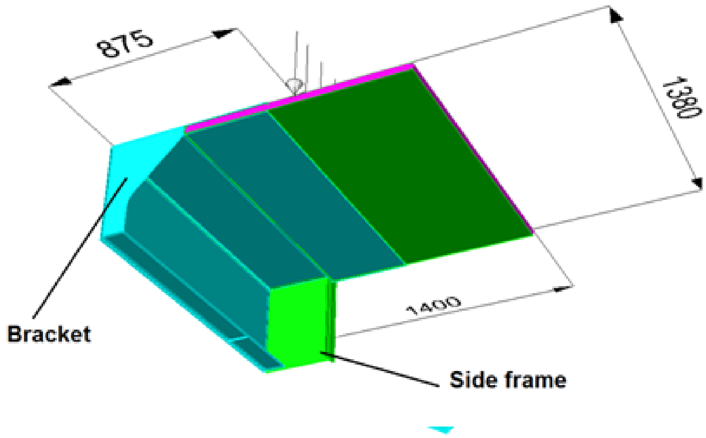


Figure 11 Design of large scale subassemblies (Balcony Overhang)

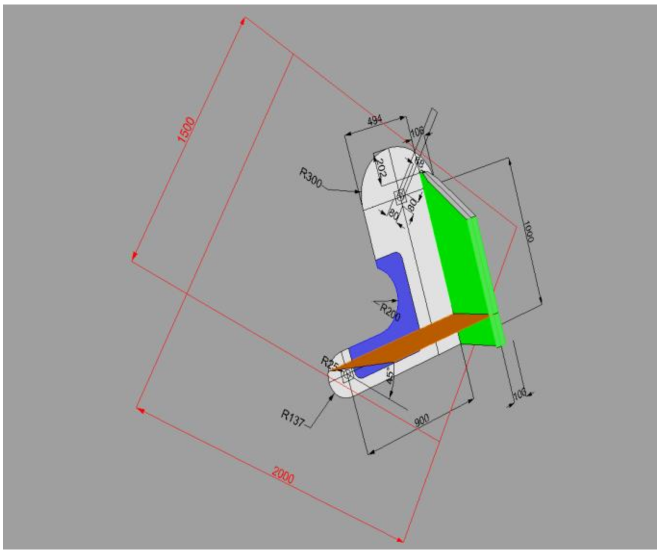


Figure 12 Design of HSLA subassemblies (Corner Opening)

