Time for light weight composite materials to enter the merchant shipbuilding.

Sven-Erik Hellbratt

Thüssen Krupp Marine Systems, Kockums AB

Introduction

Kockums AB is one of the major producers of large composite structures for the Swedish Defence Forces and has been working with composites for more than 40 years.
The company has a long tradition in the building of naval ships both in metallic materials such as steel and aluminium, and also in composite materials, preferably in FRP-Sandwich.

In the past 30 years more than 25 vessels of different sizes, from 20 to more than 70 m have been designed and produced at the yard.
Development of the technology has been in close co-operation with the Swedish Defence Material Organisation (FMV) and other research organisations, including the Swedish Defence Research Establishment (FOI), the Department of Aeronautics (KTH) but also participating material suppliers.

Figure 1: The Visby Class Stealth-Corvettes with a length of 72m,

entirely built in CFRP –sandwich at Kockums

Weight benefits using alternative composite design

Traditionally, large ships are made of steel. From a pure manufacturing point of view, steel is the most economical material. However, a ship will continue to cause costs for operation and maintenance during its usage. Therefore, the interest in costs in a life cycle perspective has increased.
Since the mid-1980s the use of composites in shipbuilding has increased considerably as the military strive to reduce the acquisition and maintenance costs and improve the structural and operational performance of naval craft of middle size.
The major achieved advantage when changing a traditional steel design in to a composite design is the remarkable reduction of structural weight.
Feasibility studies for both large and smaller ships have been performed.

As examples can be mentioned feasibility study of a large military patrol ship for the Danish Navy (1999) with a water line length of 105 m, where one version was designed according to Det Norske Verities (DNV) rules as a traditional steel design in high tensile steel (NV 36) and one version was designed as a FRP sandwich design entirely built in carbon fibre according to the same principles as the Visby stealth-corvettes.
When the two different hull concepts were compared it was found that the CFRP-sandwich version gave about 60% weight saving compared to the steel version.

Figure 2: The final ship with a length of 137 m built in steel at
Odense Staalskibsværft

Life Cycle Cost Assessment
Other comparisons have been made in a performed Life Cycle Cost Assessment (LCCA) of 3 different structural concepts for a high speed ferry.
The three studied hull concepts were:

1. Complete structure made of steel
2. Complete structure made of aluminium
3. Complete structure made of CFRP-sandwich

The studied ferry concepts had a length of 128 m and an operating speed of 42 knots.

Figure 3: The high speed ferry with a length of 128 m used for the LCCA

The structural weight reduction for both the CFRP-sandwich version and the aluminium version was in a region of 50% compared to the steel version.

In a life cycle cost analysis the accumulated costs of the ferry system was studied over the entire life time.
The life span for the different version must be taken into consideration. To get comparable figures it was set to 25 years, since it was assumed to be the absolute maximum life time for aluminium version. The composite ship was assumed to be in service up to 30-35 years, while calculating 25 years might be rather optimistic for an aluminium ship of that size, since fatigue is expected to become a serious problem toward the end of the operational life time.

The life cycle cost considers cost for engineering and development, production, operation, maintenance and disposal (Figure 4) and can help to evaluate alternatives of a project.

