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First steps of the FIBRESHIP project: Engineering, production and life cycle management for the complete construction of large length fibre-based ships.

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Abstract

The main objective of the FIBRESHIP project is to enable the building of the complete hull and superstructure of large-length seagoing and inland ships in FRP materials by overcoming few technical challenges. In order to achieve this objective, the project will develop, qualify and audit innovative FRP materials for marine applications, elaborate new design and production guidelines and procedures, generate efficient production and inspection methodologies, and develop new validated software analysis tools. Clear performance indicators will be designed and applied in the evaluation of the different solutions developed for three targeted vessels categories. Finally, the different technologies generated in FIBRESHIP will be first validated and then demonstrated by using advanced simulation techniques and experimental testing on real-scale structures.
This paper is dealing with the presentation of the project scope and progress of the FIBRESHIP project over the first six months.

Keywords: European niche market; Large length fibre-based ships; Seagoing and inland ships; Lightweight structures; Fire-resistance; Shipbuilding, Design numerical tools.

Nomenclature

FRP	Fibre-Reinforced Polymers
GHG	Greenhouse gas
EU	European Union
BV	Bureau Veritas

1. Introduction

Europe is today a major player in the global shipbuilding and shipping industry. In fact, Europe has a leading position in value terms of civilian and naval ships built, classifies the largest proportion of new constructions, and continues to control about a 40% of the world's fleet.

In particular, the European shipbuilding industry remains in a leading position thanks to a clear determination to offer high added-value products, including a great development of lightweight constructions. Today, Fibre-Reinforced Polymers (FRP) materials are extensively used for building lightweight hull structures of vessels with length up to about 50 meters. The main benefits resulting in the application of FRP in shipbuilding are clear. On one side, a significant weight reduction (around 30%), which implies a substantial fuel saving (aligned with Directive 2012/33/EU), an increase in cargo capacity and also a reduction of greenhouse gas emissions. On the other, FRP are immune to corrosion that results in a better life cycle performance and a reduced maintenance costs (Directive 2013/1257/EU). Furthermore, those materials can offer additional advantages like an increase in ship stability and a reduction of underwater noise (Directive 2008/56/EU).

However, the use of these materials for ships above 50 meters in length is limited to secondary structures and components. One of the main reasons for this limitation is the lack of design guidelines allowing to prove that the use of FRP does not adversely affect the safety level of the vessel, as required by the Convention for the Safety of Life at Sea. Actually, different technology gaps have to be filled to demonstrate the full feasibility of using FRP materials in large-length ships; different functional characteristics of the new materials, coatings and components, such as durability or fire-resistance, have to be extensively tested to be certified for marine application; innovative design procedures and guidelines have to be elaborated; specific joint solutions have to be developed; new production procedures have to be developed and implemented; different computational tools that can assist in the design and functional safety assessment must be developed and validated; and finally, demonstrators have to be built and evaluated by an extensive technical and experimental assessment.

The main objective of the FIBRESHIP project is to enable the building of the complete hull and superstructure of large-length seagoing and inland ships in FRP materials by overcoming the few technical challenges. In order to achieve this objective, the project will develop, qualify and audit innovative FRP materials for marine applications, elaborate new design and production guidelines and procedures, generate efficient production and inspection methodologies, and develop new validated software analysis tools. Clear performance indicators will be designed and applied in the evaluation of the different solutions developed for three targeted vessels categories. Finally, the different technologies generated in FIBRESHIP will be first validated and then demonstrated by using advanced **s**imulation techniques and experimental testing on real-scale structures.

2. Project motivation

2.1. The challenge

The challenge of this project is to enable the integral construction of large-length ships in composite materials. Nowadays, large-length structure in composite is a fact in the aeronautical sector, as well as a lot of medium-length ships in composite materials, which are in operation since decades in the maritime domain. Therefore, there is no reason to delay the application of composite materials in large-length ship tackling few technical and regulatory gaps for getting many benefits for the shipping and shipbuilding industry as well as the environment to be in compliance with the new EU-directives.