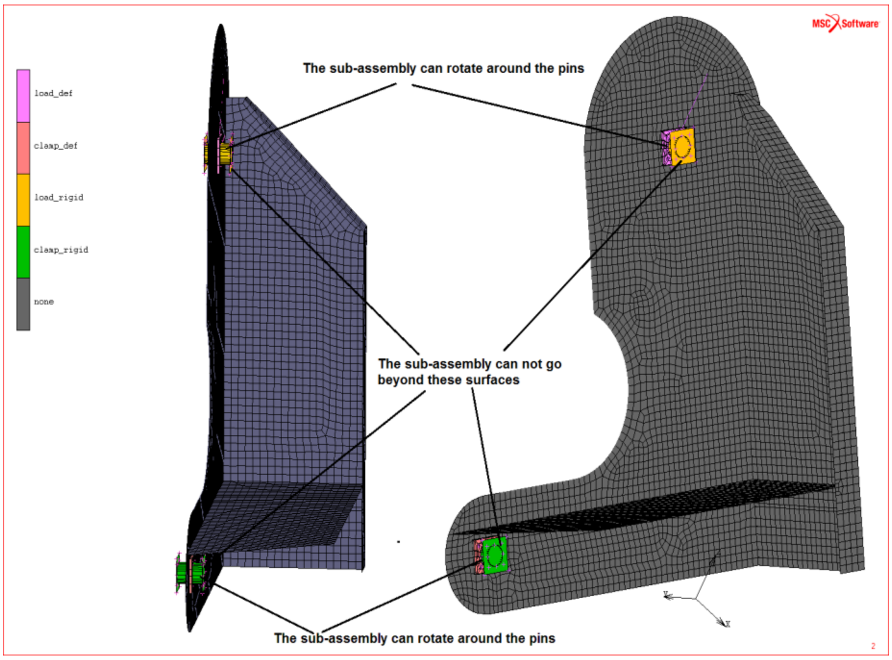


Figure 13 - Design of the subassemblies tested in WP5

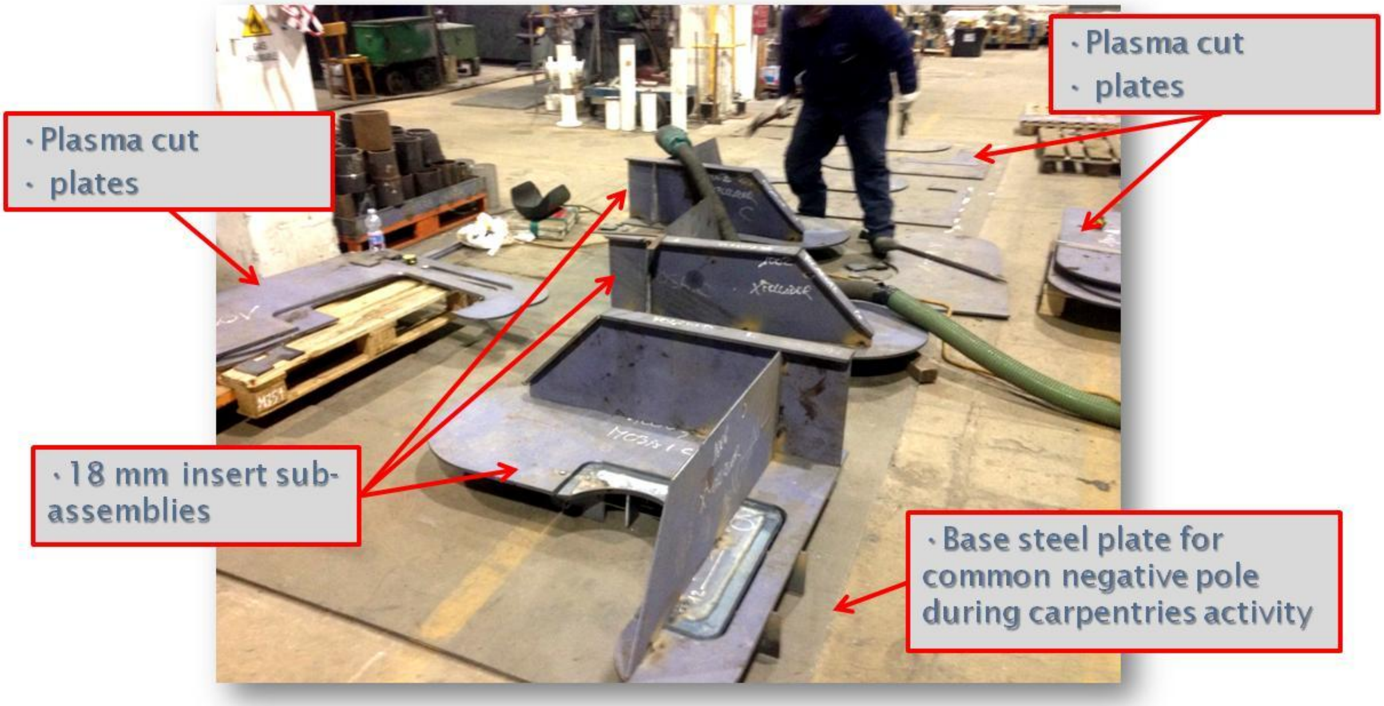


Figure 14 - Large scale subassemblies construction

Figure 15 - Test on large scale subassemblies (Corner Openings)

4.4 POTENTIAL IMPACT AND MAIN DISSEMINATION ACTIVITIES AND EXPLOITATION OF RESULTS

The new material solutions that were investigated by the MOSAIC consortium are addressed to adoption in large merchant vessels including cruise ships, ferries, container ships, tankers, bulk carriers, etc. These solutions are intended to reduce the overall life-time costs associated with operation and maintenance of a ship.

HSLA steel solutions aim to prevent the development of fatigue cracks and subsequent structural failures, thus reducing the structural risks and maintenance/repair costs. The localised use of HSLA steels can also reduce the weight of the ship by using thinner plates at unwelded stress concentration areas. The advanced steel welding process FSW has the potential to be a less energy demanding and more environmentally friendly process than conventional arc welding, and may offer improved weld properties that permit optimisation of design leading to lighter ships. Although the effect of using HSLA steels in local structural parts is not expected to considerably influence the lightship weight (although this may be a significant improvement for cruise ships where weight savings in the superstructure can improve stability), its effect in a life cycle perspective is significant (around 3% of global economical saving in the whole life of a ship).

Previous studies have indicated that the use of composite materials can result in weight savings of more than 50% in the case of a fibre reinforced plastic (FRP) superstructure replacing a steel one. The use of FRP can also be envisaged for other structural applications. The exact value of weight saving will of course depend on the extent of use of composite materials within a metallic hull and this issue will be also quantified within WP6 and the corresponding LCCA study. The weight savings associated for MOSAIC application cases are significant (around 30%), resulting in a reduction of the fuel cost and emission in air, which is by far the greatest portion of operational cost of the ship. Moreover, composite materials are immune to corrosion, thus reducing material wastage and corresponding repair cost.

Both composite materials and HSLA steels, in cooperation with advanced joint design and fabrication processes, can synergistically reduce the life time costs of a ship considering manufacturing, operation and maintenance.