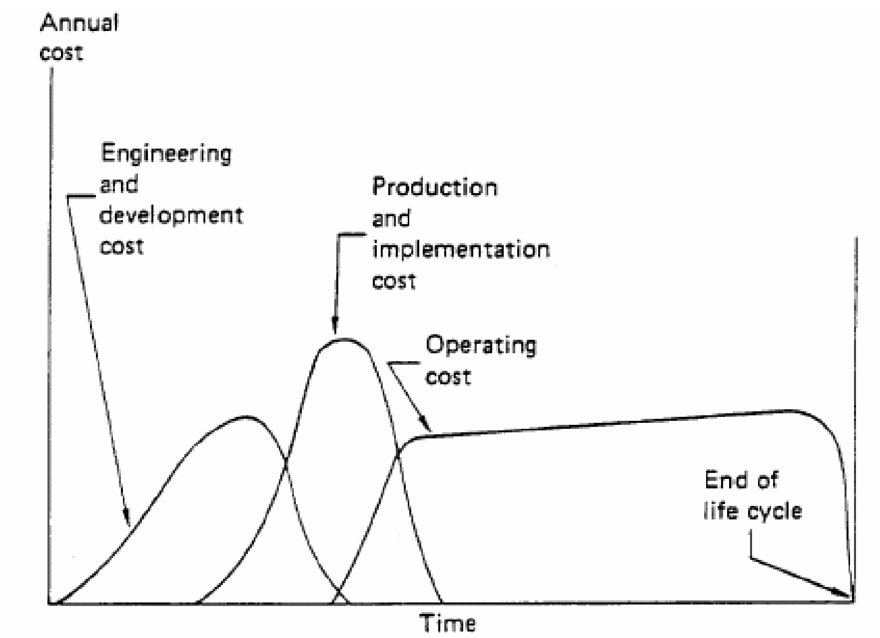

Figure 4: Example of cost categorisation (stages of life cycle costs)

From a pure manufacturing point of view, steel is the most economical material when producing large ships and cruising vessels.
However the ship will continue to create cost for the owners in form of cost for operation and maintenance during its usage.
Since only costs and no operational revenues are taken into consideration during the LCCA, the same service in terms of payload, range and speed was chosen to enable a comparison. This means that the engine power can be reduced for the lightweight structure ship and the fuel consumption can be decreased.

As an input for the LCCA data from the existing steel version was used.
For the aluminium version an existing optimised preliminary design made by Akeryards was used. For the composite version the same design as for the aluminium versions was used since the weight of the hull structure was similar.
The costs during the life cycle, including cost for design, production, operation, maintenance and disposal were based on experiences from Akeryards and Kockums.

Life cycle cost analysis may be defined as a systematic analytical process for evaluating various designs or alternative courses of actions with the objective of choosing the best way to employ scarce resources
The accomplishment of an LCCA includes all costs of an item from the first consideration of its acquisition until the end of its disposal. Therefore, costs of all producer, supplier, customer (user), maintainer and related costs need to be regarded.
Current trends show that, in general, the complexity of systems and products is increasing while the time to market needs to be reduced. At the same time, technology in almost every industrial sector is changing rapidly. This reason for cost growth combined with inflation makes it essential to optimise the value for money more than ever.

Optimising in this term does not mean to minimise the acquisition costs as a short-term objective but rather to focus on the overall cost in the meaning of a long-term strategy. The costs related to an acquisition are often not transparent at first glance, what is illustrated with the “iceberg effect” in Figure 5