2.2. The impact

The massive application of FRP materials in large-length ships and the development of the related construction principles can provide a step change in vessel efficiency. Experience in building small-length vessels and naval ships indicates that a significant weight reduction, which is in the range of 30-40%, can be accomplished by using FRP materials. This fact, coupled with an improvement of the trim for any condition can result in a saving of fuel consumption about 10-15% and the corresponding decrease in GHG emission. On top of that, the operating cost of FRP ships is estimated to be lower than conventional steel ships. The weight reduction directly reduces the cost per ton and allows increasing the load capacity at a similar rate. Moreover, different studies suggest that the FRP industry is capable of achieving a recycling rate up to 75% (compared with a 34% of the steel industry). Finally, a strong reduction of the ships underwater noise signature is expected as well. The Figure 1 shows all the potential benefits of the composite construction.

Fig. 1 FIBRESHIP Benefits & Impact

2.3. General project information and field of application

Three vessels categories have been targeted as the most promising for the final project market orientation: Cat I-Lightweight commercial vessels, Cat II-Passengers transportation & leisure and Cat III-Special Services. In this regard, a container vessel, a ro-pax and a fishing research vessel have been chosen as representative vessels for each category. These types of vessel will be under an iterative design process in which will analyze several basic alternative designs (arrangement, stability, seakeeping, etc…), as well as structural configurations and safety solutions to take advantage of the weight reduction. The application of these design will be able to adapt itself to inland and seagoing tasks.

Fig. 2 FIBRESHIP Vessels Categories

FIBRESHIP brings together an outstanding partnership, representative of the European shipbuilding and shipping industry. The consortium is composed of a network of organizations with a proven record in research and technology innovation, which covers the entire chain of the vessel life. The consortium consists of 18 EU partners, representing the entire supply chain players in the maritime industry. The FIBRESHIP consortium includes three major certification and class societies: LLOYD´S REGISTER, BUREAU VERITAS and RINA, four medium European shipbuilders like IXBLUE, NAVREP, SOERMAR and TUCO, three prestigious research organizations selected according to their expertise and experimental capabilities: ULIM, VTT and CIMNE, four relevant European ship-owners: FOINIKAS, IEO, DANAOS and ANEK, and four companies with complementary expertise in naval architecture and marine engineering, advanced composite solutions, development of CAE software for naval architecture and business development consultancy: TSI, COMPASSIS, TWI and ATEKNEA. The FIBRESHIP consortium possesses both specialized and multi-disciplinary know-how that shall be availed of in order to meet the objectives of the project.

Furthermore, an Advisory board has been created in order to advise and follow-up to the project consortium helping with its dissemination. This group is made up relevant players like as flag authorities (Spain, Panama, and Denmark), big shipyards (Fincantieri, Navantia, Harland and Wolff, Gondán), Industrial partners (Sika, Schottel, Teknocontrol, MJM marine, Galloo, Sener), associations (Gican, SSA) and research centers and universities (University of Athens, Royal National Lifeboat Institution, Cehipar, Fidamc). The objective is to extend this group over the 36 months of the FIBRESHIP project life.

Fig. 3 FIBRESHIP Stakeholders

2.4. Thematic areas definition

The internal work in FIBRESHIP is subdivided in workpackages, nevertheless for a better understanding of the way to tackle the project four thematic areas have been defined (Fig 4). These areas include the activities of those workpackages that develop theoretical and testing activities related to the same topic.