The dissemination activities broadcasted the objectives and the results of MOSAIC project both internally, among partners and externally to the wider external audience (both scientifically inclined or not) in a clear and precise way.

As a first concrete achievement, the Consortium collaborative website has been set up for the dissemination and exchange of documents, drafts, ideas within the project. A mailing list, organized by technical areas of the project, has also been set up.

Internal meetings and brainstorming sessions continued to be organized during the project.

On the external front, we maintained and continuously updated the public website www.mosaicships.com

The partners have also presented some papers at external workshops and conferences and a final workshop has been organized during the NAV conference that was held in Lecco last June.

Articles were presented in national and international Maritime Scientific magazines like “The Naval Architect” and “Tecnologie Trasporti Mare”

An ad-hoc leaflet has been distributed during public events and through several mailing lists and the newsletter was disseminated.

More in detail, dissemination actions can are described here below:

Internal Dissemination:

Internal dissemination includes actions aiming at ensuring a good diffusion of information and documentation among the project partners with the aim of sharing the developed know-how. The Internal Dissemination is achieved through the usage of an internal document system (Alfresco) as well through the exchange of information by e-mail and through personal communication in project meeting and events. The internal document system has been set up and is used to ensure proper information availability and visibility of activities’ progression for all partners.

External Dissemination:

Actions aiming at ensuring the visibility and awareness of the project results outside the Consortium border, i.e., in the scientific community, academic institutions, organizations, or companies. In particular, external visibility and public awareness and knowledge of the MOSAIC project have been ensured through the following channels/measures:

Public project website:

MOSAIC public webpage provides general project information, scientific publications done during the project, news about project developments and events, as well as an overview of public deliverables.

Workshops:

All project partners have actively participated in workshops with the aim to disseminate results of the project to the wider research community.

Publication of research results:

Project results and innovations have been and will be submitted for publication in scientific journals, conferences, and workshops relevant to the topic of the research activity carried out during the project.

MOSAIC WORKSHOP

MOSAIC workshop, to which all stakeholders were invited, was organized in June 2015. The workshop presented the most interesting findings and results of the project, to the general public as well as to main stakeholders and potential end users. The dissemination activities broadcasted the objectives and the results of MOSAIC project both internally, among partners and externally to the wider external audience (both scientifically inclined or not) in a clear and precise way.

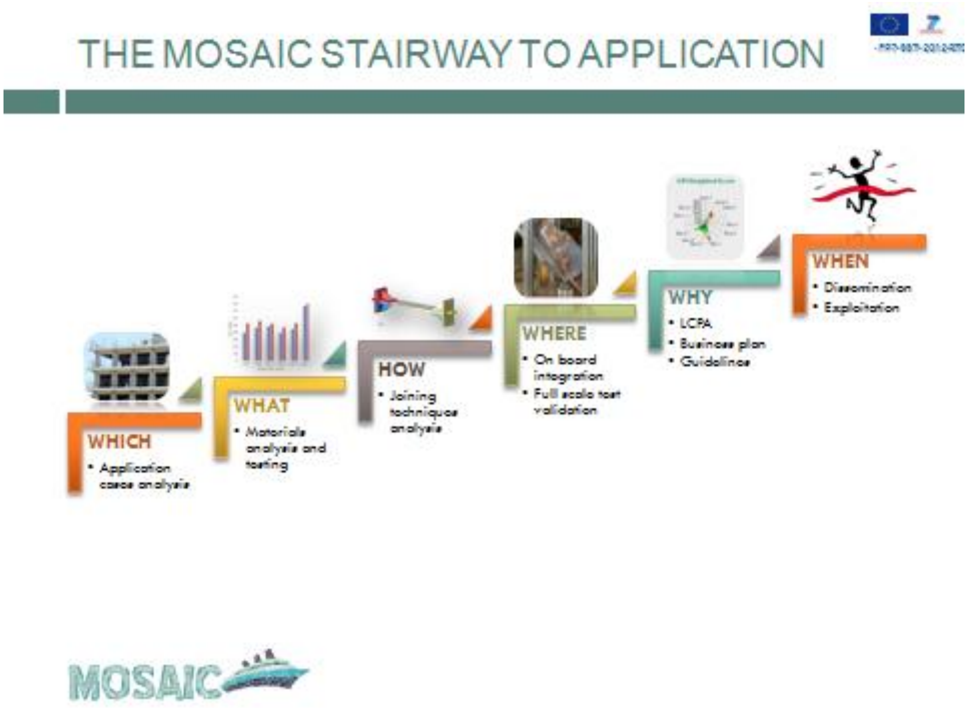


Figure 16 - MOSAIC "Stairway to Application"

4.5 PROJECT WEBSITE AND CONTACT DETAILS

The project started on 1st September 2012 and ended on 31st August 2015. The project web site is www.mosaicships.com and contact can be made contacting the project coordinator Mr. Carlo Cau at carlo.cau@cetena.it