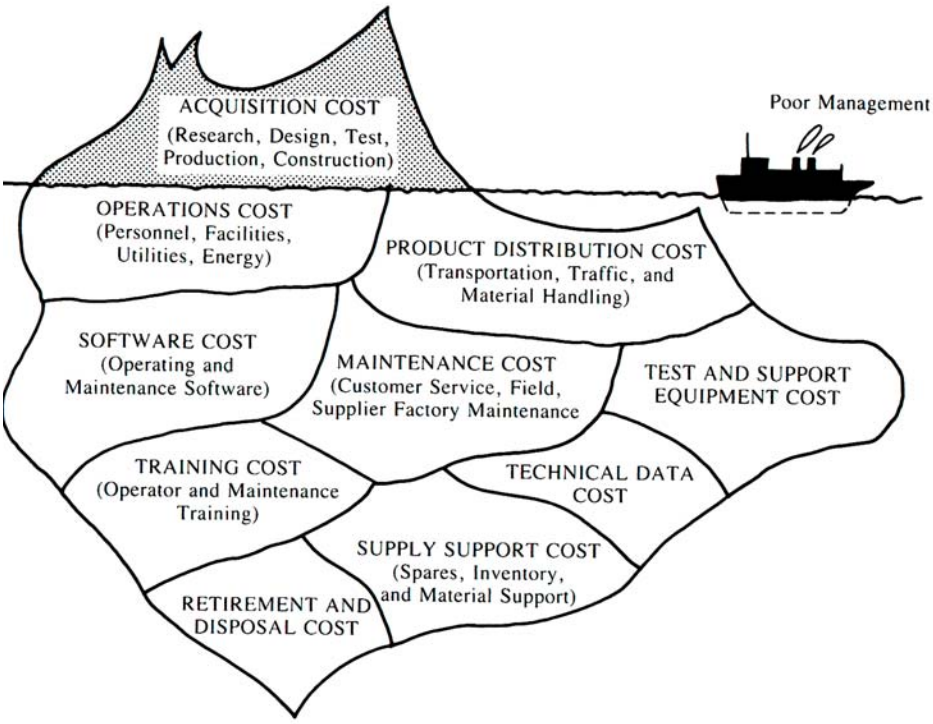

Figure 5: Total cost visibility shown

The relevant comparison of all cost elements is presented in Figure 6, where an overview of the cost split-up into the four life cycle phases is given, using costs at their current price 2002 when the LCCA was performed.
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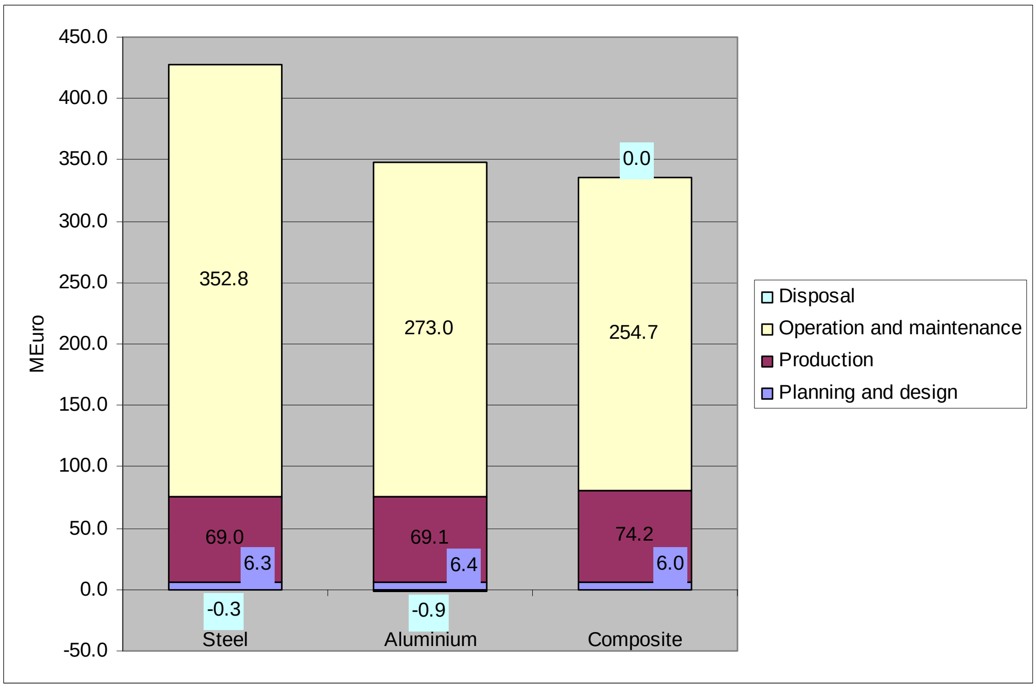

Figure 6: Accumulation of costs, at current prices 2002 in the LCCA .

The planning and design costs show quite an evened picture for the three versions with a slight advantage for the composite craft. The expectation of the conceptual formulation, that steel is the most economical material from a pure manufacturing point of view, is confirmed within this study. However, the inclusion of the machinery balances the production costs of the investigated steel and aluminium ship nearly. Due to the high material prices the composite ship is the most expensive alternative in the production phase, which contains engineering, material and manufacturing costs. The major part of the entire life cycle costs stem from the operation and maintenance. The steel version needs owing to its heavier weight additional machinery, what raises both fuel consumption and the maintenance costs. The major advantage of the composite version is the lower maintenance costs for the hull structure. Revenues and costs of the scrap do not significantly affect the life cycle costs of a ship.
The calculation indicates that the composite version is definitely the most economical option. The accumulated costs of the steel version exceed those of the composite version after only 4 years (2 years of operation). In the same perspective, the aluminium version tops to composite version after 12 years (10 years of operation).

The distribution of energy consumption onto the three ferries shows the highest energy consumption for the steel version, as expected. More than 99.5 % of the consumed energy over the entire life span of all versions comes from the operational fuel consumption. The investigated aluminium version possesses slightly smaller energy consumption compared to the composite version. This difference stems from the energy consumption of material production, where carbon fibre has the highest energy rate per unit.
The cost break even for a composite ship versus the steel ship was only 4 years.
At the initial studies the fuel price was just above 32 $ per barrel and now when the fuel price is in a region of 100 $ per barrel the cost benefits are obvious.
With a recalculation of LCC with current fuel prices 2008 (90 $ per barrel) the break even was less than one year of operation and the cost benefits over 25 year of life time was 160 million €.