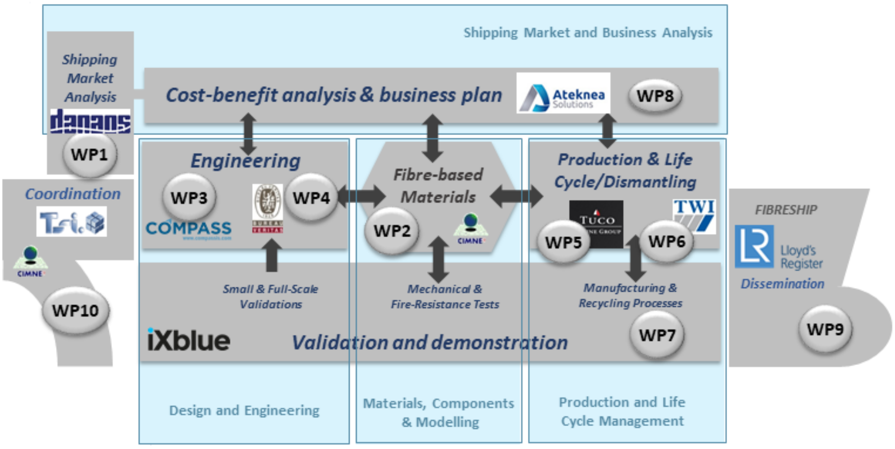

Fig 4 FIBRESHIP Thematic areas & Workpackages

3. Thematic Approach

3.1. Materials, components, and modeling

The conception and identification of new fibre-based materials and joining solutions for its use in large-length ships is one of the key aspects of the project. In fact, FIBRESHIP will research the functional characteristics of fibre-based materials newly introduced in aerospace, automotive and wind energy industry, as well as several solutions resulting of recently completed RTD projects to assess their potential for being used in large-length shipbuilding. A comprehensive list of candidates will be built. The corresponding composite manufacturing and processing methods (resin infusion, compression moulding/hot press forming, automated tape placement, autoclaving) would need to be evaluated in parallel. Furthermore, recycled materials and other alternatives will also be considered to evaluate lower costs options.

First of all, the material selection comprises those available in the market besides the new fibre-based material systems that will be identified. This will generate a comprehensive list of candidate constituents which will be evaluated in an extensive small scale experimental campaign that will include manufacture, mechanical and fatigue testing. Down selection will account for a wide range of design requirements including mechanical and environmental performance plus cost, scalability of the manufacturing process, availability etc.
This thematic area pretends to bring enough information necessary to create a catalogue of materials and joints, besides FIBRESHIP will generate the material regulatory documents, through the conception, identification, and assessment of new fibre-based materials and joining solutions. The composite materials selected will be tested for their comprehensive mechanical characterization. The campaign will include three sets of experiments, in order to obtain a comprehensive picture of the material behaviour:

- Mechanical characterization tests: Static tests of composite laminates with various lay-ups to determine key mechanical properties under different loading conditions: tension, compression, shear, fracture toughness, flexural strength and stiffness.
- Fatigue performance tests: to determine the degradation of the mechanical properties, i.e. stiffness, and strength, under cyclic loading. The loss of stiffness due to the accumulation of fatigue damage will be determined via obtaining the quasi-static stiffness at discrete cycle intervals. Sections for microscopic examination will be obtained after discrete number of loading cycles to evaluate damage build-up due to matrix cracking, delamination, fibre-resin debonding, fibre breakage etc.
- Fire performance tests: Different laboratory-scale experiments will be carried out to characterize the material properties related to solid-phase pyrolysis and gas-phase combustion. These will provide comprehensive information on the material's thermal degradation behaviour, smoke production and toxicity, and propensity to contribute to a fire.

This thematic area will also characterise the fatigue and fire performance of the composites considered, as well as will conduct a comprehensive study of the different joining options and techniques to be used in FIBRESHIP. Different numerical material models will be formulated for the simulation tools developed in the engineering area. Special emphasis will be paid to consider the failures due to delamination, fatigue, and fire in the models.

On the other hand, another challenge of FIBRESHIP project is to develop a connection strategy, adjusted to shipyards requirements, for the construction of modular large length ships. In order to achieve this goal, it is necessary to develop and assess the performance of connections for:

- Assembling different ship structures (i.e. hull to deck).
- Assembling modular sections.

FIBRESHIP will look into composite-to-composite connections, as well as to composite-to-steel connections. Several partners in FIBRESHIP project has a large experience in composite manufacturing and composite connections in small ships. This expertise will be adapted to the new requirements, but also standard and novel approaches will be explored to obtain the optimal solution for different connection cases. These joints should be tested in medium and large-scale tests at the design and engineering thematic area.

Finally, the pre-selected materials and joints will be categorized, according to the normal practices of the Classification Societies, for the different applications with reference to the design concepts and the specific solution requirements, based on the results of the experimental tests.

3.2. Design and engineering

Nowadays the use of composite materials is limited to small vessels (length < 50m) or just limited to some parts of a vessel (e.g. superstructure). This is due to the absence of structural design rules and guidelines, so in order to cover this aspect, the need of generating a new regulatory framework for the use of FRP materials on board ships has been identified. On top of that, several analysis software tools already exist, but these are only useless for steel or for small composite ships, so it is of profound importance to adapt the existing analysis software for the requirements of the design and assessment of large composite vessels.

FIBRESHIP project has undertaken the design of three vessel concepts that have been targeted as the most promising for the final project market orientation: lightweight commercial vessels; passenger transportation and leisure; and, special services. The methodology conceived to achieve the proposed goals, start with the development of the design of three representative vessels -corresponding to each one of the targeted categories- and the assessment of the technical implications resulting from the fact that they are completely built in fibre-based materials -e.g. structural weight reduction around 30%-.

On one hand, the objective of this thematic area is to develop project design guidelines for functional design and certification for the chosen vessels categories. These guidelines will intend to regulate, according to the classification society's criteria, all the required aspects of the engineering basic design, structural design and fire protection, for any vessel of the three targeted categories. It will consist of a main part applicable to any category and dedicated annexes for the particularities of each one. The methodology conceived to achieve the proposed goals, start with the development of the design of three vessels -corresponding to each one of the targeted categories- and the assessment of the technical implications resulting from the fact that they are completely built in fibre-based materials. In addition, and following classification societies' recommendations, specific computational analyses will be carried out in order to assess the global structure behaviour during a fire event (collapse study). This will be developed using both ISO standard fire curves and realistic fire descriptions. In the case of the fishing research vessel, a minimum underwater signature is crucial for their operation. Therefore, a dedicated underwater noise prediction analysis will be carried out, aiming to demonstrate the environmental impact benefits arising from building this kind of vessels in FRP materials.

On the other hand, FRP-structures of large-length ships need to be able to withstand extreme loads and environmental conditions with minimum maintenance. Furthermore, large vessels are classified according to their expected life, and therefore it is essential to have advanced simulation tools that are able to assess and optimize the life-time performance of FRP-based ship structures. FIBRESHIP will overcome this challenge by delivering a rational, robust and consistent computational analysis solution for assessing the structural integrity of large-length FRP ships during their life time. The computational solution will be based on innovative computational tools that couple existing advanced time-domain seakeeping solvers with state-of-the-art multi-scale FEA formulations to predict the mechanical response of FRP structures. Furthermore, fire behaviour of the designed vessel concepts in realistic fire scenarios will be studied using a coupled CFD and FEA fire simulation tool, whose framework was developed in a recently completed EU project and demonstrated in the context of classification tests. An existing thermo-mechanical analysis tool will be extended for the requirements of the project. The temperature dependence of the elastic properties and the yield limit of the FRP materials will be taken into account, as well as the thermal degradation of the mechanical properties determined in the different laboratory tests to be carried out. The influence of the temperature on the nonlinear behaviour of the FRP material will be included in the model by means of a thermal damage variable. Finally, FIBRESHIP will generate a computational solution for structural health monitoring of the vessel, aiming at optimizing the maintenance management and inspection tasks. This solution will combine the use of embedded sensors for real-time monitoring of the structure condition, with the application of Operational Modal Analysis to generate structural damage maps. This solution will be based on the so-called Inverse Finite Element Model Updating (iFEM) method. For all these purpose, an integrated CAE/FEA solution will be implemented, including the advanced composite materials constitutive models. It will be capable of providing an assessment regarding the different failure modes of FRP materials, by means of certain implementations as, for example, fatigue analysis tools, structural health monitoring, and structural collapse assessment under fire. All the mentioned tools and implementations will have extensively validated using standard benchmarks and the experimental information to be generated along with medium and large-tests.