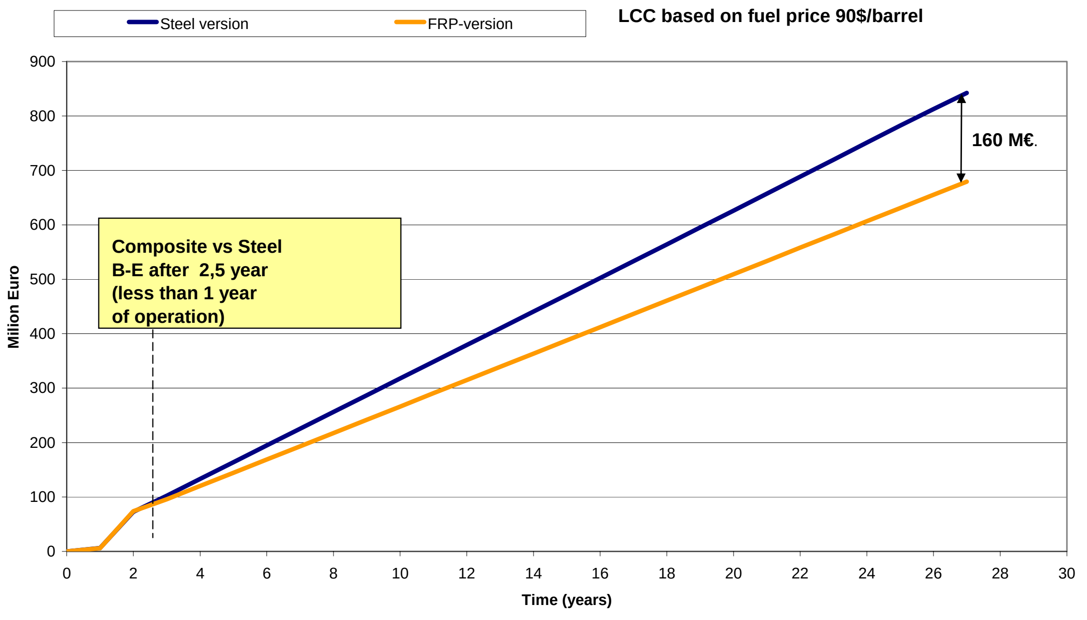

Figure 7: Life cycle cost comparison Steel Version versus Composite Version of a 128 nm High Speed Ferry at current fuel prices 2008.

Aluminium has already been used for construction of vessels subjected to the High Speed Craft Code (HSC), exemplified by of the high speed ferry “Stena 1500” built by Akeryards.

Figure 8: The 126.6 m high speed Ferry “HSS Stena Explorer” built in Aluminium by Akeryards

Light weight sandwich composite materials have only been used in a smaller amount and basically in smaller passenger ships in Norway. These smaller passenger catamaran ferries have been developed by Brødrene AA in carbon fibre sandwich technique, after an initial support from Kockums regarding design in CFRP-sandwich, have shown to be extremely successful and are now the leading concept for the Norwegian smaller high speed transportation due to the lower fuel consumption and the high speed compared to conventional hull designs in aluminium or steel.

Since 2003 when the first design assistance was conducted more than 16 high speed vessels have been built and the concept has been extremely successful in Norway

Figure 9: A 24,5m high speed catamaran ferry built by Brødrena AA in CFRP –sandwich technique.

Scrapping of a composite ship at the end of the economical life time

Disposal of large composite structures has earlier been assumed to be a very complex process. Its main steps are dismantling, cutting and crushing.

However the scrapping of a large composite ship was relatively easy. This can be verified by a scrapping of one of the Danish Standard Flex 300 ships. The complete scrapping was done in an environmental friendly way in a floating dock and the complete scrapping was made in seven days. The total amount of composite scrap was 150 tons and the metal scrap was 50 tons.

The composite scrap, which has high content of energy, was disposed by incineration.

The total cost for the scrapping was less than 0.1 million €.