3.3. Production and life cycle management

Application of standard FRP shipbuilding solutions may result in higher building costs, and therefore the development of optimized production technologies must be addressed in FIBRESHIP, aiming to ensure a profitable return-of-investment. Guidance notes on the new production procedures, validated by the classification societies, will be developed in order to complete the set of working documents commonly used in the marine industry. Finally, the technical feasibility and cost to adapt existing small and medium shipyards to this new market will be assessed as well. One important outcome is to understand how the shipbuilding European industries (small, medium and big companies) should work together in order to implement optimal strategies for leading this new worldwide market and support policy makers.
The first group of specific objectives are:

- Develop and qualify production techniques to build large components
- Develop and qualify modular assemblies techniques of large vessels parts
- Study and qualify the techniques to manage large composite parts (lifting, rolling out, upside down turning) to define the best production strategy for each vessel category.
- Development of the new classification societies guidance notes for the large vessel composite construction
- Analysis of the best facilities to build large composite vessel parts and small-medium shipyard adaptation.

For the validation of every aspect described above a full-scale demonstrator should be developed in order to qualify the processes and technologies, train the production and design staff, critical parameters identification, numerical tool validation and so on.

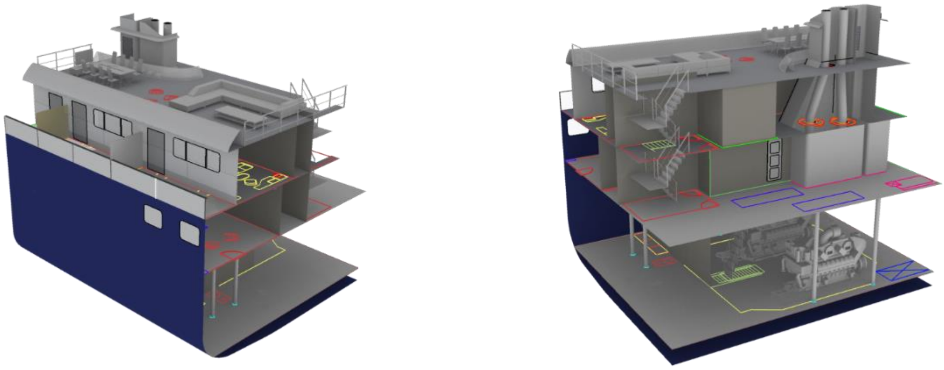

Figure 3. 3D views of the ship block demonstrator to be built in FIBRESHIP
(approx. dimensions 15.0m x 12.3m x 14.6m).

On the other hand, cost efficiency and environmental impact reduction, needs to be proven for the uptake of these technologies in the maritime industry. The cost effectiveness of the innovative solutions to be developed within FIBRESHIP will be measured during the project and validated during the demonstration phase. For this purpose, key performance indicators will be designed.
In addition, the vessels should be kept in optimal operational conditions over their life cycle. Therefore, new inspection, repair and maintenance procedures to maintain the integrity of the FIBRESHIP solutions, structural health monitoring and long term damage control strategies need to be developed. Finally, the waste management and dismantling activities are essential to provide recommendation for optimal solutions, considering life cycle costs, risk and environmental impact.

3.4. Shipping Market and Business Analysis

An initial task of the project will be to develop an in-depth shipping market analysis in order to identify potential niches markets and validate the selection of vessels categories. First, current market situation will be presented in terms of 4P marketing mix and SWOT matrices, integrating the point of view of all the stakeholders in one holistic presentation. The main focus is to underline and pinpoint the specific factors that render the market susceptible to ex-ante regulation, as well as to identify the contestability and the subsequent barriers to entry in the

abovementioned market. The product differentiation advantages will be explicitly defined and quantified, and finally the shipping market exploitation roadmap will be clearly identified and monitored. Specific studies should be done for an adequate base of financial viability and to ensure the economic advantage of using composite materials at naval construction.
As a conclusion of the shipping market analysis, the market interest on large-length FRP-based ships will be formalized to define the applicability area as well as the usability time window. This will be formalized by assessing the three vessels categories and generating detailed specifications for three ships concepts -each belonging to one of the categories- that will be used to develop three detailed ship designs as test bench for design and production, as well as definition of class societies' guidelines. In order to ensure the industrial relevance of the project, the cost effectiveness and commercial potential of the large length FRP-based vessels compared to standard steel-based solutions will be analyzed and quantitatively monitored during the project. Furthermore, a business plan covering the different phases of the life cycle, from design, shipbuilding and operation to the final dismantling of the vessel, and identifying the business opportunities for the different actors of the chain, will be developed. Nevertheless, improvements on regulatory bodies with the purpose of creating guidance notes, guidelines and finally applicable rules to promote this promising business are required.

On top of that, the previously defined information will be the provision of economic support for making decisions in a relatively short time throughout the progress of the project, based on the outputs of the technical WPs. This activity will be an interaction between the several project stakeholder groups and the consortium and will provide rapid responses to material selection, joining and inspection techniques, maintenance, dismantling, fuel saving and other environmental externalities. The results of these activities will be presented in a detailed, but easy to understand cost-benefit analysis to the stakeholder groups.
Based on the market research and the conclusions of the cost-benefits analysis, a global business plan will be elaborated and presented in the framework of the FIBRESHIP business canvas, in order to prove the financial viability and the economic advantage of the proposed solution.

3.5. FIBRESHIP summary and main outcomes

As a summary of all the previous thematic areas description, the figure below compiles in a highly synthetic view the existing problems and market needs, the actions within FIBRESHIP and the outcomes to move ahead.