Figure 10: Scrapping of a 55 m composite sandwich hull with an excavator with hydraulic yaws

Alternative designs deviating from the prescriptive rules for steel ships

For a long time the prescriptive rules for safety at sea in SOLAS have excluded other construction material than “steel or equivalent material”, which means that composite materials not could be used in, superstructures, structural bulkheads, decks and deckhouses since they are combustible.
Since 2002 a new rule 17 in SOLAS allow construction of other material than steel provided that they can provide same safety level that ship should have had if it had been constructed according to the prescriptive rules for non-combustibility in steel.
This new approach open up the possibility of using light weight composite material for other marine applications than the military and those designed and operating under the HSC Code, where composite materials in ships have been used for more than 30 years in similar applications..
During the past 2 years an extensive work have been carried out in project LASS (light weight construction application at sea), which aims to improve the efficiency of the marine transport systems.
Fire safety has therefore been a central theme for the project and a major obstacle of light weight material has been the risk of reducing the fire resistance compared to steel.
The benefits do not necessary implies that the whole ship is built in composite materials.
For a RoPax-design, where the superstructure module was exchanged to a FRP-sandwich design the weight saving of about 60% of that model could be achieved compared to the traditional design when accounting for inclusion of structural fire protection and other risk control measures.
It is not only in fast going ships a use of composite material should give economical and environmental benefits.
Also in supply vessels a use of composite materials in the superstructure could be of major interest.
The weight of the superstructure is some times driving the total ship to a larger size than necessary for its primary purpose due to stability reasons.
A lighter superstructure, made of composite material, could have given a positive design spiral with a smaller and cheaper ship better designed for its purpose if superstructure and heliport made of composite material

Figure 11: A modern supply vessel designed by Ulstein Verft AS, which might be able to have been smaller with a superstructure and heliport are made of composite material.

A major obstacle of using composite material has been the risk of reducing the fire resistance compared to steel. It has therefore been essential to demonstrate high fire resistance performance as a result of appropriate fire protection, which is verified at an accredited test facility.

Figure 12: The non exposed side with several kinds of pipe and cable penetrations before the 60 minutes fire test

Figure 13: The exposed side with burning cable insulation after the 60 minutes fire test successfully was passed

During autumn 2007 several fire tests were conducted at Technical Research Institute of Sweden (SP), both interior and exterior, on a full scale part of a passenger vessel with composite superstructures produced at Kockums.
The most spectacular test was when a fully equipped IMO approved four bed cabins which were arranged in a GRP-sandwich superstructure was set on fire in one of the beds and with the cabin door open and with mal functioning sprinklers. The fire resulted in flash over in the cabin within 5 minutes and the fire lasted for one and a half hour. During the fire parts of the ceiling fell in and the fire spread to adjacent compartments above the ceiling.
The composite structure did not contribute to the fire. The fire load consisted of four bed mattresses, four suit cases, the floor board mat of PVC and the PVC lining on the interior bulkhead and ceiling.
Despite the extreme fire intensity no visual damages could be seen on the composite structure during the 60 minutes fire test.

Also the tests with exterior fire went out well. One test was done with an exterior sprinkler and one test was done with a malfunctioning sprinkler where the sprinkler started after 10 minutes after the fire had spread through the window to the exterior surfaces.

The experiences from the tests have been several and generally the composite structures ability to carry loads at high fire-load density was verified.

Conclusion

Lightweight composite material has a long and successful track recording in demanding and weight critical in naval applications where strength and stiffness is required. In high speed crafts composite materials offer light weight at a competitive cost level due to the lower life cycle cost, which basically is earned during operation by the lower fuel consumption.

Maintenance costs also have a positive influence since they appear repeatedly and are favourable for composite structures.
In fast going vessels the benefits are easily seen since the large reductions in fuel consumption can be the base for the decision.
On large slow vessels the benefits are not so easy to see, but achievable benefits can be such as higher superstructure or more heavy equipment high up in the structure compared to traditional steel designs.
Hulls of large vessels are normally built in steel and well optimized, but other secondary structures like superstructures, masts and funnels are not always optimized from a weight point of view.
A combination of steel and composite design seems therefore be favourable for large ships.
The benefits of light weight composite materials have so far not been available for the merchant ship designers due to the prescriptive international regulations for "steel or equivalent".
Recent amendments in the SOLAS convention allow alternative designs that deem to give equivalent safety.
Prescriptive regulations describes in detail how the ship shall be designed while performance based regulations only gives the desired goals and allow for many different solutions to fulfil the regulations.
The problem with equivalency is that the prescriptive rules do not necessary give you the level of safety as could be seen from the described fire tests.
The amount of material combinations for a functional based approval however leads to a large number of tests as long as long as composite material suppliers, fire insulation companies and shipyards cooperate and commonly present the functional based solutions that fulfil the requirements for the alternative solutions.
The positive result from the tests within the LASS project is a big step forward towards the day when the first ship with composite superstructure, which fulfils the SOLAS convention, is sailing.

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