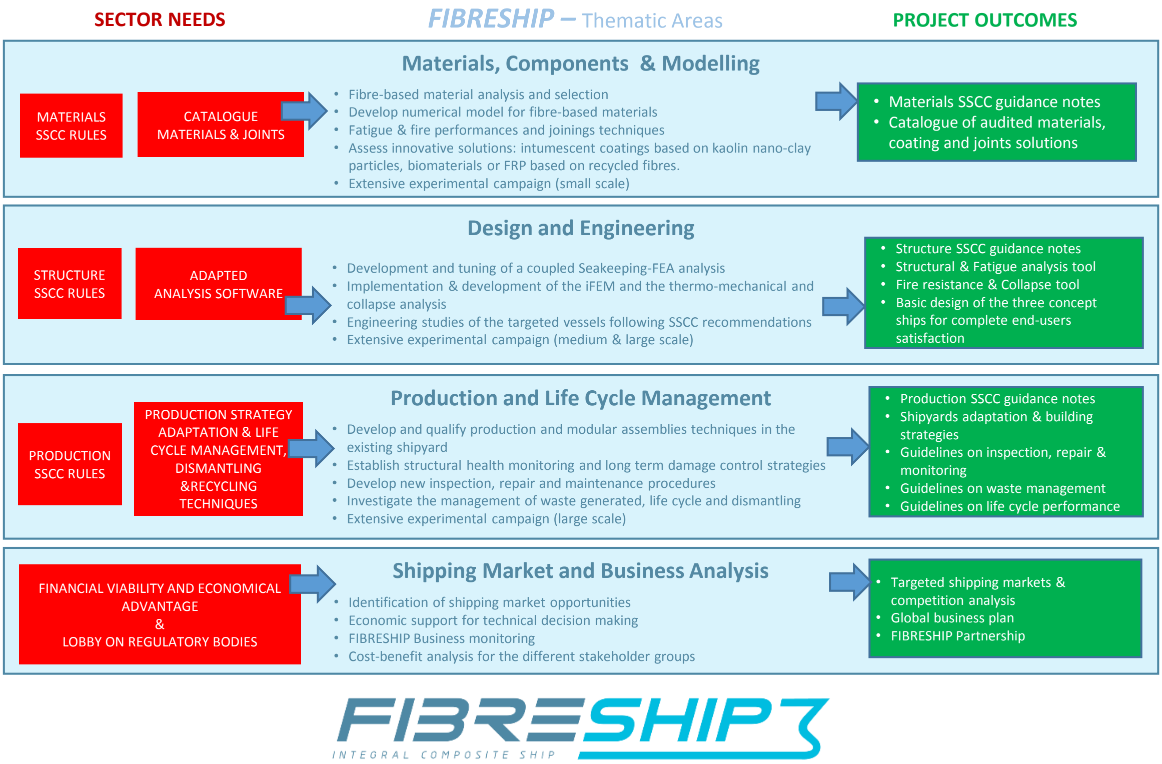

Fig. 4 FIBRESHIP Thematic areas

4. Regulatory Framework

Within the framework of the initial FIBRESHIP steps as well as the first contact with RAMSSES project and the marine composite industry in general, the most relevant conclusion is that the international regulatory framework is an issue to normalise the design and construction of large- length vessels in FRP materials. The existing regulations in force are not directly related to FIBRESHIP concern. These regulations focus on small vessels (less than 50 meter length) or non-structural elements in composite materials. Therefore, they are far to be an optimum framework for the design and construction of integral large-length composite vessels.

There are two main "blocking points", one from mechanical point of view and the other related to fire safety:

a) Missing structural rules for large length vessels in composite materials that will be developed in FIBRESHIP at "guidance note" level. These document should be internally discussed in the classification societies and IACS (International Association of Classification Societies) to be upgraded to "rules" level.

b) Unclear requests for the use of composite material on board ships affected by fire incident being in compliance with SOLAS II/2.

According to the aforementioned background there is a strong need to review the exiting regulatory framework and define a reasonable itinerary to propose the optimum regulatory modifications. The figure below is a schema that tries to identify a way to progress to get a proper regulatory framework for fire safety design.

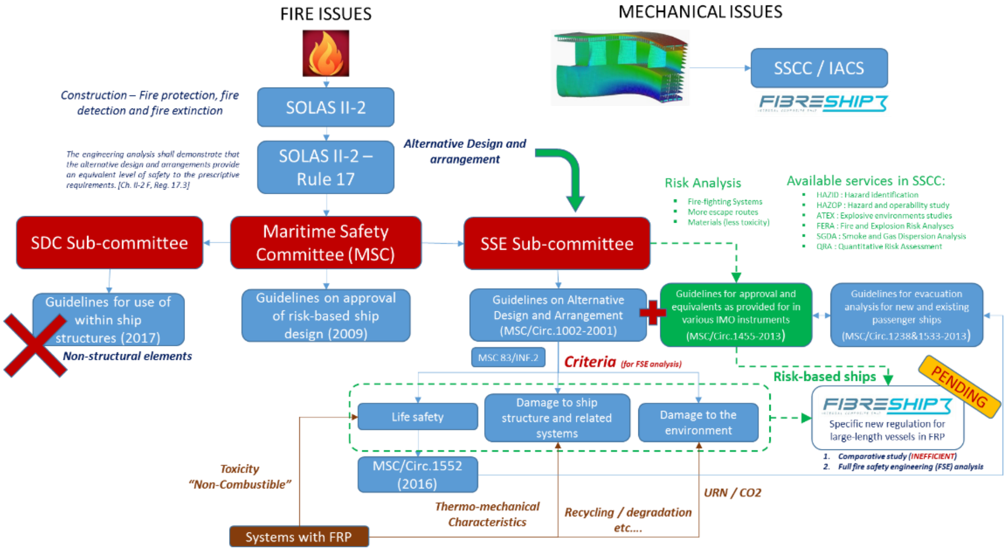

Fig. 5 Composite vessels - Regulatory Framework

The SOLAS Convention in its chapter II-2 includes detailed fire safety provisions for all ships and specific measures for passenger ships, cargo ships and tankers. According to SOLAS Chapter II-2, Part F, Regulation 17 an "***alternative design***" may be allowed provided that the design and arrangements meet the fire safety objectives and the functional requirements in SOLAS, Chapter II-2, Parts B, C, D, E or G.
It is required that an engineering analysis shall be performed as described by the IMO MSC/Circ. 1002 [2]. In this document is commented the necessity of fulfil criteria about life safety, damage to ship structure and related systems, and damage to the environment. From a fire safety point of view, the novel regulation approved by SDC-Guidelines for the use of fibre reinforced plastic (FRP) within ship structures, it is only applicable on non-structural components, therefore useless for integral composite ships.

On the other hand, there is a complementary regulation, the MSC/Circ 1455-2013 [3], that should be used for the design and approval process of alternative designs or arrangements (that is, design or arrangements which deviate from the prescriptive solutions). The document calls for a comprehensive risk assessment but does not give any suggestions on how to perform the risk assessment. Nor does it provide any risk evaluation criteria, e.g. " acceptable loss of human lives per ship year" .The document only suggests a framework for the corporation

between stakeholders and the exchange of information between design team and approval body. Therefore, specific tools and acceptance criteria must be found elsewhere.
The research project SAFEDOR [4] which was finalised in 2009 carried out an extensive work on risk based design and operation of ships. The project developed tools and methods for the design process and provided worked case examples. A regulatory framework was also suggested which was later adopted by IMO as MSC/Circ. 1455. [5]

In summary, the way to overcome the existing regulatory lack is the combination of both circulars: IMO MSC/Circ. 1002 and MSC/Circ. 1455, to produce a new regulation that focus on clear instructions and procedures to put in practice the risk-based design for the entire composite vessels, complying with the three mentioned criteria:

- Life safety
- Damage to ship structure and related systems
- Damage to the environment

In this regard, the required actions to be completed in FIBRESHIP over the project life are as follow:

a) From a structural point of view, the missing regulatory framework for large length vessels will be overcome with the guidance notes developed in FIBRESHIP.

b) From a fire safety perspective, it is utmost important to orient FIBRESHIP vessels designs to support as much as possible the defined regulatory strategy in order to support, through the entire project, our recommendations to the policy makers. On top of that, there are several dissemination activities, as part of the project, which have to be oriented to support this regulatory improvement.

5. First steps of the project and conclusions

FIBRESHIP stands out as a highly innovative European initiative funded by the EU's H2020 Programme, but also presents a clear business opportunity for companies and other stakeholders in the shipbuilding industry. This paper has been written in between the third and fourth month of the project and hence without very impacting results at this stage. Nevertheless, the huge potential justifies the dissemination by now to the marine and maritime community about the expected impact of the FIBRESHIP project in Europe.

The aforementioned initiative can turn out in a new European niche of market that requires, at present, the support and involvement of the largest number of stakeholders, in particular, states authorities and international bodies. Therefore, we take advantage of the TRA2018 conference to encourage any interested party to contact us through our website (www.fibreship.eu) and social media to determine their particular interest and role in the forthcoming business.

6. Acknowledgements

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